LEAN VERSUS AGILE MANUFACTURING: AN EMPIRICAL INVESTIGATION INTO THE MIDLANDS (UK) AUTOMOTIVE INDUSTRY

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ABSTRACT

Lean and Agile manufacturing concepts have received substantial development within the literature; however, there remains a scarcity in studies investigating the concepts simultaneously within a singular investigation. Furthermore, studies that have investigated the lean-agile debate have only included limited dimensions of performance, especially flexibility, and have used limited methods when distinguishing lean and agile organisations, highlighting the research gap this study sought to fill. These limitations have resulted in contradictory performance results presented in the literature, which has given rise to a sense of confusion between the two paradigms. Therefore, by using the automotive industry as the context of investigation, and by theoretically grounding this research on the notion of 'trade-offs', the main aims of this study were to: a) distinguish lean and agile organisations based upon a range of production methods; and b) rigorously identify the contextual and performance trade-offs between lean and agile manufacturing strategies. Survey data from 140 organisations operating within the West Midlands automotive industry were obtained via emails. Logistic regressions were used in order to statistically test whether lean and agile firms presented performance trade-offs. Lean firms were found to be significantly superior in cost and quality levels, while agile firms were significantly superior in terms of flexibility and speed. Importantly, lean and agile firms were found to be predominantly operating downstream and upstream within the automotive supply chain respectively. First, this thesis makes a methodological contribution to the field by providing an innovative way in which lean and agile firms can be distinguished based upon a set of production methods. Second, as lean and agile firms demonstrated performance trade-offs, findings theoretically approve Skinner's (1969) assertions, i.e. the 'trade-off law', and refute that lean and agile capabilities can be 'cumulatively gained'. Finally, considering the supply chain position in which lean and agile firms were discovered, findings have theoretical implications as they directly contradict the '*received wisdom*' concerning 'leagile' supply chains. Therefore, this study invoked Resource-Dependence Theory, and more specifically a power perspective, to speculate and shed some light into why lean and agile firms were discovered to be predominantly operating at different tiers of the automotive supply chain.

DEDICATION

Dedicated to my parents.

For their continuing love and support.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr Mark Hall, for guiding me through my PhD journey. Over the years I have enjoyed our many conversations in which Mark has helped me to develop my academic arguments. I would like to think that over this time, I have come to class Mark as not only a trusted advisor, but also a friend. I hope that we will continue to work together in the future.

I would also like to thank Dr Joe Sanderson for his insightful suggestion that I not only investigate the concept of lean production, but also agile production, within this thesis. This was just one of many suggestions from Joe that have helped me shape this thesis. I am also grateful to Joe for offering his time in the final stages of this research.

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GLOSSARY

5S
5S refers to a workplace organization method that consists of sorting, sweeping, straightening, systemising and standardising.

Capability for Reconfiguration
The ability of a firm to change its structure, in order to quickly adjust its production capacity and functionality in response to sudden market changes.

Cellular Manufacturing

Cellular Manufacturing seeks to take full advantage of the similarity between parts, through standardization and common processing i.e. similarities in products results in firms grouping together (cell), all the necessary machines, equipment and operators.

Concurrent Engineering

Also known as simultaneous engineering, is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively.

Continuous Improvement

An ongoing effort to improve products, services or processes. These efforts can be in the form of 'incremental' improvement over time or 'breakthrough' improvement all at once.

Core Competence Management

When a firm acknowledges, manages and develops its factor of competitive advantage (core competence) over competitors, which can be acquired via collaborating with alliances.

Decoupling Point

Refers to the point in a supply chain where lean and agile firms/activities meet.

Elimination of Waste

Practice adopted aimed at eliminating waste concerning motion, transportation, waiting time, overproduction, processing time, defects and inventory.

Employee Empowerment

Employee empowerment is giving employees a certain degree of autonomy and responsibility for decision-making regarding their specific organizational tasks.

Just-in-Time

An inventory practice that companies employ to increase efficiency and decrease waste by receiving goods only as they are required within the production, purchasing and distribution process.

Kanban

A manufacturing system where the supply of components is regulated through the use of an instruction card sent along the production line.

Knowledge Driven Enterprise

A knowledge-based enterprise derives knowledge from various sources that include customer knowledge, competitor knowledge, employee knowledge, product knowledge and process knowledge.

Leagile

Refers to the process in a supply chain where the supply chain comprises of both lean and agile firms.

Line Balancing

Line balancing is the optimization of the assignment of operations to workstations in an assembly line to minimize the time and the number of workstations required.

Multi-Functional Machines

A multi-functional machine refers to a machine that can be used for a range of functions.

Multi-Functional Teams

Groups formed with members who possess varying skill-sets across a range of activities.

Production Smoothing

Production smoothing refers to maintaining total manufacturing volume as constant as possible.

Single-Minute Exchange of Dies

A system that aims to drastically reduces equipment changeover times, this can be internal (when machine is running) and external (when machine is not running).

Total Productive Maintenance

Total productive maintenance (TPM) is a system of maintaining and improving the integrity of production and quality systems through machines, equipment, processes and employees that add business value to the organization.

Total Quality Management

A structured approach to organizational management that seeks to improve the quality of products and services through ongoing refinements in response to continuous feedback

Rapid Prototyping

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data.

Value Stream Mapping

A technique used to map and eliminate out all forms of waste within the value chain, which helps to improve the flow of information/materials required to produce a product.

Virtual Enterprise

Virtual enterprise refers to when a firm forms a short-term (temporary) network of alliances with other organisations in order to make a specific product for a specific period of time

Zero Defects

A system that tries to make certain that a company's products or services contain no problems that will cause them not to work correctly.

ABREVIATIONS

ASC	Automotive Supply Chain
CAD	Computer Aided Design
CI	Continuous Improvement
CFA	Confirmatory Factor Analysis
CT	Contingency Theory
CV	Coefficient of Variance
EF	External Flexibility
FSCA	Firm Supply Chain Agility
IF	Internal Flexibility
JIT	Just-In-Time
LAASC	Lean Agile Automotive Supply Chain
LAPD	Lean Agile Performance Differences
MNE	Multi-National Enterprise
OEM	Original Equipment Manufacturer
OM	Operations Management
RBV	Resource Based View
RDT	Resource Dependence Theory
RQ	Research Question
SC	Supply Chain
SCA	Sustainable Competitive Advantage
SCF	Supply Chain Flexibility
SCM	Supply Chain Management
SIC	Standard Industrial Classification
SME	Small-Medium Enterprises
SMED	Single-Minute Exchange of Dies
TPM	Total Productive Maintenance
TPRCs	Tools, Practices, Routines and Concepts
TPS	Toyota Production System
TQM	Total Quality Management
VSM	Value Stream Mapping

CHAPTER 1 – INTRODUCTION

With its origins traceable to the Japanese Toyota Production System (TPS) and the publication of one of the best-selling books amongst both academics and practitioners, 'The Machine that Changed the World', the concept of lean production has received substantial attention and has become well embedded within Operations Management (OM). Over the last 25 years, although it has been continuously developed and refined, the philosophy behind lean remains simple and clear. The underlying principle, that all waste be eliminated, has led to the assertion that the lean concept is applicable to any organisation or economic system (Womack *et al.*, 1990). However, in an age of modern technology where the push of a button can alter production systems dramatically, it is indisputable that the dynamics of the global marketplace are not the same today as they were in the past. As a result of globalisation and free trade, resources and capabilities that may have enabled a firm to gain competitive advantage over their rivals in the past may not necessarily have the same effects today. Within the current business environment, in order for firms to survive and compete, the capability to responding quickly and effectively to customer needs is just as important as cost priorities (Chi and Gursoy, 2009).

In an attempt to revitalise the American manufacturing industry against a lack in sales in the 1990's, as the US was inadequately responding to the market environment, the agile manufacturing concept was born (Rattner and Reid, 1994; Duguay *et al.,* 1997). Since the introduction of the agile concept there has been an intense academic debate as scholars attempted to define it as a manufacturing paradigm (Gunasekaran, 1999; Yusuf *et al.,* 2003) and examine it as a performance capability (Sharifi and Zhang, 2001). Theoretically, the literature has outlined the performance capabilities associated with both lean and agile production respectively, however, a review of the literature revealed that only ten studies have looked to explore the performance trade-offs between each of these paradigms in sufficient detail. This lack of research which simultaneously tests the trade-offs of the two demonstrates the need for greater attention in this area through in-depth empirical investigations. More importantly, and as will be mentioned throughout this thesis, the majority of studies which have investigated the performance trade-offs have debated findings which have been deduced from case study research or opinion-based Likert-Scale questions. It can therefore be argued that although previous methodologies may have led to generalisations within the field of OM these generalisations cannot be considered accurate, as it would be daunting to suggest that if replicated, those studies would yield comparable results. This concern is not limited to lean and agile production, but a widespread concern within the field of performance and OM (Frohlich and Westbrook, 2001; Vachon and Klassen, 2008), highlighting the need for future studies, as well as this investigation, to include '*more*' objective performance data.

Arguably, lean production is a precursor to the agile concept (Hormozi, 2001), and due to similarities between the two, there is a confusion with regards to 'when' and 'how' to become agile, as opposed to becoming lean. Consequently, understanding the differences and trade-offs between lean and agile production is of great research importance, not just in terms of settling the academic debate, but also to provide clarity to those applying these concepts within organisations.

As a result of the confusion within the domains of lean and agile manufacturing (Narasimhan *et al*., 2006), this work aimed to: First, systematically distinguish lean and agile firms based upon the tools, practices, routines and concepts (TPRCs) employed within organisations; and second, rigorously address the trade-off concerns between lean and agile systems relative to five performance measures, namely: cost; dependability; flexibility; quality; and speed, which have been acknowledged (Neely *et al*., 1995; Slack *et al*., 2010) as a means of measuring multiple layers of performance within OM. This study was set against a backdrop of firms operating within the automotive industry in the West Midlands (UK). As research into flexibility, especially supply chain flexibility (SCF), is underdeveloped (Bernardes and Hanna, 2009; Malhotra and Mackelprang, 2012), this thesis prioritised analysing the flexibility trade-offs in greater depth than previous studies. This is not to say that the other four performance measures under investigation were not considered, rather that as the literature (Narasimhan *et al.*, 2006; Gunasekaran *et al.*, 2008; Purvis *et al*., 2014) revealed that the greatest trade-off between lean and agile systems concerns flexibility levels, the analysis of this variable was magnified to a greater extent. In doing so, this thesis not only contributes to the field of OM, but also develops existing knowledge surrounding supply chain management (SCM), especially SCF.

This chapter is divided into six sections. First, an overview of OM and the evolution of manufacturing strategy is provided, while the second section presents a detailed description of the research problem and research gap. Thirdly, the background and justification of the selected industry is explored, before the fourth section outlines the research questions under investigation. In the fifth section, the choice of methodology is briefly mentioned. Finally, this chapter outlines how the thesis is structured.

1.1 Background

Operations Management & Supply Chain Management

When a firm creates a product, many processes must occur for that product to be manufactured and delivered. Each of these individual processes acts as an operation of the firm. The discipline of OM therefore concerns several process stages such as design, control and production. Slack *et al.* (1998, p.6). previously stated that *“Employees within the operations department are the ones ‘who’ have particular responsibility for managing some, or all, of the resources which comprises the operations function”.* Furthermore, Slack *et al*. (2010, p.62) defined operations strategy as a *“pattern of strategic decisions and actions which set the role, objectives and activities of the operations”*. Each individual process within the organisation is operating in an extensive supply chain (SC), with one main over-arching objective, to satisfy the end customer. It has been suggested that SCM, previously known as purchasing, has only just started to attract ‘serious attention’ within the last few decades as a result of the impact of notable economic events worldwide. For example, the oil crisis in the 1970’s, the increasing nature of global competition, multiple global recessions and the revolution of Japan’s efficient way of manufacturing have all been regarded as contributory factors affecting this rise in popularity and the importance now placed upon the role of SCM with organisations (Cousins *et al.*, 2006).

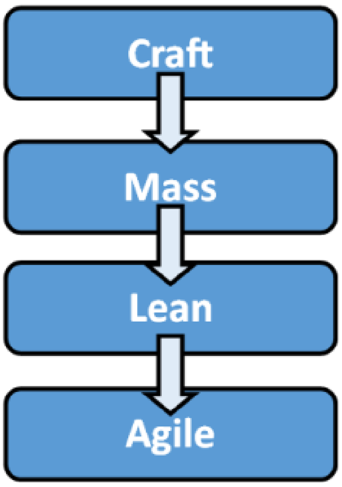
The SC is traditionally characterized as a process that is interspersed by multiple business entities such as suppliers, manufacturers, distributors and retailers/customers. These business entities work together in order to acquire raw materials and reform these inputs into finished goods, which in turn are delivered either directly to end customers or retailers. The SC is conceptualized by a downstream flow of materials needed to create the final product. By contrast, information is often thought of as flowing upstream within this chain. Due to technological advances, the rate and ease of firm internationalisation is increasing (Collinson *et al*., 2016). As a result, organisations are able to easily change between suppliers, especially in non-niche markets, signalling a reduction in switching costs and potential increase in the level of buyer power (Gelderman and Semeijn, 2006). This in turn may explain the increased focus on the adaptability of the SC, especially SCF within the academic literature.

Theoretical Foundations of Manufacturing Strategy

One may argue that the foundations for manufacturing strategy were actually first articulated by Skinner (1969), who refuted Taylor's assertion that there was a single best way to manufacture. With this in mind, Skinner introduced the idea that in order for a firm to compete, a well-defined manufacturing strategy would entail a solid link between manufacturing and corporate strategy, an aspect commonly known as the 'missing link'. In this work, he notably claimed that no single manufacturing plant is able to compete on all measures of performance. In essence, suggesting that those firms who attempt to may be guilty of acting as a 'jack of all trades, but master of none', a notion which has evolved into what is now referred to as the 'trade-off law' (Schmenner and Swink, 1998).

Looking back over the evolution of manufacturing strategy, three significant paradigm shifts can be identified; craft production, mass production and lean production (Smith, 1992; Womack *et al.,* 1990). Craft production relates to when craftsmen were contracted to work on individual jobs on a daily basis, where products were created according to the specifications of the procurer, resulting in a bespoke quality to all goods. The subsequent shift towards mass production is exemplified by Henry Ford's production assembly line, where the standardization of goods enabled greater output in a given time, allowing the firm to achieve economies of scale. The third paradigm concerns lean production, pioneered by Toyota's Production System, which retains the advantageous properties of mass production while simultaneously introducing concepts such as just-in-time and other waste reduction strategies in order to help firms to reduce costs and improve efficiency. Hormozi (2001) however has asserted that there is a fourth revolutionary paradigm, agile production, which focuses on meeting customer demand whilst simultaneously maintaining relatively high standards and efficiency. This approach is geared towards firms operating in a competitive environment that is constantly experiencing fluctuations in demand, volume and supplies. This chronological journey is outlined below in Figure 1.1.1. This thesis does not involve examining craft production or mass production but instead focuses on the lean and agile paradigms, the rational for which will shortly be addressed.

Figure 1.1.1: Evolution of Manufacturing Production



Based upon Skinner's (1969) assertion, lean and agile concepts were analysed with the assumption that each strategy would inevitably lead to different performance strengths and weaknesses, therefore trade-offs will be present. More recently, this has been expressed as a 'law', known as the 'trade-off law' (Schmenner and Swink, 1998). However, prior examining the trade-offs and in order to distinguish between lean and agile firms, this investigation adopted the resource-based view (RBV), which suggests that if a firm is to reach a position of sustainable competitive advantage (SCA), it must acquire and control resources and capabilities (Barney, 2002) in line with their objectives. Considering this, firms within this study were conceptualised and therefore categorised as being either lean or agile based upon the set of bundled tools, practices, routines and concepts (TPRCs) that they were implementing to the greatest extent. The rationale for this was simple, i.e. firms that were implementing TPRCs associated with lean production would lead to strengths affiliated with being lean and firms implemented TPRCs in line with agile production would inevitably lead to agility strengths.

Further theoretical perspectives have influenced this research, for example evolutionary economic theory and contingency theory was incorporated when determining if contextual factors, namely, firm age and firm size possessed a relationship with either of the two production concepts under investigation. In addition, the Fisher Model (Fisher, 1997), although only to a certain extent, was used when seeking to explore whether lean or agile production was more likely to be adopted across a range of manufacturing industries. Finally, this thesis also invoked the use of SCM literature concerning the decoupling point. Essentially, literature has suggested that SC's can either be lean, agile or consist of a combination of lean and agile firms, hence 'leagile' in nature. As will be discussed in Chapter 3, received wisdom (Mason-Jones *et al.*, 2000) within this field has outlined that when operating in a 'leagile' SC, lean firms are generally found at the lower levels of the SC and operate upstream, whilst agile firms are found at the top levels of the SC and operate downstream. Based upon the findings of this research, particularly with regard to supply chain flexibility (SCF), the discussion chapter also incorporates the use of Resource

Dependence Theory (RDT) and more specifically a power perspective. However, this was only invoked in order to provide a speculative insight into why certain findings were observed.

1.2 The Problem

Even though lean and agile concepts both share similarities, each strategy emphasises a distinct set of elements. For instance, lean manufacturing has received a consensus definition as a concept which ensures the elimination of waste whilst emphasising the flow of goods (Womack, 2002), whereas agile manufacturing prioritises the ability to respond to sudden changes within the market environment (Naylor *et al*., 1999).

Despite the contrasting priorities evident in these definitions, since the emergence of agile manufacturing in 1991, there has been a wide discussion attempting to distinguish between agile manufacturing and lean manufacturing (Shah and Ward, 2003; Chase *et al*., 2004). There is also ambiguity in terms of 'when' and 'how' to implement either strategy leading to a growing sense of confusion in the field (Narasimhan *et al*., 2006). However, as will be outlined in Chapter 2, the fundamental principles of lean and agile production are far from similar; therefore, it could be asserted that such confusion is unwarranted. Nevertheless, in order to 'pin-point' the root of this ambiguity, it is first necessary acknowledge that similar characteristics that are shared between the two, and as a result of these shared properties, certain TPRCs are thus applicable to both paradigms. For instance, both share features such as the elimination of waste and just-in-time (JIT), which has resulted in authors not only overlapping definitions, but also overlapping performance capabilities.

As will be mentioned in the following section, this overlapping of performance capabilities and resultant disorder has given rise to an inconsistent set of research findings, exacerbating the lack of clarity within the field. Therefore, in order to tackle this problem, in comparison with previous studies which have looked into the lean-agile debate, it is necessary to robustly distinguish between the two concepts and capture ‘more’ objective data on firm performance. Excluding the use of Likert-Scale or opinion-based questions in performance studies will undoubtedly produce more rigorous results than previous studies. However, it is important to note that Likert-Scale questions were still incorporated within this study; however, they were not utilised when capturing levels of performance. Furthermore, although performance is captured in numerical form, as Managing Directors/Operations Directors completed surveys, subjectivity may influence the results to a certain extent. However, this study takes the view that numerical data is ‘more’ objective than that produced using Likert-Scale questions to measure levels of performance.

Therefore, in order to inject clarity into the lean and agile debate, the aims of this thesis were to:

(1) Robustly distinguish lean and agile systems by outlining the key tools, practices, routines and concepts associated with lean, agile and both (hybrid) manufacturing strategies.

(2) Test if contextual factors play a part in determining whether firms are lean or agile.

(3) Rigorously measure the effects of each approach amongst multiple features of performance.

1.3 The Research Gap

As a result of the success enjoyed by *The Machine That Changed the World*, it is no surprise that lean manufacturing has received notable development within the academic literature. Even though agile manufacturing has also been significantly developed since its origin in the 1990's, undoubtedly, this has not been to the same extent as lean production. As previously mentioned, there is a growing sense of confusion between the two concepts, as the literature has outlined similarities in practices and performance capabilities. However, it is crucial to note that they are fundamentally different. Surprisingly, although lean and agile literatures are widely incorporated within the realms of OM and SCM, as will be discussed in Chapter 3 (see Table 3.5.1), only ten studies have looked to explore the performance trade-offs simultaneously within one piece of research. Although it would be suggested that 10 studies investigating the trade-offs between each manufacturing concept are sufficient, these studies have generally produced mixed findings relating to costs, dependability and quality performance measures, demonstrating the need for further clarification. Nonetheless, these studies have consistently identified flexibility as a performance indictor that is key to distinguishing between the two approaches.

The literature surrounding manufacturing flexibility has been well developed as there have been many studies outlining elements, dimensions and measures with regard to this performance dimension (Sethi and Sethi, 1990; D'Souza and Williams, 2000; Oke, 2005; Stevenson and Spring, 2007). Taking this into account, in relation with the importance of flexibility in the differentiation between lean and agile systems, it may be expected that many studies have principally investigated this performance variable in more detail, however only few studies have investigated flexibility in great depth (Mendes and Machado, 2015). More recently, Mishra *et al*. (2017) advocated that there is a limited consensus on manufacturing flexibility. In fact, studies which have looked into flexibility differences relative to the lean-agile debate have only ‘touched’ on this performance measure, as they have only examined limited dimensions within flexibility, or they have failed to include other performance measures such as costs, dependability, quality or speed. For instance, Narasimhan *et al*.’s (2006) attempt to disentangle lean and agile only involved two sub-variables within flexibility (process flexibility and product mix flexibility). Furthermore, Hallgren and Olhager’s (2009) study which looked to explore the outcome effects of lean and agile production also only measured two sub-variables concerning flexibility (volume flexibility and product mix flexibility). Considering that the literature surrounding manufacturing flexibility alone has been significantly improved in terms of ways in which to examine multiple dimensions of flexibility (Sethi and Sethi, 1990; D’Souza and Williams, 2000; Oke, 2005) it is necessary to question why lean and agile studies are not investigating flexibility in more detail.

In order to attempt to answer this question, it is necessary to acknowledge the difficulties in acquiring the relevant information when seeking to measure flexibility levels. Inevitably, these difficulties have resulted in studies using case studies or Likert-Scale type questions, which are of limited validity as they capture perceived values as opposed to objective values (Vachon and Klassen, 2008). Furthermore, during recent times, lean and agile literature has also emphasised the importance of SCF (Stevenson and Spring, 2007; Purvis *et al*., 2014) which refers to the ability to reconfigure supply chains and has been described as being within the infancy stage of theoretical development (Mackelprang, 2012), with its full understanding yet to be discovered.

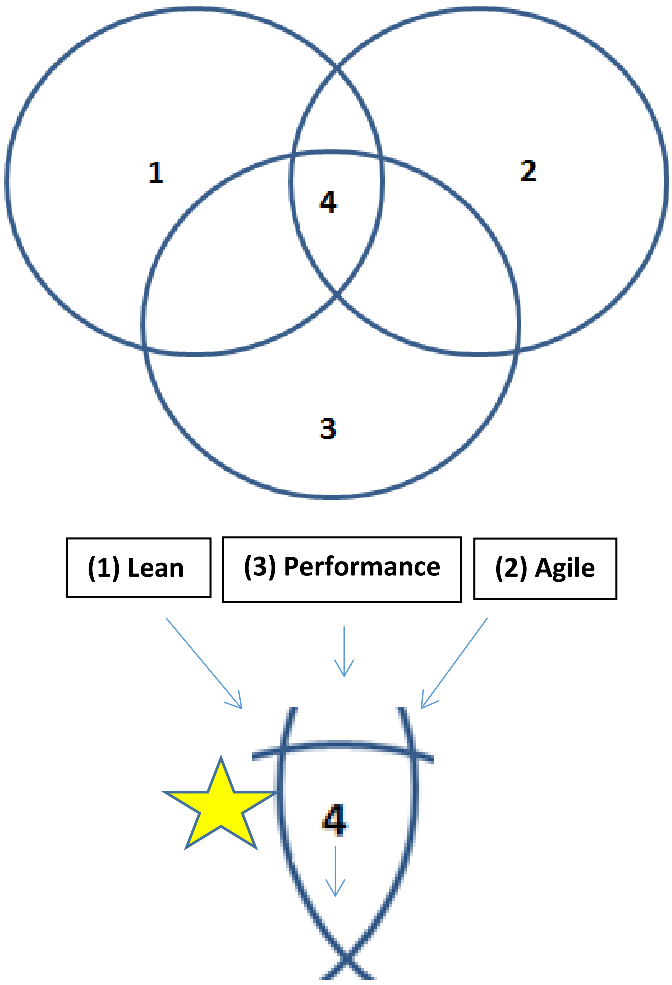
Overall, there is limited research on lean and agile flexibility levels (Purvis *et al*., 2014), therefore, studies that do wish to evaluate the trade-offs between lean and agile manufacturing concepts, not only need to collect more objective forms of data, but investigate a range of flexibility dimensions, which also include SCF.

Figure 1.3.1 illustrates the research gap addressed in this thesis. Although the concepts of lean (1), agile (2), and performance (3) have received substantial attention within the literature, the application of all three of these concepts simultaneously remains underdeveloped, thus resulting in the research gap (4) this study sought to fill. Literature supporting Figure 1.3.1 is provided in Chapter 3, and more specifically, the literature surrounding the research gap (4) is outlined in Table 3.5.1.

In summary, studies which have investigated the performance trade-offs between the two concepts have either: a) contradicted each other in terms of costs, dependability and quality; b) only measured a few dimensions of flexibility and generally excluded the examination of SCF; and c) incorporated the use of case studies or opinion-based Likert-Scale questions measuring levels of performance.

These can all be regarded as contributory factors as to why previous research have led to confusion and ambiguity concerning 'when' and 'how' to implement each strategy. With this in mind, the main research question was set, 'What are the trade-offs between lean and agile manufacturing?' In essence, the fundamental aim of this thesis was to definitively distinguish between the effects of lean and agile production. In turn, this thesis provides greater clarity into the field of OM as it clearly illustrates the advantages and disadvantages of each of the production concepts in relation with performance. As previously mentioned, external factors have been associated with the implementation of lean and agile production and so were also explored in the form of contextual variables in this research. Thus, one main over-arching research question is set followed by three sub-questions:

Figure 1.3.1: Illustrating the Research Gap



RQ1: What are the trade-offs between lean and agile manufacturing?

(a) What are the trade-offs in contextual factors between lean and agile manufacturing?

(b) What are the trade-offs in performance between lean and agile manufacturing?

(c) Are flexibility trade-offs the most significant performance level by which to differentiate lean and agile firms?

1.4 Industry Focus

The automotive industry within the West Midlands (UK) was selected as the context within which to investigate the research questions, however, before explaining the rationale behind the choice of industry, the following section will outline an overview of both manufacturing in the UK and the West Midlands respectively.

Why does the UK still manufacture?

The UK holds significant strengths embedded within the manufacturing sector, which in turn explains why British firms continue to manufacture. Over time, the UK manufacturing industry has gained a wealth of technical skills and knowledge, as well as significant technical abilities possessed by employees, which it has stimulated further by developing strong R&D centres (Brusadelli, 2013). These R&D centres enable the development of new products or even new manufacturing processes, which in turn offer consumers a range of new products, increasing demand and exports. It is also important to note that according to headlines (Qamar, 2016), a large number of manufacturing firms are re-shoring to the UK (Bailey and De Propris, 2014), with figures suggesting that one in six firms (Tovey, 2014) have decided to bring manufacturing back home between the years 2011-14. These firms once looked to reduce labour costs by moving production to lower-cost emerging countries (Bailey and De Propris, 2014, however as these economies are maturing, labour costs are increasing, and it seems as though more businesses have been following the call of the UK's former Prime Minister David Cameron's speech at the 2014 World Economic Forum to bring manufacturing activities back to the UK and rebalance the economy between the service and manufacturing industry. Importantly, as a result of the Brexit vote, the UK will leave the EU within the upcoming year. Taking this into account, manufacturing firms within the UK may not consider costs to be the key factor for remaining competitive, as flexibility, speed and quality will inevitably be just as important (Qamar, 2016).

Importance of the UK Manufacturing Industry

It may be difficult to believe that the manufacturing industry is a crucial part of the British economy, given the rhetoric of Britain as a post-industrial society. However, the UK manufacturing industry employs 2.6 million people, generating 11% of GVA and contributing to 54% of exports (EEF, 2014). Furthermore, as of 2014, the UK was ranked as the 11th largest manufacturing nation globally (EEF, 2014). The sector is comprised of a diverse range of industries, all of which have varying levels of technologies and capabilities.

Importance of the West Midlands Manufacturing Industry

The West Midlands region is situated in the heart of England, covering an extensive area of 1300km^2 and comprising of six counties (see Figure 1.4.1). Traditionally heralded as the birthplace for metal, leather, ceramics and glass related products, despite a decline in the sector, as of 2015 the region still consists of 14,205 manufacturing businesses (EEF, 2016).

Figure 1.4.1: Map of West Midlands

Source: MacNeil and Liu (2008)

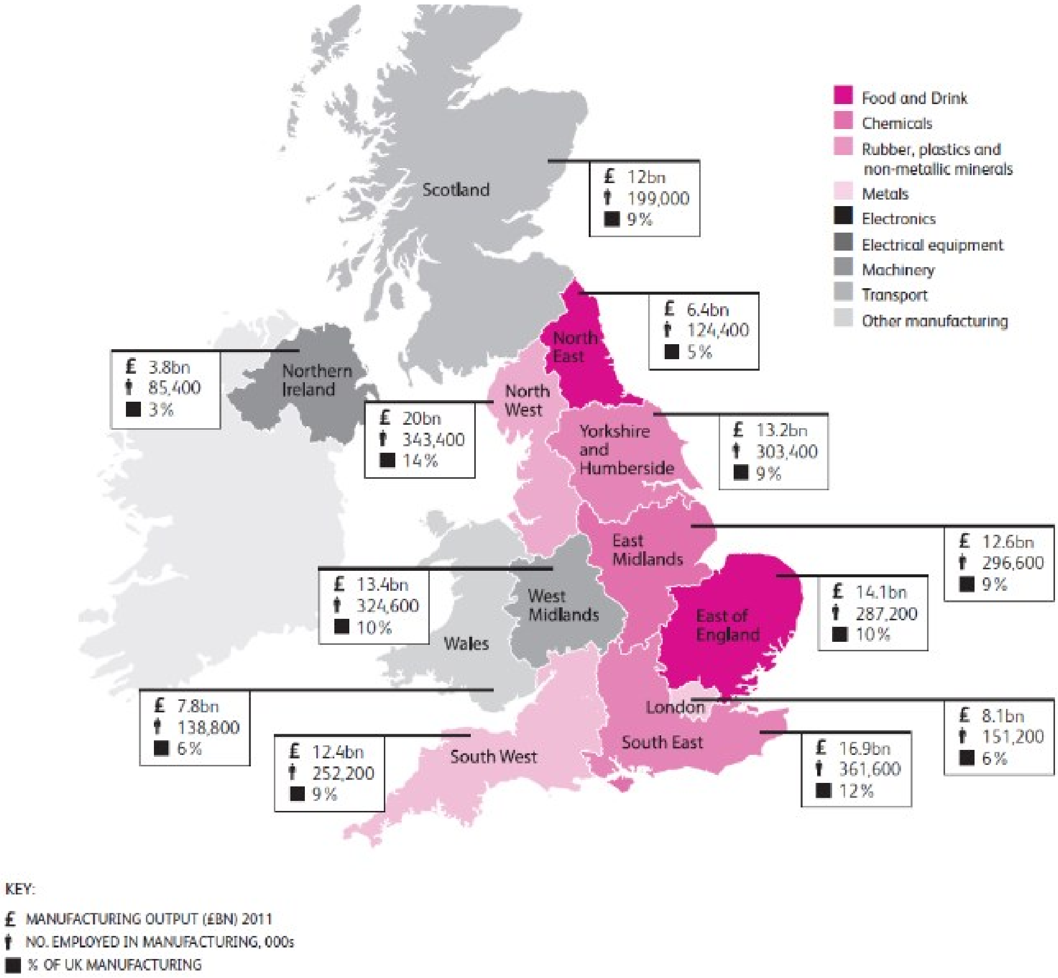
Not only does the manufacturing industry account for approximately 10% (323,000 jobs) of all full-time employment within the West Midlands, it accounts for 14.5% of the region's output (EEF, 2016). Even though the manufacturing industry within the West Midlands only exports 42% of its products to the EU, the region does export 22% and 21% of its products to Asia and North America respectively (EEF, 2016). Thus, it could be suggested that post-Brexit, the West Midlands will experience a relative smaller knock-on effect compared to other UK manufacturing regions that primarily export to the EU.

Regional Differences

Figure 1.4.2 illustrates the dominant manufacturing industries across different regions of the UK while simultaneously reporting the manufacturing output (£bn), number of employees in manufacturing related jobs and the percentage of manufacturing which contributes to the total manufacturing output of the UK, for each region respectively. At £20bn, the North West region is generating the greatest output which accounts for 14% of the total manufacturing in the UK. The second largest manufacturing region is the South

East, producing an output valued at £16.9bn, which accounts for 12% of the total manufacturing in the UK. Even though East of England (£14.1bn) is producing a greater output in comparison with the West Midlands (£13.4bn), both regions contribute the same percentage (10%) of total UK manufacturing. The South East, North West and West Midlands employ the greatest number of workers, reported as 361,600, 343,400 and 324,600 employees respectively. With the exception of the West Midlands, all of the regions within England are predominantly operating in Food & Drink, Chemicals and Material (Rubber, Plastic, Metals etc.) industries. The West Midlands is one of the only regions where the majority of manufacturing is within Machinery and Transport, which is traceable to the extensive network of organisations operating in the Automotive Supply Chain (ASC) within the region.

Figure 1.4.2: Regional Manufacturing Differences within the UK



Source: EEF (2014).

UK Automotive Industry

With approximately 1.6 million vehicles produced in 2014, the UK was ranked as the fourth largest European nation in terms of automobile production (see Table 1.4.1). Comprising of over 2,000 first-tier suppliers, the UK ASC employs approximately 770,000 people (SMMT, 2015). With a turnover of £64.1bn and contributing £12.4bn of value-added to the economy, the UK automotive industry is a crucial part of the economy. In addition, the UK automotive industry invests £1.9bn within R&D initiatives and the industry exports £34bn worth of products, accounting for over 10% of the UK's total export goods (SMMT, 2015).

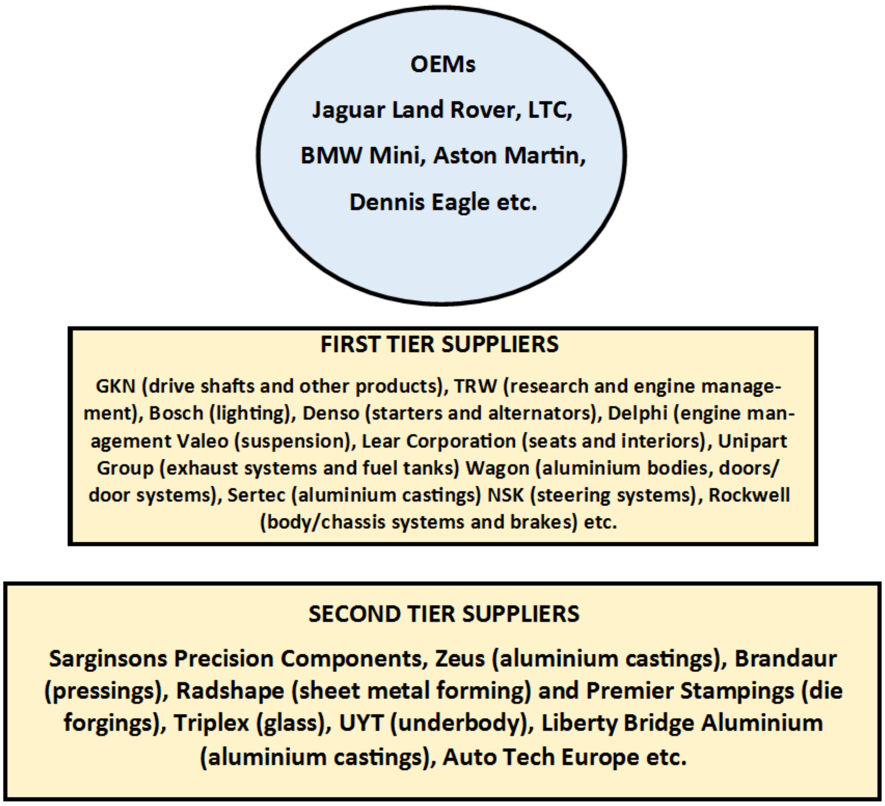
Table 1.4.1: 2014 Top 10 European Automotive Manufacturing Nations

Rank	Country	Cars	Commercial Vehicles	Total	% change
1	Germany	5,604,026	303,522	5,907,548	3.3%
2	Spain	1,898,342	504,636	2,402,978	11.1%
3	France	1,495,000	322,000	1,817,000	4.4%
4	**UK**	**1,528,148**	**70,731**	**1,598,879**	**0.1%**
5	Czech Rep	1,246,506	4,714	1,251,220	10.4%
6	Slovakia	993,000	0	993,000	1.8%
7	Italy	401,317	296,547	697,864	6.0%
8	Poland	473,000	120,904	593,904	0.6%
9	Belgium	481,637	35,195	516,832	2.6%
10	Romania	391,422	0	391,422	-4.8%

Source: SMMT (2015).

With component groups such as: the driveline; chassis and body panel; engine components; interior trim; electrical components; and design, the West Midlands has a large manufacturing cluster operating within the automotive industry. Even though the West Midlands has commonly been associated with Original Equipment Manufacturers (OEMs) such as Jaguar Land Rover, Aston Martin and Mini, there are many major firms within the first-tier and second-tier of the ASC (see Figure 1.4.3).

Figure: 1.4.3: Organisations within the West Midlands ASC



The majority of firms operating with the West Midlands ASC are of overseas ownership, demonstrating the open nature of the region in comparison with other global major automotive regions. The industry has previously suffered due to poor industrial relations and high global competition, and Small Medium-Sized Enterprises (SMEs) within the West Midlands are constantly under pressure as Multi-National Enterprises (MNEs) have the ability to switch to alternative facilities globally. Therefore, in order for SMEs to remain competitive, they have to implement a manufacturing strategy that takes their respective critical success factors into account (MacNeil and Bailey, 2010). The most popular manufacturing strategy in the automotive industry is lean production, however, having recognised the dynamics of the market, it is necessary to evaluate whether or not lean manufacturing is actually a suitable option for firms located in the West Midlands. This is particularly necessary given that the majority of firms within the West Midlands are SMEs and operate at the lower levels of the ASC, raising the question of whether or not an agile strategy may be more beneficial. With this in mind, and considering the confusion amongst lean and agile academic literature, there is an urgent need for greater clarity concerning the effects of each of the strategies.

Further Justification of Industry Focus & Research Questions

Although this chapter has already outlined the significance of the West Midlands automotive industry as a suitable context in which to investigate the research questions, this section provides further justification as to why analysing lean and agile systems within the automotive industry is most appropriate.

Firstly, as the birth of lean production can be traced to Toyota, the automotive industry is arguably the most mature one in terms of lean thinking. Secondly, even though firms operating within the automotive industry share similarities in terms of equipment and employee profile, there are clear differences in contextual factors such as firm size, firm age, manufacturing classification, and the position to which they belong within the ASC (Marodin *et al.*, 2016).

More specifically, within the UK automotive industry, quality and production sustainability is more pertinent than ever given the UK government's recent pledge to cease production of petrol and diesel vehicles by 2040 (Asthana & Taylor, 2017). Automotive organisations have been prioritising internal quality production sustainability initiatives, as demonstrated by a rise in OEMs employing dedicated managers and teams who focus on energy production efficiencies and the recyclability of defects (SMMT, 2016). One of the key ways that they have achieved environmental sustainability is via the implementation of lean production methods (Mayyas *et al*., 2012). This is because a focus on lean has led to reduced waste, lower levels of inventory, a reduction of defects, reduced warranty claims and reduced scrap levels, i.e. higher levels of production quality.

As the automotive industry was the 'home' of lean conceptualisation, the majority of studies investigating the concept of lean production have been grounded in that context (Bhamu and Sangwan, 2014). With this in mind, as lean production has been affiliated with sustainability via high levels of production efficiency (Cabrita *et al*., 2016), it would be expected that high levels of efficiency are obtained within the automotive supply chain (ASC). However, high levels of flexibility are also required within the ASC (Doran, 2004). For instance, during recent times, the automotive industry has been facing six challenges: (1) A general shortage of qualified engineers/operators; (2) Extreme fluctuations in terms of product mix and production volume etc.; (3) Safety precautions; (4) Energy efficient production techniques; (5) Reduction of production costs; (6) The availability of products in time (Brooke, 2008, Elmoselhy, 2013). Considering this list of flexibility concerns, it is important to address agile production, a concept that has been continually affiliated with flexibility, (Purvis *et al*., 2014; Fayezi *et al*., 2015) within the automotive context. The motivation of this study was not only to contribute to existing knowledge surrounding lean and agile production, but to also providepractical solutions to tackling issues (2), (5) and (6).

1.5 Research Methodology

The primary aim of this study was to evaluate the trade-offs between lean and agile production. Considering that positivism is associated with the researcher adopting a 'value-free' stance, a positivist, deductive approach was deemed most suitable for this research. As data relating to performance in lean and agile firms was not readily available, primary quantitative data was collected via a cross-sectional survey, as this enables the researcher to gather relatively high volumes of data within a reasonable amount of time. As this research sought to gather as much information concerning costs, dependability, flexibility, quality and speed, in order for statistical testing, the involvement of using a cross-sectional survey was deemed most appropriate. Furthermore, as this study primarily seeks to answer 'what' questions, such as determining 'what' the differences are between lean and agile systems in relation with performance objectives, as opposed to 'why' questions, collecting quantitative rather than qualitative data was most suitable in order to effectively answer the research questions.

The survey was designed to: a) robustly distinguish between lean and agile firms by weighting a set of bundled TPRCs employed within organisations; b) rigorously and 'more' objectively record cost, dependability, flexibility, quality and speed performance levels without the use of subjective questions. Baemon (1996) suggests that in order to ensure that a performance measurement tool is effective, it is necessary to consider inclusiveness (measurement of all activities), universality (comparisons can be made), measurability (data can be measured) and consistency (consistent with goals). Therefore, in order to achieve reliable and valid results, all performance data was captured in numerical form, rather than using Likert-Scale questions. However, the mode in which lean and agile firms were distinguished incorporated the use of Likert-Scale questions, which may be a limiting factor to this thesis.

The population of interest was defined as manufacturing firms operating within the West Midlands ASC. Out of the possible 450 contacted firms, a total of 140 Managing Directors/Operations Directors returned the survey revealing a response rate of 31%. The survey questions were pre-tested and piloted in a different, but comparable industry, before the final version of the instrument was sent out (see section 4.4). In total, the scorecard used to distinguish lean and agile organisations revealed that 74 firms and 66 firms were implementing lean and agile production methods respectively. Furthermore, out of the 140 organisations 49 firms employed a workforce greater than 250 employees, therefore were considered as large firms. The remaining 91 firms were identified as SMEs. Firms that responded to the survey ranged from being OEMs to 5^{th} tier suppliers within the West Midlands automotive supply chain. More information concerning the sample can be found in Chapter 5.

Having obtained numerical values for performance, the next step involved categorising each of these performance levels into low, medium and high, in order to allow for comparisons to be made. This study involved benchmarking via the use of logistic regressions. For instance, each manufacturing concept was compared with the other depending on three categorised performance levels (low, medium, high) concerning costs, dependability, flexibility, quality and speed. Neely *et al.* (1995) asserted that categorising performance measures into quality, speed (time), flexibility and cost categories is a useful method when analysing data. In this case, involving the use of categorised performance dimensions and levels allowed for not only comparisons to be made with respect to each strategy, but conclusions relating to the likelihood of each of these strategies acquiring varying levels of performance in line with each of the five performance dimensions to be drawn. More information concerning this process can be found in Chapter 4.

1.6 Organisation of the Thesis

This thesis is organised into 10 chapters.

- Chapter 2 will begin with the theoretical underpinnings and rationale for this investigation. Next, the chapter will provide a descriptive summary of the origins, principles and drawbacks of lean and agile production. The final section of this chapter outlined the similarities and differences between the TPRCs affiliated with lean and agile production.
- Moving on, Chapter 3 also looks into the literature which asserts that contextual factors (driving forces) may play a role in lean and agile firms, which then are conceptualised into hypotheses at the end of this chapter.
- Chapter 4 evaluates findings from the lean and agile performance literatures individually, but also highlights studies that have outlined the performance trade-offs between each of the two concepts. Taking this into account, this chapter also outlines the research gap and conceptual framework used within this thesis.
- Chapter 5 illustrates the choice of methodology (largely quantitative) and research design used to test the conceptual framework. Furthermore, this chapter illustrates the technique used to calculate performance levels based upon the five measures of performance.
- Chapter 6 consists of the statistical analysis concerning the differences in contextual factors. In this chapter firm age, firm size, manufacturing classification and positional tier within the SC are considered to assert whether these factors may affect whether firms were more likely to be lean or agile.

- Chapter 7 details the majority of the statistical analysis employed in this investigation. In this chapter, costs, dependability, and quality and speed performance were examined and the trade-offs between lean and agile systems were noted.
- Chapter 8 reports on the flexibility trade-offs between lean and agile manufacturing systems.
- Chapter 9 presents the discussion of the findings from Chapters 6, 7 and 8.
- Chapter 10 will conclude this study, where the limitations of this investigation and guidelines for future research are outlined.

CHAPTER 2 - INTRODUCTION TO LEAN AND AGILE PRODUCTION

***"…defining theory is problematic. It has been argued that it is easier to define what is not a theory"*.**

Chicksand *et al.* (2012, p.456).

The main aims of this chapter are to outline the theoretical context underpinning this investigation as well as outlining the fundamental principles of lean and agile manufacturing. With this in mind, this chapter consists of four sections. First, this chapter looks into the trade-off concept in association with the RBV perspective. Second and third, this chapter will provide a thorough understanding of lean manufacturing and agile manufacturing respectively. Fourth, this chapter outlines the similarities and differences in the TPRCs affiliated with each of the production paradigms.

2.1 Theoretical Background

Chicksand *et al.* (2012) asserted that theories are crucial in order to make sense and understand the complex environment in which we work and live, as they can help us to move away from just observing descriptive events towards a position where we can predict relationships within a particular setting (Kerlinger and Lee, 2000). Defining theory is a difficult task where authors have advocated that description, references, data, hypotheses and metaphors are not theory building (Sutton and Staw, 1995), whilst others (Colquitt and

Zapata-Phelan, 2007) have suggested that theory can be defined as the relationship between independent and dependent variables. Also, it is important to distinguish studies into those which build new theory and those that test existing theory (Ibid., 2007). Acknowledging the difficulties in defining theory, it can be quested to what extent previous studies in SCM or OM are based upon a theoretical foundation. Disturbingly, Chicksand *et al.* (2012) and Walker *et al*. (2015) found that only approximately one third of studies within the realms of SCM and OM respectively, included the use of some kind of theoretical and intellectual tradition, highlighting the need for future studies within these areas to make some kind of linkage between findings and theoretical stances.

The justification of why studies within OM have failed to link theory with their findings may stem from the fact that over the years, it has become abundantly apparent that the discipline of OM is missing its own flagship theory (Schmenner and Swink, 1998). For instance, the finance discipline houses economic theory as its core theory and other disciplines generally have at least one or two theories that are embedded within their respective domains. It seems as though OM authors are either: a) Not using any theory within their studies; b) Reluctant to develop theory within the OM discipline; and c) Reluctant to borrow theory from other disciplines. In addition, it seems as though the OM literature generally sides with the assertion made by Colquitt and Zapata-Phelan (2007), suggesting that theory can simply be defined as the relationship between independent and dependent variables. Building on this concern, Schmenner and Swink (1998) provided many avenues of thought around the theoretical understanding of the OM discipline, with a particular focus between 'laws' and 'theories', advocating that it is crucial to distinguish between the two.

Schmenner and Swink (1998, p.99) stated that "*Laws are the precise descriptions of observed and supported regularities. Laws show how something to be explained can be accounted for. Moreover, laws, like hypotheses, can exist independent of theories. Kepler's laws of planetary motion and Boyle's law of gases were accepted as laws well before there were theories to explain why they work as they do*". It is only when a hypothesis is accepted and continually supported by a growing set of empirical evidence, that propositions may be categorised into laws. Within the realms of social sciences, laws are described as 'modes of phenomena' (Ibid.) and as these laws are not referred to as theories, they may contain a sense of incompleteness (Little, 1992). In comparison, theories exist at a deeper and more meaningful level than laws and normally are introduced when a phenomenon can be expressed via the form of empirical laws. These theories are used to precisely explain why laws are occurring, while the phenomenon itself is the enactment of the theory in practice (Schmenner and Swink, 1998).

As will be discussed, lean and agile organisations were distinguished in this research based upon the TPRCs that were employed within organisations. It may be suggested that findings of this research can inevitably be explained using RBV, however, as mentioned in Chapter 1, the ultimate focus of this study was to rigorously determine the performance trade-offs between lean and agile firms. Therefore, the theoretical foundation of this study is not necessarily set up from an existing theory, but based upon an existing law, known as the trade-off law (Ibid, 1998). The following section will outline Skinner's (1969) theoretical assertion in more detail.

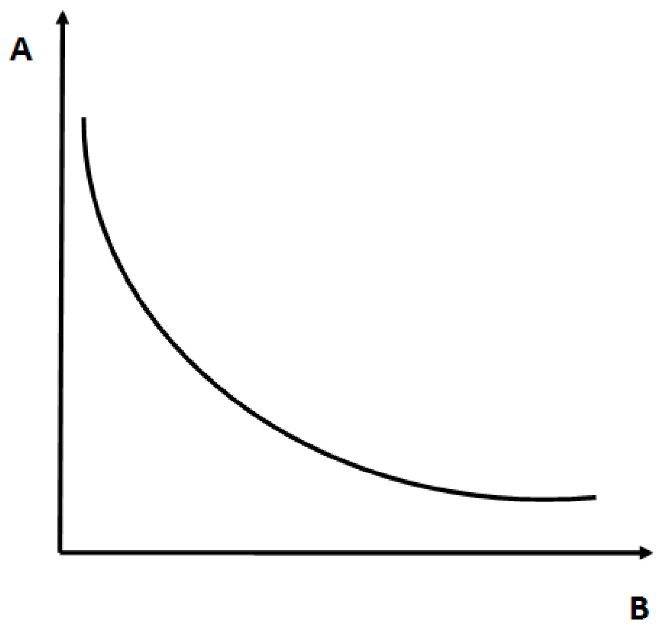
Skinner (1969) asserted that firms may compete on aspects other than just on costs and with this in mind, suggested that no manufacturing organisation can do everything well; that there must be trade-offs. These trade-offs may be in the form of performance objectives, where firms would need to prioritise which performance objectives are vital for the success of the firm. It can therefore be suggested that the idea of strategic trade-offs, now more commonly known as trade-off law, is attributable to Skinner. In an attempt to find the cause of performance trade-offs, Da Silveira and Slack (2001) suggested that what is happening internally within the organisation must be observed, by examining resources and capabilities. The notion here is that firms must acknowledge which performance objectives are most important for their respective organisation, and then focus their attention on acquiring the relevant resources which would in turn enable them to achieve their performance objectives or competitive priorities. Krajewski and Ritzman (1996) suggested that there are four competitive priorities, namely: cost, flexibility, quality, and speed/time. However, during recent times authors such as Slack *et al*. (2010) have also proposed dependability as an additional competitive priority. Therefore, in order to compete successfully, firms will acquire the relevant resources depending on which performance objective/competitive priority (cost, dependability, flexibility, quality, speed) they value most and deem most important. The discussion of performance objectives is developed Chapter 3. Evaluating the resources and capabilities of firms links this thesis with the resource-based view (RBV). Even though literature within the field of OM has not always linked findings with existing theoretical stances, many OM and SCM studies have adopted theoretical stances from the field of business management, especially the RBV (Peng *et al*., 2008), which is one of the most widely cited and influential theories within the realms of management. Fundamentally, the RBV proposes that if a firm is to reach a position of sustainable competitive advantage (SCA), it must acquire and control valuable, rare, inimitable, and non-substitutable (VRIN) resources and capabilities (Barney, 2002). Amit and

Schoemaker (1993, p.35) define resources as "*the stocks of available factors that are owned or controlled by the firm*", such as technologies, methodologies and skills; whereas capabilities have been defined as the processes or functions which are performed within a system (Da Silveira and Slack, 2001), and can include management, shop-floor abilities, and skills. In essence, capabilities can be conceptualised as the organisation's operational strengths (Noble, 1995; Boyer and Lewis, 2002; Flynn and Flynn, 2004), which are captured via measures such as cost, dependability, flexibility, quality and speed. Due to the ease in highlighting a firm's competitive advantage internally and externally (across SCs), OM has embraced the RBV, especially the notion of capabilities, as it is a useful means of understanding the way in which SCA is achieved via the effective acquisition and leveraging of resources and capabilities (Corbett and Claridge, 2002; Peng *et al*., 2008). In addition, literature within the wider management field has often linked operational tools with resources, and practices and routines with capabilities. Peng *et al*. (2008, p.731) suggested that practices which are implemented repeatedly can be regarded as routines and even went on to define routines as "*the way things are done or patterns of activities*". Furthermore, Hannan and Freeman (1984) and Weick (1979) advocated that routines are in fact sources of inertia and maintain the status quo respectively.

Given there is a wide array of literature which not only defines, but operationalises capabilities based upon a selection of TPRCs (Prahalad and Hamel, 1990; Stalk *et al*., 1991; Hult *et al*., 2003; Peng *et al*., 2008), this may provide a starting point by which to differentiate lean and agile systems prior to investigating the performance trade-offs. This approach to research allows capabilities to be distinguished based upon a set of bundled TPRCs, which in turn can be used as the means for methodologically categorizing firms as being either lean or agile. Taking this into account, even though an RBV perspective was utilised as a way of distinguishing between lean and agile manufacturing systems within this study, this was not the focal point of this research, as this study is primarily anchored around the performance trade-off debate.

Returning to the proposition that pursuing multiple objectives will result in compromises, literature concerning trade-offs has commonly depicted this 'law' (Schmenner and Swink, 1998) as a simple curved graph, as shown in Figure 2.1.1. In association with Figure 2.1.1, literature (Skinner, 1992; Da Silveira and Slack, 2001) has suggested that trade-offs ultimately encompass a minimum of two performance variables (A and B), where the strength of dimensions are inversely related. In summary, Figure 2.1.1 suggests that if a firm is competing effectively on competitive priority A, then they will not be able to achieve success with competitive priority B.

Figure 2.1.1: The Trade-Off Law



Source: Adapted from Da Silveira and Slack (2001, p. 951)

Although Da Silveira and Slack (2001) have suggested that many studies upheld Skinner's (1969) assertion, a major debate concerns whether or not capabilities lead to trade-offs or whether capabilities are cumulatively gained, also known as the 'Sand Cone Model' (Brown *et al.*, 2007), which has given rise to the notion of world-class manufacturing (Schonberger, 1986). World-class manufacturing and the 'law of cumulative capabilities' revolves around the belief that manufacturing organisations are able to compete on all measures of performance via the implementation of 'best-practices'. Schonberger (1986) suggested that performance trade-offs are actually a 'myth', supported by Collins and Schmenner (1993) who emphasised an approach that looked to explore the complementarities as opposed to trade-offs. Flynn *et al*. (1999) investigated just-in-time practices and found that organisations implementing these may in fact experience positive synergies between varying levels of performance objectives. Even though the best-practice and world-class manufacturing approach have been explored (Schonberger, 1986; Flynn *et al.*, 1999) this approach has not been widely accepted (Brown *et al.*, 2007). Harrison (1998), having reviewed this matter in-depth, found that organisations were unlikely to be competing across all aspects of performance. Furthermore, as will be discussed in Chapter 3, after conducting a review of studies that have explored the effects of lean and agile manufacturing strategies relative to performance, each strategy was identified as holding strengths in varying aspects of performance. Therefore, the theoretical premise behind this thesis sides with the trade-off law as opposed to the law of cumulative capabilities.

Aside from the literature investigating lean and agile performance capabilities, during the 1990's many studies attempted to build on the trade-off debate, however findings were heterogeneous. For instance, Mapes *et al.* (1997) found that firms prioritising product variety, more commonly known as flexibility, demonstrated signs of trade-offs while even though White (1996) obtained positive correlations with performance, findings were not sufficient to disregard the notion of trade-offs. In addition, Schroeder *et al.* (1996) identified quality as the most significant performance objective which illustrated signs of trade-off. As there are mixed views regarded trade-offs and performance measures, as well as a contradicting assertions concerning the effects of lean and agile production on levels of performance (Chapter 3).

Summary

In summary, even though authors have contended Skinner's (1969) assertion that no manufacturing strategy, and in turn organisation, can do everything well, this has not overshadowed the concept of performance trade-offs. With this in mind, the main objective of this research is to provide clarity into the trade-offs between lean and agile manufacturing organisations. Therefore, the theoretical foundation upon which this investigation is conceptualised involves Skinner's (1969) assertion that no manufacturing organisation can compete on all performance objectives and trade-offs will inevitably be present. Therefore, depending on a firm's manufacturing strategy, they will acquire the relevant TPRCs that are geared towards their performance objectives. However, as will be discussed within Chapter 3, as there are many commonalities concerning the set of TPRCs affiliated with each of the manufacturing strategies under investigation, the distinction between each of the manufacturing approaches is not so clear. A reason for the ambiguity concerning each of the paradigms lies in the fact that the literature has often overlapped each concept in terms of both capabilities and performance objectives. Therefore, before delving in to the literature, which looked to explore the differences in contextual factors or performance outcomes of lean and agile manufacturing, the remaining sections within this chapter will explore the fundamental principles, drawbacks and set of TPRCs implemented within each manufacturing concept under investigation.

2.2 Lean Production

The main aims of this section are to detail a robust understanding of the lean concept, as well as acknowledge its drawbacks. This section consists of four sections. First, the origins of the lean concept are outlined. Second, the reasoning into why lean production has become popular amongst both practitioners and academics is mentioned. Third, the five over-arching principles of lean management are detailed. Fourth, the drawbacks of the lean concept are discussed.

2.2.2 Lean Origins

Even though the lean concept gained popularity within western economies as a result of the publication of '*The Machine that Changed the World'*, it is important to consider why the nation of Japan became so efficient (i.e. lean) in the first place. Between 1950 and 1973, Japan's GNP (Gross national product) increased by approximately an average of 10% each year leading to the question of how this was achieved.

After World War II (WWII), aided by investment from the US, Japan focussed its initiatives on becoming a highly efficient nation. Considering Japan is a country with little to no natural resources, it may be argued that there was no alternative but to become global leaders in what they actually do. With high levels of investment allocated to technological sectors (Gordon, 2003) after WWII, Japan realised that it was necessary to become an export-orientated nation if they were to survive or compete in the global environment, with the capital earned from exports destined for reinvestment in technology, management and raw materials. During the 1950's, Japan had become favourable to open trading networks via treaties such as the US-led GATT (General Agreement on Trade and Tariffs). Japan was able to take advantage of this agreement by purchasing its energy supplies from the Middle East, enabling the nation to grow industrially at relatively low cost. Due to the scarcity of natural resources, Japan built its economy by taking advantage of international trade and ensuring efficiency in domestic production.

The roots of the lean concept can be traced back to Henry Ford, who started operating an automotive production system in 1913, the Highland Park Ford Plant, located in Michigan (US). The clever use of a set of practices (interchangeable parts, standardisation and the assembly line) enabled Ford to produce large volumes of automobiles at great speed. Even though it was highly efficient, it was inflexible; in fact, the Model T Ford, the automobile manufactured at this plant, remained virtually unchanged for 19 years. Inevitably, due to the rising demand for automobiles of shorter life-cycles, as well as a changing market structure post WWII, Ford was unable to sustain its competitive position. Ford's mistakes did not go unnoticed, particularly by Eiji Toyoda (a member of the founding family of Toyota) and Taiichi Ohno (Toyota's leading manufacturing engineer), who visited Highland Park after WWII in order to analyse Ford's operations. Ohno viewed Ford's mass production technique as an unsuitable strategy for Toyota to adopt in the long-run due to the high inventories it required, which simultaneously restricted the diversity of products that could be produced. However, they were convinced that if they incorporated previous knowledge gained from their Toyoda power loom company, along with a set of new ideas, they could adapt Ford's mass production system in order to enable Toyota to become a key player within the automotive industry (Duque and Cadavid, 2007).

Ohno and Toyoda did not wish for Toyota to follow established manufacturing protocols which emphasised machine and workstation optimisation, instead wanting Toyota to emphasise product flow throughout the total production process (Dahlgaard and Dahlgaard-Park, 2006; Duque and Cadavid, 2007). With the use of innovative practices (dimensioning manufacturing resources in accordance to real demand; increasing self-monitoring capabilities ensuring quality (Jikoda); mapping the process layout; analysing and improving setups which enhanced rapid changeovers (SMED); using Kanban systems to coordinate production pull from one workstation to another; and linking the organisation to its supplier which enabled just-in-time (JIT) supply (Womack, 2002)), Toyota were able to offer a relatively wide variety of products in accordance with the market's demand. These practices minimized lead times whilst eliminating the requirements to holding large inventories. Thus, a management system was developed which strictly followed these guidelines and is now known as the 'Toyota Production System' (TPS) (Dahlgaard and Dahlgaard-Park, 2006; Duque and Cadavid, 2007). Centered on the concept of continuous flow, the TPS appreciates that only a small amount of time and effort actually adds value to the end customer. It is difficult to identify exactly when the methodology behind the TPS was first implemented, however, in 1965 the Kanban system was extended outside of Toyota's factories to their suppliers. Toyota is considered one of the most profitable automotive manufacturers (Taylor, 2007), whose success has often been attributed to the TPS (Hino, 2006). Crucially, Toyota's success cannot be ascribed to one point in time, but rather to the accumulation of gradual innovations (Fujimoto, 1999) which has spanned decades. Even though the lean concept originated from the TPS, it would not gain popularity until the 1990's (Holweg, 2007), the reasons for which will now be explored.

2.2.1 Why did the Lean Concept become so popular?

The business world was introduced to lean manufacturing techniques by Womack *et al.*'s 'The Machine That Changed the World' in 1990*,* a book which through its simplistic form appealed to both academics and practitioners alike. Outlining the timeline of how operations within the automotive industry evolved from mass production to lean production, this book paid particular attention to Toyota, where comparisons were made between the practices employed in the firm in Japan and those of other world-leading manufacturers across Europe and the US. In essence, the book identified how the TPS was used as a competitive weapon against rivals (Holweg, 2007). The name 'lean' was applied to the TPS, as it used less of everything to produce the same product in comparison with mass production strategies, with the book describing how lean production required half the human labour, half the space required for machines, half the investment and half the time of mass production. Inevitably, lean overshadowed mass production, as it was able to produce a greater variety of products that consisted of lower defects, whilst using less of everything. However, in order to truly understand the concept of lean production, it is necessary to explore how lean is defined, and the five pillars upon which it is built.

2.2.3 Five Principles of Lean Production

As is evident from Table 2.2.1, definitions generally assert that the elimination of waste and the creation of value are the foundations for lean manufacturing. There are also five underlying principles regarding this production concept (Womack and Jones, 1996; Emiliani, 1998; Murman *et al*., 2002; Hopp and Spearman, 2004) which the following section will outline in turn.

Table 2.2.1 – Lean Manufacturing Definitions

Author(s)	Definition
Shah and Ward (2003)	Collection of practices that work together synergistically to create a streamlined, high quality system that produces finished goods at the pace of customer demand with little or no waste.
Hopp and Spearman (2004)	Production that is accomplished with minimal buffering cost.
Narasimhan *et al*. (2006)	Production is lean if it is accomplished with minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations.
Treville and Antonakis (2006)	Integrated manufacturing system intended to maximise capacity utilisation and minimise buffer inventories through minimising system variability.
Hallgren and Olhager (2009)	Lean manufacturing is a program aimed mainly at increasing the efficiency of operations.
Taj and Morosan (2011)	A multi-dimensional approach that consists of production with minimum amount of waste.
Yang *et al*. (2011)	Set of practices focused on reduction of wastes and non-value added activities from a firm's manufacturing operations
Alves *et al.* (2012)	A model where the persons assume a role of thinkers and their involvement promotes the continuous improvement and gives companies the agility they need to face the market demands and environment changes of today and tomorrow.

Identify Customers and Specify Value

When initiating lean production, firms must recognise that only a small amount of time and effort actually adds value to the end customer. Therefore, after identifying the value of a certain product in the eyes of the end customer, the organisation can set out to remove all of the non-value adding activities (Murman *et al*., 2002).

Identify and Map the Value Stream

In order for firms to map production, a value stream has to be created, which can ensure that each individual process provides some kind of value to the end customer. The value stream refers to the collection of processes and activities across the whole organisation which are involved in delivering the product. In essence, value stream mapping represents the end-to-end process. Value streams are not limited to one individual organisation, hence it is a key reason why suppliers, manufacturers and distributors strive to integrate with one another (Hopp and Spearman, 2004).

When organisations are analysing their value stream, they should identify and eliminate all activities that do not add value and sustain all activities that do. Even though certain non-value adding activities may be unavoidable, organisations should try to develop a process that does not require the use of them in the future.

Create Flow by Eliminating Waste

Creating flow within an organisation involves organising activities in such a way that the product can move smoothly throughout the individual value-creating steps. For instance, when an organisation maps their respective value stream they may find that only 5% of activities add value to the end customer. Therefore, eliminating the remaining avoidable activities that do not add any value can ensure that products flow to the end customer without encountering any forms of disruption.

Respond to Customer Pull

Responding to customer pull concerns only producing goods which are demanded at that certain point in time, an idea which revolves around the notion that firms should not try and push their products on to customers, but rather to let them 'pull' the products themselves. Therefore, all parts of the production process should be linked in such a way that the materials and activities are not released until they are actually needed (Womack and Jones, 1996). The use of Kanbans enforces this 'pull' discipline.

Pursue Perfection

When an organisation pursues perfection it must constantly strive to meet customer needs, whilst simultaneously improving its own process with zero defects. As processes link together, more layers of waste become apparent and firms should continue improving their operations, towards an end point of perfection. Continuous improvements will only be successful when a firm applies a philosophy which emphasises improvement efforts as perpetually incomplete (Womack and Jones, 1996).

In summary, firms that follow each of the underlying principles will eventually exhibit a lean production system. These principles will ensure that firms are constantly reviewing processes within their organisation that add value to the end customer, however, in order to develop a deeper understanding concerning how each of these principles are implemented, it is crucial to outline the set of TPRCs applied within lean production, which are discussed in section 2.4.

2.2.5 Lean Enterprise

Bhasin and Burcher (2006) asserted that one of the fundamental weaknesses behind lean production concerns the inability of firms to accommodate signification variations in orders or products. With this in mind, it is important to consider the developments concerning this manufacturing approach, more specifically the lean enterprise. Chase (1999) suggested that firms implementing lean production should view it as a long term strategy and Emiliani *et al.* (2003) went on to suggest that firms must extend their focus to include the SC. More specifically, Bicheno (1999) asserted that organisations seeking to implement lean, especially as an enterprise, need to integrate change with the help of the customer, strategy and workers within the firm, and that it is vital to extend lean thinking beyond the manufacturing process. Furthermore, Bicheno (1999) highlighted the importance of lean enterprises and stated that factors concerning new product development are the areas in which leading lean firms are becoming more competitive. In order for firms to transition from a lean operation to a lean enterprise, Krizner (2001) emphasised the need to bring together different sections and eradicate the barriers between them. For instance, Baker (2002) asserted that the implementation of lean as an enterprise must extend into SCs, as it is crucial to work with suppliers. As will be discussed in section 2.3.4 (see virtual enterprises), Bicheno (1999) advocated that SCs have changed from their traditional format, noting how both buyers and suppliers could gain advantage via the notion of a 'partnership philosophy'. Previously, businesses looked to control SCs via vertical integration (Hines and Taylor, 2000); however, this has changed as organisations have outsourced many of their activities (Bhasin and Burcher, 2006). Although Liker (2004) suggested that in order for firms to truly be lean, they must expand lean principles across the entire value chain, it is important to understand that looking beyond the organisation is a difficult task (Bhasin and Burcher, 2006). With this in mind, lean enterprise encourages SC co-ordination (Sharma *et al*., 2011), such as working to common quality standards, sharing transport/logistics and sharing inter-company communication (Bhasin and Burcher, 2006). In fact, given that material costs can account for over half of the cost of goods sold for most firms, Sharma *et al*. (2011) advocated that the front end of the SC is critical for lean enterprises.

2.2.5 Lean Limitations

The TPS has gained popularity within western economies, demonstrated by Osterman's (1994) assertion that by the mid-1990's, 80% of American manufacturing organisations with at least 50 employees had in one way or another initiated lean/TPS practices. Importantly, lean initiatives have not only been utilised within western manufacturing organisations; they are also applied within the service sector, illustrated by the fact that lean concepts have been at the forefront of NHS operations in the UK (Bancroft *et al.,* 2016). Nevertheless, there are limitations and weaknesses associated with lean, which it is necessary to understand in order to build a holistic comprehension of the concept.

Kamata (1983) and Mehri (2006) have contended the advantages of lean production, asserting that the production of high quality goods under a tight lean operating strategy ultimately comes at the cost of employee welfare, based on their own experience of working within Toyota's production systems. Despite their respective experiences being spaced 30 years apart, they observed similar issues regarding employee working conditions, implying that the situation failed to improve within this 30-year time period in Toyota's history. Kamata (1983) noted several issues relating to employee working conditions, such as the speed of the production line inevitably burdening workers with stress and the demoralisation of employee satisfaction as workers are replaced with machines. Kamata (1983) also stated that even though Toyota are successful when increasing productivity via lean techniques, which ultimately encompass many advantages, the subsequent wealth is unequally divided amongst the workers who produce the goods. Kamata (1983) further asserted that Japanese workers continue to work under these lean conditions as they believe they have no choice as, for instance, working in other industries will result in lower wages.

Although there is considerable literature on the lean theory, western organisations are still finding it difficult to gain the full benefits of practices associated with lean manufacturing (Liker and Hoseus, 2009). For instance, Pay (2008) found that only approximately 5% of organisations implementing lean initiatives actually achieve the results they first anticipated. Even though an organisation may invest in resources enabling the implementation of lean, national cultures may impact the degree to which lean activities carried out on a daily basis (Haan *et al*., 2012). The impact of culture on the level of lean has also been confirmed by Mehri (2006), who asserted that Japanese culture can be categorised into two concepts, tatemae (what you are supposed to feel or do) and honne (what you actually feel or do); finding that when Japanese workers felt mistreated, instead of raising any concerns (honne), due to their culture these workers carry on with their duties even though they are not happy (tatemae). Disagreements and raising concerns regarding welfare conditions is considered as bad behaviour and negative working practice in Japan. Arguably, culture can impact the extent of lean's successful application within an organisation, especially within western firms. Furthermore, Mehri (2006) also witnessed similar employee working condition issues as identified by Kamata (1984), and even went on to state "*rarely do new ideas emerge from within the company"* (Mehri, 2006, p.27), suggesting that most forms of innovation are from Toyota's purchase of small businesses, who are actually the sources of innovation.

It has been stated that lean initiatives fail because workers have mistaken "*lean solutions for the process that leads to what we see in a Toyota plant… (instead of) the human thinking and processes that underlie specific practices that we observe"* (Liker and Rother, 2011, p.2). This statement implies that lean manufacturing practices may actually be supported by the cultural values of workers within the organisation (Rother, 2009). Although lean manufacturing practices may be initiated, cultural values within a workforce can significantly vary amongst different countries (House *et al*., 2004). There is a growing interest on cultural and behavioural factors in relation to lean manufacturing (Liker and Hoseus, 2010; Rother, 2009; Shook, 2010).

Overall, multiple sources have suggested culture can play a large part within the implementation of lean, however, is this really the only reason to explain why lean initiatives can fail? Although this investigation acknowledges that culture can play a pivotal role in the successful implementation of lean initiatives, it does not side with culture being the sole reason to why firms fail at implementing lean. For example, Toyota is currently the largest global automotive manufacturing organisation, producing 9.98 million vehicles in 2013 (Toyota, 2014), however, despite the TPS philosophy which promotes quality, efficiency and reliability, Toyota has faced reputational issues after a series of recalls and safety issues. For instance, over 6.5 million (window defect) and 1.4 million (airbag defect) vehicles have been recalled in 2015 and 2016 respectively (BBC, 2015; 2016) as a result of problems which arose due to poor quality checks within the line manufacturing process. If even the founders of lean manufacturing are unable to always implement lean initiatives successfully, surely organisations who are attempting to replicate this production concept will also face difficulties.

Summary

Originating from the TPS, lean manufacturing has been defined as a concept that prioritises the elimination of waste in order to enable the flow of goods (Womack and Jones, 1996) and is a manufacturing paradigm built upon five underlying principles: identify customers and specify value, create flow by eliminating waste, respond to customer pull and pursue perfection. However, the UK manufacturing industry is not solely competing on efficiency, with flexibility, speed and quality levels proving to be just as important. With this in mind, and considering the strong affiliation between lean and efficiency, is this really the most suitable strategy for SMEs within the UK manufacturing industry, or is agile production more suitable? Before exploring the similarities and differences between the two manufacturing concepts, the next section will provide an introduction to the agile concept.

2.3 Agile Production

This section is designed to provide an overview of agile manufacturing concept, as well as address this paradigm's limitations. Divided into three section, initially the origins of agile production, as well as definitions, are outlined, before the four over-arching principles of agile manufacturing are detailed. Finally, the limitations of the agile manufacturing are discussed.

2.3.1 Agile Origins

The birth and development of the agile manufacturing concept occurred as increased levels of global competition diminished domestic barriers against foreign competition (Rattner and Reid, 1994). American manufacturers experienced a decline in sales as they were unresponsive to the marketplace, while smaller, more flexible and more responsive manufacturers took control of global markets. The concept of 'agility' was first noted during a four-month collaborative workshop in 1991 at Lehigh University (21st Century Manufacturing Enterprise Strategy: An Industry Led View), the objective of which was to develop a manufacturing revitalisation strategy to counteract the decline of American manufacturers against foreign competition, as the current improvement strategy in 1991 was insufficient for competing in the global market. Lehigh University developed this early notion of agile manufacturing via the use of research, focus groups and industry collaborations (Dove, 1994). The Agility Forum has evolved from the early developments of agility whilst contributing much to the theory of agile manufacturing, and has continued to develop the notion of agile manufacturing, defining agility in many ways:

"Agility is dynamic, context specific, aggressively change embracing, and growth orientated it is not about improving efficiency, cutting costs, or battening down the business hatches to ride out fearsome competitive storms. It is about succeeding and about winning profits, market share and customers in the very centre of competitive storms that many companies now fear". (Goldman *et al.,* 1995, p. 26).

"Agility is the ability to thrive and prosper in a competitive environment of continuous and unanticipated change, to respond quickly to rapidly changing markets driven by customer-based valuing of products and services. It is the coming business systems that will place the mass production businesses of today". (De Vor and Mills, 1995, cited in: Gunasekaran *et al.,* (2002, p. 1360)

"Being agile means being proficient at change – and allows an organisation to do anything it wants to do whenever it wants to". (Dove, 1994, p. 14, cited in: Haricombe and Lusher, 1998)

Table 2.3.1 also provides outlines a more 'recent' list of definitions concerning agile manufacturing.

Table 2.3.1: Agile Manufacturing Definitions

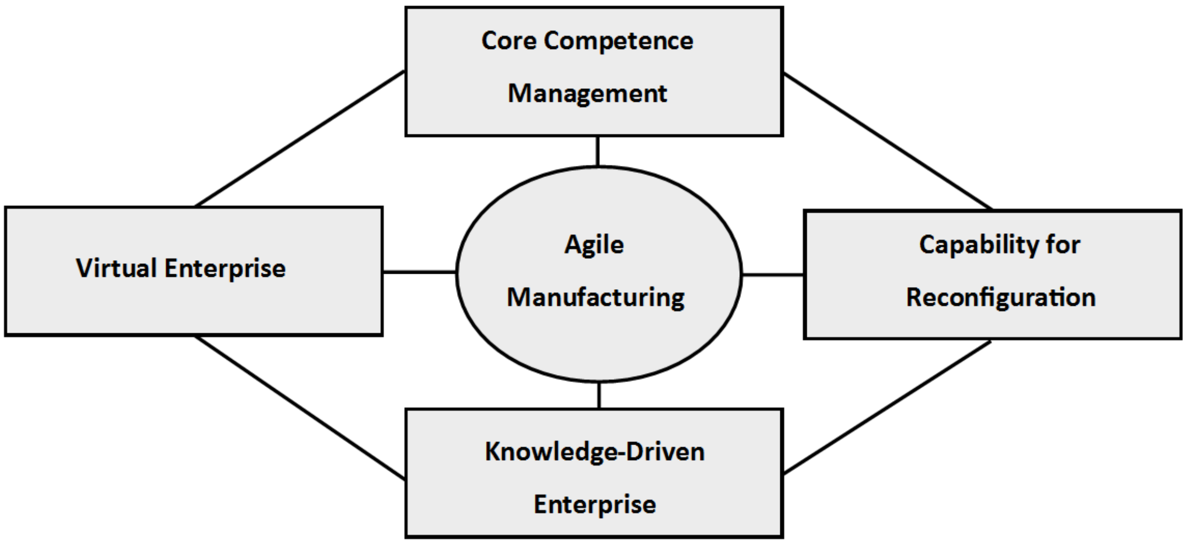
Author(s)	Definition
Christopher (2000)	The ability of an organisation to respond rapidly to changes in demand, both in terms of volume and variety.
Sharifi and Zhang (2001)	Ability to sense, respond and exploit anticipated or unexpected changes in the business environment.
Jin-Hai *et al.* (2003)	A system that shifts quickly (speed and responsiveness) among product models or product lines (flexibility) ideally in real time response to customer demands.
Prince and Kay (2003)	Ability to respond to sudden changes and meet widely varied customer requirements in terms of price, specification, quality, quantity and delivery.
Brown and Bessant (2003)	The ability to respond quickly and effectively to changes in market demand.
Narasimhan *et al*. (2006)	Production is agile if it efficiently changes operating states in response to uncertain and changing demands placed upon it.
Gunasekaran *et al.* (2008)	Agile manufacturing systems have a focus on speed and flexibility and not cost.
Jain *et al.* (2008)	Agility can be evaluated with both hard and soft criteria of flexibility, profitability, quality, innovativeness, proactivity, speed of response, cost and robustness.

These three definitions, as well as the definitions in Table 2.3.1, describe agile manufacturing in terms of outcomes; however, they do not specify how agile manufacturing can be operationalised within an organisation. Therefore, the following section will discuss the four core principles of agile manufacturing.

2.3.2 Four Principles of Agile Manufacturing

Research conducted by the Agility Forum suggested that agile manufacturing refers to the ability to thrive in an unpredictable, volatile market by rapidly responding and reconfiguring products to customer needs (Dove, 1994). With this in mind, the underlying principle of agility is the capability to respond quickly to changes in the business environment, also known as change proficiency (Goldman *et al*, 1993) or change competence (Kidd, 1995). Literature (Goldman *et al*., 1995; Yusuf *et al.,* 1999) has stated that agile manufacturing consists of four underlying principles: 1) Core Competence Management; 2) Capability for Reconfiguration; 3) Knowledge-driven Enterprise; and 4) Virtual Enterprise, which are presented in Figure 2.3.1.

Figure 2.3.1: Four Underlying Principles of Agile Manufacturing



Source: Yusuf *et al.* (1999, p.38)

Core Competence Management

Core competence management is associated with an organisation's workforce and product, which can be identified at two independent but related levels, the individual and firm (Yusuf *et al.,* 1999). For individuals, core competencies concern skills, knowledge, attitude and expertise (Kidd, 1995), and can be developed via investment in training and education. Individual workers have often been described as the critical resource for an organisation (Ibid.) as they are the competence carriers and can be used as a weapon when dealing with threats (Prahalad and Hamel, 1990). Prahalad and Hamel (1990) have previously asserted that core competencies can stem from corporation-wide learning processes, the integration of diverse skills, the delivery of value, work organisation, and the capability for inter-organisational cooperation. In order for a core competence to be of strategic importance, it must meet three conditions, namely: ability to multi-venture; enrich customers valuing end goods; and difficult to replicate and imitate by rivals (Yusuf *et al,* 1999). However, the creation and sustainability of core competencies is a difficult task, as the management system will be required to rank the organisations main capabilities, whilst identifying any missing links which can be acquired via the use of alliances. This is where cooperation with competitors is of significant value, as agile manufacturing implies that competition and cooperation are mutually compatible (Yusuf *et al*., 1999). Even though this may be hard to believe, there is evidence of this occurring within many successful MNEs, for instance: General Motors have worked with Toyota in the assembly of automobiles; Siemens and Phillips have collaborated when developing semiconductors; Canon use to supply photocopiers to Kodak; Renault and Nissan have formed a partnership; and more recently

Samsung manufacturing many of the components within Apple's iPhone (Hamel *et al*., 1989; Minasians, 2016).

However, as core competencies are endogenous resources that are created internally within organisations, there are exogenous factors which may act as barriers with the transfer of core competencies across organisational borders (Binder and Clegg, 2006, 2007a). For instance, there may be high transaction costs, high asset specificity, or even a relatively high dependence on tacit knowledge which prevent this from happening. With this in mind, Klein *et al*. (1978) argued that core competencies are more likely to be deployed effectively internally within an organisation. In contrast, Combs and Ketchen (1999) asserted that organisations are likely to place competence issues ahead of organisational economic factors when evaluating whether they are to engage in collaborative ventures, as firms look for the most appropriate strategy given the situational contingencies (Watson, 2003; Binder and Clegg, 2006, 2007a). This opposes traditional thinking surrounding the idea of competitive advantage and proposes that collaboration may be more advantageous depending on the given situation. More specifically, this advantage would occur "*when the minimization of operational transaction costs has become a less significant factor than the gaining of new external core competencies via the formation of new collaborative organizational structures in an enterprise*" (Binder and Clegg, 2006, p.3816).

Virtual Enterprise

Binder and Clegg (2007b, p.136) adopted the European Commission's (2003) definition that an enterprise is "*an entity, regardless of its legal form ... including partnerships or associations regularly engaged in economic activities*". This study adopts the approach that an enterprise can be a single integrated company and considers that the cooperation between two different enterprises can constitute a virtual enterprise. More specifically, a virtual enterprise is defined as ''*a temporary network of independent companies linked by information to share skills, costs, and access to one another's markets they have an evolving corporate model that will be flexible enough to exploit a specific opportunity*'' (Byrne and Brandt, 1993, p.38, Cited in: Binder and Clegg, 2007a).

In terms of enterprise management, literature suggests that there is an increasing emphasis on firms operating as enterprises as opposed to traditional companies and traditional supply chain structures (Al-Mudimigh *et al*., 2004; Binder and Clegg, 2007;). Binder and Clegg (2007b) stated that enterprise engagement is most likely to occur "*partially at a modular level with many different companies simultaneously*", before comparing and contrasting three key enterprise structures within the literature, namely: vertically integrated enterprise; extended enterprise; and virtual enterprise.

Clegg and Wan (2013) suggested that vertically integrated enterprises typically operate as large multi-functional organisations that are striving for economies of scale. These forms of enterprises are more likely to process raw materials through to end-consumer products and services, which enables firms to embed their respective organisation within an industry (Vallespir and Kleinhans, 2001). With this in mind, competitive advantage is typically gained via reduced transaction costs (Harrigan, 1985), higher levels of quality and establishing barriers to new entrants (Rothaermel *et al*., 2006). However, a limitation to vertically integrated enterprises is that their structure and size can inhibit engagement with other organisations (Clegg and Wan, 2013).

In comparison with vertically integrated enterprises, extended enterprises are defined as "*a business value network where multiple firms own and manage parts of an integrated enterprise*" (Lyman *et al*., 2009, Cited in: Clegg and Wan, 2013, p.1462). Therefore, practices such as JIT, collaborative innovation and data warehouse interoperability are more likely to be easily deployed across company boundaries (Clegg and Wan, 2013). Firms operating within this type of enterprise typically outsource non-core activities (Thun, 2010) and focus their attention to core business and technical activities. Therefore, extended enterprises can be considered more agile when compared with vertically integrated enterprises (Clegg and Wan, 2013). Although there are reduced cross-company boundaries within extended enterprises, Clegg and Wan (2013) suggested that theses enterprises cannot cope with high levels of economic turbulence, as they operate in a partially restricted environment.

Unlike vertically integrated enterprises and extended enterprises, virtual enterprises are described to be able to cope with highly turbulent and very unpredictable market behaviours (Byrne and Brandt, 1993), thus are considered the most agile enterprise structure (Clegg and Wan, 2013). In fact (Clegg and Wan, 2013, p.1459) suggested that virtual enterprises are "*best thought of as a jigsaw of operations and information systems from more than one business entity loosely governed by decentralised specific objectives which delivers value to its markets*". Therefore, virtual inter-organisational relationships assist innovative agile production (Sharp *et al*., 1999). Table 2.3.2 highlights the differences between each of the three enterprises discussed in this section.

Table 2.3.2: Comparing Three Enterprise Structures

Characteristics	Enterprise Structures		
	Vertically Integrated Enterprise	**Extended Enterprise**	**Virtual Enterprise**
Core Competencies	Mature	Semi-mature	Quick response to changing market
Strategic Aims	Long-term	Medium-term	Short-term
Drivers	Control	Focus on outsourcing core competencies	Profitability
Duration of Relationships	Foreseeable as permanent	Medium-long term	Short-term (temporary)
Scope of Relationships	Command & control, focus on economies of scale	Often spans whole product life cycle across company boundaries	Project based, rapid exploitation of opportunities across company boundaries
Risk	Low	Moderate	High
Information Systems/IT	In-house development, traditional ERP systems	Advanced ERP merged with other functional modules	Sophisticated web-based technologies

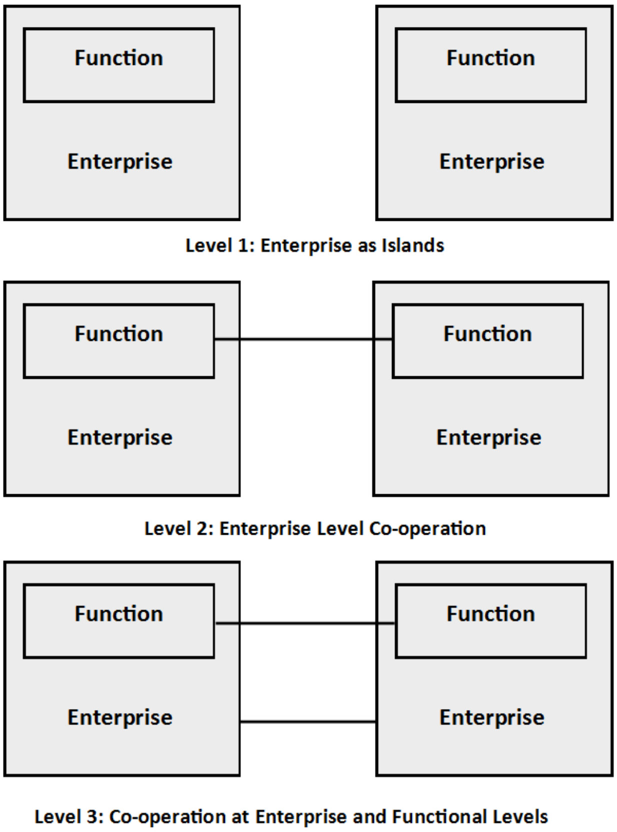
Source: Adapted from Binder and Clegg (2007a, p. 413) and Clegg and Wan (2013, p. 1463)

Binder and Clegg (2007a) suggested that each of the three enterprise structures are best thought of as a closed loop continuum of the same strategy seeking to boost collaboration. However given the nature of this research, as agile production specifies virtual enterprises as one of its four underlying principles (Yusfuf *et al*., 1999), the following section will discuss virtual enterprises in more detail.

As mentioned previously, virtual enterprises are of great importance as they provide the platform to respond rapidly to changes in demand. However, Yusuf *et al.,* (1999) suggested that it is important to understand that there are three different levels of cooperation between enterprises operating in a virtual enterprise, see Figure 2.3.2.

The first stage (Level 1) illustrates firms who operate in isolation. The second stage (Level 2) suggests a certain degree of interaction between organisations, but involves limited liaison at operational levels, such as what may occur when companies initiate purchasing agreements that aid cooperation between firms. Stage three (Level 3) represents agile manufacturing organisations that form virtual enterprises. These organisations cooperate at both corporate and operational levels. Agile systems possess teams that work across company partners, a characteristic which is cited as the climax of cooperative venturing (Yusuf *et al*., 1999). Cooperative venturing allows the range of skills and resources to be spread across all organisations in order to quickly respond and manufacture customer-specified products.

Figure 2.3.2: Partnership Development Model



Source: Yusuf *et al.* (1999, p.38)

Collaboration within a virtual enterprise can increase a firm's competitive capability, as a collective range of competencies can be brought together for that period of time. However, it is important to maintain collaborations, as alliances can dissolve as the different entities move on to other projects and partners (Yusuf *et al.*, 1999). Collaborating within a virtual enterprise leads to the creation of cross-functional teams that have the ability to solve problems as well as seize opportunities, and Davidow and Malone (1992) have suggested that firms operating within a virtual enterprise can maximise and capitalise upon pockets of excellence, which can enable them to compete at a greater level than they would be able to individually. However, in order to gain the full benefits of a virtual enterprise, firms must adopt a culture that promotes creativity and innovation across all boundaries of the virtual enterprise.

Capability for Reconfiguration

Firms wishing to be agile must possess capabilities which enable them to diversify, reconfigure, and re-align themselves. Obtaining these capabilities can help a firm to respond to the market environment at speed which is crucial when a window of opportunity may be limited. It is claimed that agile systems can pre-empt competition by developing a strategic architecture that incorporates a wide map of skills (Prahalad and Hamel, 1990). An organisation that follows these guidelines will be well positioned to use speed as an advantage, as they will be able to produce new products just before the need arises, allowing them to obtain first-mover advantage. Operational reconfiguration is vital for firms to capitalise on the strategic architecture, and may be achieved by investing in technologies that confer operational flexibility at the plant level (Yusuf *et al*., 1990).

Knowledge-driven Enterprise

Knowledge, with regards to manufacturing, is said to include the experience of employees within the organisation, company reports, historical case studies, databases and other repositories (Kidd, 1995). Organisations who wish to be agile need to place an emphasis on the development of well-trained employees, who possess the right skills, knowledge and expertise. Firms have to recognise and push the notion that 'knowledge is power', with investment in human capital considered a positive factor with regard to the future competitiveness of a firm. Firms wanting to increase their agility have to reduce the hierarchical control, as well as support teamwork amongst employees and the ability for individuals to act autonomously and make decisions for themselves (Prahalad and Hamel, 1990). Agile manufacturing also looks at the ability of organisations to release and unlock potential from within its workforce via suggestions (Hormozi, 2001). Gunneson (1997, cited in Hormozi,2001, p.136) states *"In the agile environment, the ability of a company to unlock its people's potential is critical to its success. Processes, advanced technology, and strategy can be copied and copied quickly people cannot. Managing knowledge capital is a little-understood key to success. Acquiring, developing, retaining, and moving knowledge capital to the "moments of truth" the customer contact points will be the key in the 1990s to sustaining a competitive advantage. ".* Thus, knowledge-driven enterprises fully recognise that the development of knowledge and information is a key factor for a successful business. The long-run success of any business depends on the firm's ability to transform the collective knowledge and skills of employees into solution products (Yusuf *et al.,* 1999), particularly given that in most industries, it is necessary to exploit a knowledge-rich workforce and information technology in order to transform the design of new products into finished goods. Agile manufacturing also includes a new dimension with relation to customer support, as it includes the provision of access to greater functionality that was originally embedded within the product. This means that customers receive an upgraded product at a lower cost, which saves time and costs for the manufacturer as they are not producing a new product for new customer requirements.

2.3.4 Agile Limitations

Having outlined the principles of agile production, this section draws attention to some of the ambiguities relating to the concepts outlined above, and in turn addresses the limitations of this manufacturing paradigm. In order to provide a degree of clarity to the concept of virtual enterprise Table 3.5.1 highlights themes commonly associated with it.

Even though Esposito and Evangelista (2014) depicted the common themes associated with a virtual enterprise, there are also a range of themes (coordination unit, organisational structure, firm size and market relationships) that are not. For instance, Jagdev and Browne (1998) suggested that the coordination unit can be internal or external to the virtual enterprise, whilst Camarinha-Matos *et al*. (2001) claimed that it is critical for a firm to act as a leader within the enterprise. Furthermore, there is an ambiguous message concerning organisational structure, as previous studies have advocated that the structure of a virtual enterprise is hierarchical, where a leading company would determine the process plans based on the different capabilities possessed by firms within that enterprise. On the contrary, Jagdev and Thoben (2001) argued that the organisational structure within a virtual enterprise is dominantly non-hierarchical in nature. In addition, Gunasekeran *et al*. (2008) stated that firms may have different participation levels within a virtual enterprise. The size of firms within a virtual enterprise is rarely discussed (Espositio and Evangelista, 2014), with the limited research reporting mixed results. For instance, Park and Favrel (1999) claimed that a virtual enterprise may help to bridge the gap between small and large firms, whereas Wu and Sun (2002) asserted that operating within a virtual enterprise is extremely suitable for small and medium sized firms only, as complemented by Hsu and Hsu (2008) who suggested a virtual enterprise can actually be observed as a business strategy for small and medium firms.

Even though literature suggests that operating in a virtual enterprise is designed to create value, it raises the question of which party manages the virtual enterprise with regard to the final customer (Espositio and Evangelista, 2014). Lefebvre and Lefebvre (2002) imply that the end customers will communicate with the product integrator during the design stages, with Jagdev and Browne (1998) claiming that the end customers are in contact with the manufacturers.

Information security is important to consider when organisations are working in a virtual enterprise, as if parties are linked together via the internet, this could make them susceptible to attacks and tampering of information. Task scheduling may also present a challenge, as these arrangements require constant communication between parties in order to complete a task, and it is therefore crucial to determine how information will flow between different members (Huang *et al.*, 2004). The development of a product in a virtual enterprise involves the product travelling via many different organisations. This wide involvement increases the probability of a problem being associated with quality, and when these occur the enterprise may find it difficult determining which organisation is responsible. The final organisation who sells the final product will then find it an extremely difficult task to offer any long-term maintenance guarantee to the customers (Elkins *et al*., 2004).

With regards to the partnership development model (Figure 2.3.2), the collaborations which occur at Level 3 may be deemed unrealistic in a practical setting if "*information is withheld, masked, distorted, or just plain missing*" (Childerhouse *et al*., 2003, p. 491). Even if firms did want to share information within a virtual enterprise, costs present a critical factor that cannot be overlooked. Sharing information requires investment between all organisations within the virtual enterprise to cover costs such as system design costs, hardware costs, software costs and management costs. Once firms form and cover the expenses of collaborating within a virtual enterprise, culture may also present an obstacle which has the potential to lower the success rate.

Finally, another limitation concerns multi-functionality. As workers are cross-trained and multi-skilled, Beukel and Molleman (2002) assert that a high degree of multi-functionality will inevitably result in tasks becoming too intensified and demanding due to increased pressure and accountability. Furthermore, Sethi *et al*. (2002) suggest that including too many workers from a wide range of functional areas does not actually lead to creativity or innovation, as even though a diverse team may lead to the generation of more ideas, it may also result in difficulty when solving problems (Yauch, 2007) as 'too many cooks spoil the broth'.

Summary

In an attempt to revitalise American manufacturers in the face of fierce foreign competition, the agile concept was conceived. Built upon four principles (core competence management, virtual enterprises, capability for reconfiguration and knowledge-driven enterprise), agile production is designed to enable manufacturers to thrive in a turbulent market environment via the acquisition of key practices and resources. Looking at the fundamental principles of lean and agile production, they are undoubtedly distinct, as lean manufacturing is outlined as a concept that emphasises efficiency via the route of eliminating all forms of waste in contrast to agile production, which prioritises the ability to quickly accommodate changes in the market environment via the alignment of resources and capabilities. It is therefore necessary to consider why confusion between these two concepts remains, which warrants a closer look at the TPRCs affiliated with both production paradigms which will be presented in the next section.

2.4 Tools, Practices, Routines and Concepts (TPRCs)

Since the introduction of agile manufacturing literature within the realms of OM and SCM has looked into this concept as a manufacturing paradigm (Gunasekaran, 1999; Yusuf *et al*., 2003) as well as examining it as a performance capability (Sharifi and Zhang, 2001). However, the discussion has been heavily focussed on attempting to distinguish agile manufacturing from lean manufacturing (Shah and Ward, 2003; Chase *et al*., 2004). Narasimhan *et al*. (2006, p.441) asserted that *"When discussed as paradigms, authors tend to treat lean manufacturing and agile manufacturing as systems of practices, also containing philosophical, value, and cultural elements"*. Furthermore, there is considerable confusion in the lean-agile debate (Bamford *et al*., 2015), as lean production has often been investigated with other paradigms, such as six-sigma and quality management concepts (Clegg *at al*., 2010), but fewer studies have investigated it directly with agile production highlighting the need for further development in this area (Purvis *et al*., 2014). When lean (Chavez *et al.*, 2013; Fullerton *et al.*, 2014) and agile manufacturing (Inman *et al*., 2011; Yusuf *et al*., 2014) have been individually addressed as paradigms, the distinctions between the two have been somewhat vague. Furthermore, studies which have investigated the lean-agile debate, have often presented contradictory findings (Goldsby *et al*., 2006; Narasimhan *et al.*, 2006; Hallgren and Olhager, 2009; Qi *et al*., 2009; Purvis *et al*., 2014). This has resulted in confusion surrounding 'when' and 'how' to become lean or agile; thus, there has been a tendency to mix both performance outcomes and associated manufacturing practices within lean and agile definitions (Narasimhan *et al*., 2006). Therefore, although the lean-agile debate has been discussed in the past, as the debated findings are mixed and unclear, and considering that the UK manufacturing industry has been acknowledged to be slow adopters of either of the manufacturing paradigms (Clegg *et al*., 2013), it is still an important area that requires further development. Therefore, understanding the trade-offs between each manufacturing concept is of great importance, providing the rationale for this primary research question:

RQ: What are the trade-offs between lean and agile manufacturing?

First, before examining the differences in contextual factors and performance objectives, which will be discussed within the upcoming chapter, it is crucial to explore the range of TPRCs employed within each manufacturing concept. Incorporating findings from a literature review, this section not only seeks to explore the differences, but also highlight the similarities between the set of TPRCs employed within each manufacturing strategy. Before moving on to the TPRCs, it is useful to revisit definitions of the two concepts. Even though lean and agile concepts outline similar priorities, the definitions in Table 2.2.1 and 2.3.1 clearly suggest that each approach emphasises a different set of elements. Therefore, even though there may be similarities in the implementation of each concept, the collection of TPRCs ascribed with each concept should be different.

Table 2.4.1 illustrates all the TPRCs that have been repeatedly affiliated with lean and agile production. The review of the literature identified 15 TPRCs (a-o in Table 2.4.1) associated with lean production, namely: Elimination of Waste; Continuous Improvement; 5S; Zero Defects; Production Smoothing; Line Balancing; Value Stream Mapping; Total Productive Maintenance; Cellular Manufacturing; Just-in-Time; Kanban; Multifunctional Teams/Machines; Total Quality Management; Employee Empowerment; and Setup Reduction (SMED). In addition, the review of the literature found 13 TPCs (j-t in Table 2.4.1) affiliated with agile production, namely: Just-in-Time; Kanban; Multifunctional Teams/Machines; Total Quality Management; Employee Empowerment; Setup Reduction (SMED); Virtual Enterprise; Core Competence Management; Knowledge Driven Enterprise; Reconfiguration; Rapid Prototyping; Concurrent Engineering; and IT Driven Enterprise. More importantly, the review of the literature revealed that TPRCs j-o (Just-in-Time, Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment, Setup Reduction (SMED)) within Table 2.4.1 have been associated with both lean and agile production, which may explain the confusion between the set of practices employed within each manufacturing concept. Even though certain practices such as continuous or elimination of waste may have also been affiliated with agile production, Table 2.4.1 consists of TPRCs which have repeatedly been ascribed to each of the manufacturing concepts. Full definitions of each TPRC are provided within section A of the appendix.

Table 2.4.1: Lean & Agile Tools, Practices, Routines and Concepts (TPRCs)

TPRCs		Lean	Agile
a)	Elimination of Waste	White *et al*. (1999); Sanchez and Perez (2001); Soriano-Meier and Forrester (2002); Hopp and Spearman (2004); Rawabdeh (2005); Malmbrandt and Ahlström (2013); Kull *et al.* (2014).	- - - - -
b)	Continuous Improvement	Flynn *et al*. (1999); White *et al*. (1999); Sanchez and Perez (2001); Soriano-Meier and Forrester (2002); Gurumurthy and Kodali (2011); Taj and Morosan (2011)); Malmbrandt and Ahlström (2013); Sundar *et al*. (2014).	- - - - - -
c)	5S	Womack and Jones (1996); Bamber and Dale (2000); Feld (2000); Sweeney (2003); Lee-Mortimer (2006); Abdulmalek and Rajgopal (2007); Gurumurthy and Kodali (2011).	- - - - -
d)	Zero Defects	Emiliani (1998); Murman *et al.* (2002); Soriano-Meier and Forrester (2002); Hopp and Spearman (2004); Sahoo *et al* (2008); Malmbrandt and Ahlström (2013).	- - - - -
e)	Production Smoothing	Womack *et al.* (1990); Abdulmalek *et al.* (2006); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Saurin *et al.* (2011).	- - - -
f)	Line Balancing	Schroer (2004); Lee-Mortimer (2006); Slack *et al*. (2010); Gurumurthy and Kodali (2011); Malmbrandt and Ahlström (2013); Sundar *et al*. (2014).	- - - -
g)	Value Stream Mapping	Womack and Jones (1996); Murman *et al.* (2002); Hopp and Spearman (2004); Lee-Mortimer (2006); Malmbrandt and Ahlström (2013); Sundar *et al*. (2014).	- - - -
h)	Total Productive Maintenance	Feld (2000); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Taj and Morosan (2011); Sezen *et al.* (2012).	- - - -
i)	Cellular Manufacturing	Shah and Ward (2003); Doolen and Hacker (2005); Lee-Mortimer (2006); Abdulmalek and Rajgopal (2007); Taj (2008); Fullerton and Wempe (2009); Kull *et al.* (2014); Sundar *et al*. (2014).	- - - - - -
j)	Just-in-Time	Boyer (1996); Levy (1997); Gunasekaran (1999); Sanchez and Perez (2001); Soriano-Meier and Forrester (2002); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Taj and Morosan (2011); Kull *et al.* (2014).	Takahashi and Nakamura (2000); Sharifi and Zhang (2001); Jin-Hai *et al.* (2003); Vazquez-Bustelo and Avella (2006); Shah and Ward (2007); Inman *et al.*(2011);
k)	Kanban	Flynn *et al*. (1999); White *et al*. (1999); Schroer (2004); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Rahman *et al.* (2013); Sundar *et al.* (2014).	Takahashi and Nakamura (2000); McCullen and Towill (2001); Sharifi and Zhang (2001); Vazquez-Bustelo and Avella (2006)
l)	Multifunctional	Sakakibara *et al*. (1997); Koufteros *et al.* (1998); Sanchez and Perez (2001);	Gunasekaran (1998); Sharp *et al.* (1999); Yusuf *et al*. (1999); Hormozi (2001); Maskell

Teams/Machines	Soriano-Meier and Forrester (2002); Bhasin (2011); Saurin *et al.* (2011); Malmbrandt and Ahlström (2013).	(2001); Vazquez-Bustelo and Avella (2006); Yauch (2007); Erande and Verma (2008).
m) Total Quality Management	Bicheno (1989); Han *et al.* (1990); Boyer (1996); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Taj and Morosan (2011).	Sharifi and Zhang (2001); Jin-Hai *et al.* (2003); Vazquez-Bustelo and Avella (2006).
n) Employee Empowerment	Boyer (1996); Achanga *et al.* (2006); Vidal (2007); Rose *et al.* (2011); Taj and Morosan (2011).	Gunasekaran (1998); Sharp *et al.* (1999); Yusuf *et al.* (1999); Crocitto and Youssef (2003); Vazquez-Bustelo and Avella (2006).
o) Setup Reduction (SMED)	Womack *et al*. (1990); Bamber and Dale (2000); Feld (2000); Lee-Mortimer (2006); Abdulmalek and Rajgopal (2007); Shah and Ward (2007); Saurin *et al.* (2011); Sundar *et al* (2014); Kull *et al.* (2014).	Iravani *et al*. (2005); Ismail *et al*. (2006); Erande and Verma (2008); Matt (2010)
a) Virtual Enterprise	-	Davidow and Malone (1992); Cho *et al.,* (1996); Gunasekaran (1998:1999); Sharp *et al.* (1999); Yusuf *et al.* (1999); Maskell (2001); Sharifi and Zhang (2001); Kaihara and Fujii (2002); Cao and Dowlatshahi (2005); Binder and Clegg (2006); Vazquez-Bustelo and Avella (2006); Binder and Clegg (2007a, 2007b)Tseng and Lin (2011); Clegg and Wan (2013).
b) Core Competence Management	-	Yusuf *et al.* (1999); Sharp *et al.* (1999); Maskell (2001); Jin-Hai *et al.* (2003); Binder and Clegg (2006:2007a:2007b); Erande and Verma (2008); Tseng and Lin (2011).
c) Knowledge Driven Enterprise	-	Yusuf *et al.* (1999); Maskell (2001); Ismail *et al.* (2006); Vazquez-Bustelo and Avella (2006); Erande and Verma (2008).
d) Reconfiguration	-	Yusuf *et al.* (1999); Maskell (2001); Binder and Clegg (2006); Vazquez-Bustelo and Avella (2006); Binder and Clegg (2007a:2007b) Erande and Verma (2008); Tseng and Lin (2011); Vinodh and Kuttalingam (2011).
e) Rapid Prototyping	-	Gunasekaran (1998:1999); Sharp *et al.* (1999); Yusuf *et al.* (1999); Onuh and Hon (2001); Vinodh and Kuttalingam (2011).
f) Concurrent Engineering	-	Cho *et al.,* (1996); Gunasekaran (1998); Sen Yan and Jiang (1999); Sharp *et al.* (1999); Sharifi and Zhang (2001); Jin-Hai *et al.* (2003); Kamrani and Vijayan (2006); Vinodh *et al.* (2010); Vinodh and Kuttalingam (2011); Tseng and Lin (2011).
g) IT Driven Enterprise	-	Wang *et al.* (1996); Gunasekaran (1998:1999); McGaughey (1999); Sharp *et al.* (1999); Hooper *et al.* (2001); McCullen and Towill (2001); Coronado (2003); Büyüközkan *et al.* (2004); Dowlatshahi and Cao (2006); Vazquez-Bustelo and Avella (2006).

As illustrated in Table 2.4.1 there are similarities and key categorical differences between the TPRCs employed within each of the production concepts. The TPRCs associated with lean manufacturing are generally more geared towards resource efficiency. In contrast, even though agile practices also include elements of efficiency, they ultimately are more focussed on the ability to cope with change (Jin-Hai *et al*., 2003). Booth and Harmer (1995) suggested that lean is an enhancement of mass production with a focus on efficiency, whereas agile production differs significantly from mass production due to the large emphasis on the ability to provide highly customised products. Furthermore, agile production strives to achieve economies of scope as opposed to economies of scale (Jin-Hai *et al*., 2003). Agile production requires an organisation to align resources in conjunction with their strategic view, whereas lean manufacturing is largely affiliated with activities on the factory floor. In essence, agile production involves the use of a collection of practices which allow the firm respond relatively quickly to changes within the market environment. Inevitably, this will require lead-time compression for both information and material. With this in mind, the ability to 'rapidly reconfigure' is not only desirable, but indeed essential for the survival of the firm. In contrast, although the TPRCs associated with lean manufacturing also focus on the ability to reconfigure the production process, which align with the literature surrounding enterprise management, the ability to 'rapidly reconfigure' is a desirable but not essential (Naylor *et al*., 1999) competitive priority.

In summary, Table 2.4.1 suggests that even though the TPRCs associated with agile production focus on efficiency, this is not the primary focus as customisability and flexibility are key attributes of this paradigm. In contrast the table suggests that although lean production contains elements of flexibility, the main focus is on efficiency and cost reduction techniques.

2.5 Conclusion

In conclusion, the theoretical framework upon which this thesis is conceptualized revolves around Skinner's (1969) assertion that no manufacturing strategy can compete effectively on all measures. Schmenner and Swink (1998) suggested that the notion of trade-offs can be referred to as the trade-off 'law'. Although the notion of performance trade-offs has been contended, and even though the literature within the realms of trade-offs have mixed findings, the overall consensus is that trade-offs are apparent.

Next, this chapter explored the underlying principles of lean and agile production as well as the drawbacks affiliated with each strategy. Taking the underlying principles of each of the manufacturing paradigms into account, although there are similarities, each production concept prioritises different capabilities. Finally, this chapter looked to explore the relevant TPRCs affiliated with lean and agile respectively. Not only did this provide clarity into the differences between each of the manufacturing concepts, but also outlined the similarities too, which may have played a role in why literature within this field has confused the two approaches. More importantly, as will be outlined in the methodology chapter, distinguishing each of the concepts effectively was critical for this research, as the bundles of TPRCs affiliated with lean, agile and hyrbid production were used in order to distinguish whether firms are implementing lean or agile or initiatives within their organisation. Findings in section 4.5.2 suggested that firms were not implementing hybrid strategies, hence, why this study focusses on lean and agile production.

Overall, the bundled TPRCs outlined in Table 2.4.1 complement lean and agile definitions, as the TPRCs associated with lean production generally are focussed towards efficiency, whilst the TPRCs affiliated with agile production are more focussed towards adaptability.

CHAPTER 3 - LITERATURE REVIEW: LEAN AND AGILE TRADE-OFFS

"…there is confusion in the literature between lean and agile performance and practice concepts. It is important to distinguish between leanness and agility as performance capabilities, and lean manufacturing and agile manufacturing as manufacturing systems that include both performance capabilities and practices".

Narasimhan *et al.* (2006, p.444).

As the previous chapter looked into the origins, underlying principles, limitations and TPRCs of lean and agile production, a basic understanding of each the manufacturing concepts was outlined. The next stage of the review was to evaluate the studies which have investigated the trade-offs amongst lean and agile manufacturing systems, however, before reporting on this matter it is important to consider contextual factors which may also play a pivotal role in distinguishing lean and agile manufacturing systems. Therefore, one of the objectives of this chapter was to explore the contextual factors which may act as a driving force in the implementation of the manufacturing paradigms, namely: firm age, firm size, manufacturing classification and supply chain positional tier. As well as discussing the potential effects of these factors, this chapter presents hypotheses in relation to the likelihood of firms choosing to pursue a lean or agile strategy. Next, this chapter evaluates the literature that has explored the performance strengths and weaknesses affiliated with each approach, which will pave the way into conceptualising the performance hypotheses used within this study. Arguably, this chapter consists of the main literature review concerning the trade-offs between lean and agile manufacturing systems. With this in mind, this chapter comprises seven sections. First, contextual factors are explored. Second, a background into the importance of performance and capturing different aspects of performance are outlined. Third and fourth, this chapter outlines an evaluative summary of the literature that has investigated the performance outcomes of lean and agile production respectively. Fifth, this chapter reviews the literature surrounding the trade-offs between lean and agile production in association with performance. Sixth and seventh, the research gap and then the conceptual framework are presented.

3.1 Contextual Factors

Assuming that lean and agile may be similar but fundamentally different in terms of implementation, this research set out to review the literature surrounding contextual factors as inconsistencies amongst the lean and agile literature have resulted in authors placing greater emphasis on their role (Godinho Filho *et al*., 2016). Contingency Theory (CT) suggests that firms align their performance priorities with their contextual factors. CT has been advocated as a major theoretical lens through which to view organisations (Sousa and Voss, 2008), and advocates that no theory, and in turn method, is applicable in every circumstance (Lawrence and Lorsch, 1967). In essence, this approach suggests that there is no single best way to design an organisation and that organisations may need to match their priorities in line with factors that are contingent in the environment. Sousa and Voss (2008) also asserted that the context in which a firm is based may play a role in the relationship between practice and performance, and that researchers should not focus solely on analysing management practices, but must also investigate the context in which firms are positioned. As a result, CT and contextual factors are becoming more popular within the domain of SCM (Demeter and Matusz, 2011; Huo *et al*., 2014; Kembro *et al*., 2014;

Tortorella *et al*., 2015; Marodin *et al*., 2016; Marodin *et al*., 2017a, 2017b; Tortorella *et al*., 2017a, 2017b).

However, the ASC is considered an underdeveloped area with regard to contextual factors (Marodin *et al*., 2016). Shah and Ward (2003) and Bayo-Moriones *et al*. (2010) have previously advocated that for the successful implementation of any manufacturing practice, contextual factors need to be considered, as such characteristics may act as a driving force behind the production strategy employed. On the contrary, contextual factors may also act as a barrier when firms seek to implement certain strategies, such as lean production (Marodin and Saurin, 2015; Marodin *et al*., 2017a). With this in mind, it should be possible to determine the manufacturing strategy pursued by a firm by looking at its contextual attributes. However, there is a sense of ambiguity within the literature concerning lean and agile production. There is a scarcity in studies solely focussing on lean and agile production relative to contextual factors, especially SC positional tier (Jasti and Kodali, 2015; Marodin *et al*., 2016; Tortorella *et al*., 2017a, 2017b). Therefore, it is reasonable to question whether or not lean and agile production concepts have a relationship with contextual factors, namely firm age, firm size and positional tier within the SC ,especially the ASC. With this in mind the following sub-research question was proposed:

RQ (a): What are the trade-offs in contextual factors between lean and agile production?

3.1.1 Manufacturing Age

Shah and Ward (2003) asserted that plant age may play a role in the strategy employed by an organisation as older firms may be more resistant to change. This view is complementary to organisational sociology, which proposes that the age of the firm is inversely related to the rate of innovations (Stinchombe, 1965). Furthermore, this view is supported by evolutionary economics (Aldrich, 1979; Nelson and Winter, 1982), which suggests that organisational routines, such as manufacturing practices, do not change on a regular basis and thus may be a source of inertia (Hannan and Freeman, 1984). It can also be argued that the more frequently and the longer the period of time over which routines are enacted, the more embedded within the organisation they become. Thus, firms may find it more difficult to adopt new practices, even though they may be superior. On the contrary, organisational ecologists suggests that even though older organisations may be implementing less advanced practices than their younger counterparts, older organisations may still be better off. This is referred to as the 'liability of newness', which proposes that it is beneficial to carry on using existing routines (manufacturing practices) as opposed to newer, potentially more effective, ones (Nelson and Winter, 1982; Shah and Ward, 2003). However, Shah and Ward (2003) and Haddach *et al*. (2016) found certain lean practices to be affiliated with age. More specifically, older organisations have been associated with higher levels of lean implementation (Marodin *et al*., 2015). Although Tortorella *et al*. (2015) presented mixed findings in this regard, they did go on to find that older manufacturing plants found it more difficult to adapt their organisational culture in a way that favoured certain dimensions of lean production (openness, participation, teamwork, transparency).

As there are mixed findings within the literature, this warranted the need for further investigation into this variable. Considering that agile manufacturing was introduced after lean production, by adopting the view that firms are resistance to change, it could be suggested that older organisations are more likely to be implementing lean practices and newer organisations are more likely to be implementing agile practices. With this in mind, the following two hypotheses were set:

H_{Al}. Lean firms are more likely to be older in age when compared with agile manufacturing firms

H_{Aa}. Agile manufacturing firms are more likely to be younger in age when compared with lean firms.

3.1.2 Manufacturing Size

Sousa and Voss' (2008) review of CT in OM highlighted that the literature deems firm size to be an important contextual factor. The importance of firm size can even be traced back to Child & Mansfield (1972), who suggested that procedures and administrative tasks tend to be more complex in larger firms. Sousa and Voss (2008) illustrated inconsistencies within their review. For instance, studies that purely focused on quality management (Ahire and Golhar, 1996) found little to no evidence of firm size effects. However, studies investigating the application of lean production did find firm size to account for some effects (Shah and Ward, 2003). Gopalakrishnan and Damanpour (1997) went on to assert that the impact of size is more apparent within manufacturing organisations as opposed to service organisations; however, it has also been argued that large firms are likely to possess relevant human capital and finances which complement the adoption of newer practices (Shah and Ward, 2003). Furthermore, previous findings have asserted that larger firms are more likely to adopt lean practices (Bonavia and Marin, 2006; Narasimhan *et al*., 2006; Bhasin, 2012; Marodin *et al*., 2016), and that smaller firms are more likely to adopt agile practices (Cohen and Klepper, 1992). More recently, Marodin *et al*. (2017a, 2017b) emphasised that larger companies are more likely to successfully implement lean practices. The positive association between lean production and large firms stems from the notion that large firms possess greater availability of capital and technological resources (Shah and Ward, 2003; Dora *et al*., 2013) thus they have greater bargaining power than small firms. Bhasin (2012) also found that larger organisations were more likely to successfully adopt lean as an ideology as opposed to just a set of practices. This was supported by Godinho Filho *et al*. (2016), who suggested that small organisations lacked an understanding of what it means to be lean. Tortorella *et al.* (2017a) found that larger firms were more likely to implement 15 lean SC practices as opposed to smaller firms, findings that were also confirmed by Susilawati *et al.* (2015) and Tortorella *et al*. (2017b). Netland (2016) suggested that small and large sized organisations may require different lean implementation approaches. However, Furlan *et al.* (2011) found no correlation between firm size and the implementation of lean production within organisations in Europe, Asia and North America. Lucato *et al.* (2014) also found little evidence to suggest that there was a relationship between the extent to which lean was being implemented within organisations and the size of a firm. Belekoukias *et al.*'s (2014) findings also went on to demonstrate that certain lean TPRCs were associated with small organisations as opposed to large organisations. Although there are mixed findings concerning firm size and lean production (Negrao *et al*., 2017), the majority of studies associate lean production with large organisations. However, it is important to question whether or not, in age of modern technology, where automated machines play a crucial role within automotive Original Equipment Manufacturers (OEMs) and 1st tier suppliers, large firms are able to be agile. The following two hypotheses were conceptualised in order to investigate this further.

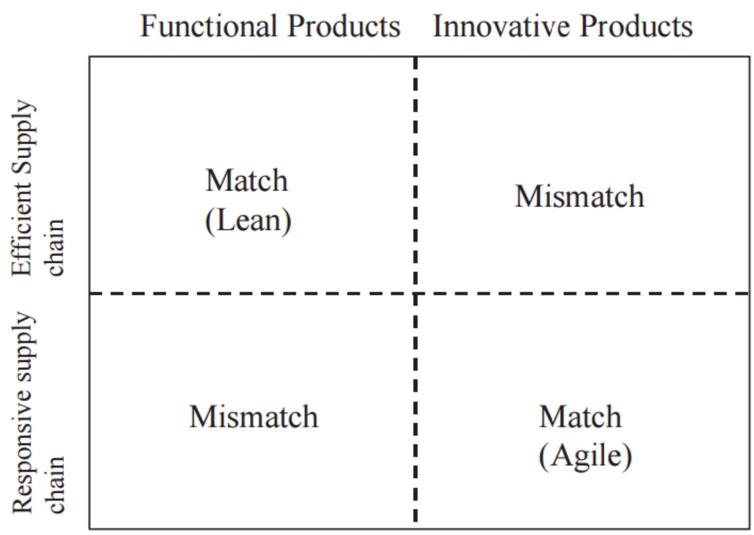
H_{MSa}. Lean firms are more likely to be larger in size when compared with agile firms.

H_{MSb}. Agile firms are more likely to be smaller in size when compared with lean systems.

3.1.3 Manufacturing Classification

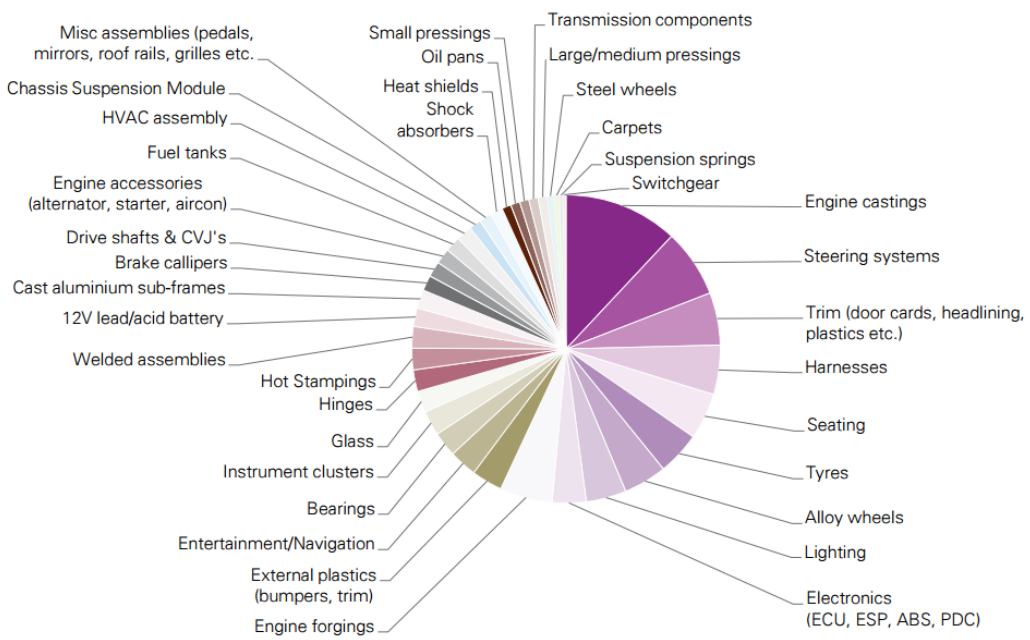
The automotive industry has been heralded as the birthplace of lean production (Womack *et al.,* 1990); however, given that the average automobile can require up to approximately 40,000 components from a range of sub-manufacturing industries, how realistic is it that all firms within such a SC are implementing lean? For instance, is it appropriate to expect firms producing carpets, fuel tanks, electrical components and steel wheels all to be operating with the same critical success factors? The foundation for this question is built upon Fisher's (1997) model, which made a distinction between functional products (where firms are operating in predictable demand conditions) and innovative products (where firms are operating in unpredictable demand conditions). Fisher suggested that this distinction is important as agile firms may experience a loss of sales if demand increases above supply, but they may experience obsolescence if the supply is greater than the demand (Stratton and Warburton, 2003). Figure 3.1.1 illustrates the Fisher Model, which emphasizes the need for firms to match their product type to the characteristics of their SC.

Figure 3.1.1: The Fisher Model



Source: Fisher (1997), Cited in: Stratton and Warburton (2003, p.188)

Figure 3.1.2: The Range of Components in ASC



Source: KPMG (2012, p. 15)

As previously mentioned, the average automotive vehicle (end product) may consist of up to 40,000 products, therefore the ASC is inevitably complex in nature. To demonstrate this, Figure 3.1.2 illustrates a small range of components from varying manufacturing industries that are incorporated into vehicles, and therefore form a part of the UK ASC. Lean and agile discussion surrounding manufacturing classification has asserted that it is vital for industries to match their needs with lean and agile competitive objectives (Mason-Jones *et al.,* 2000). Given the vast range of products needed for the end product (automotive vehicle), from a range of different industries, it is likely that there will be varying levels of innovation across these industries. With this in mind, by drawing upon the Fisher Model, the following hypotheses were proposed in order to investigate whether or not sub-manufacturing classification influences whether firms implement lean or agile strategies. However, it is important to re-inforce that the Fisher Model is built upon products as opposed to low/high innovative industries. Therefore, although the hypotheses are theoretically grounded on the Fisher Model, whether they are accepted or rejected in this study does not necessarily infer that Fisher's Model is accepted or rejected. Instead, results would simply imply that lean and agile firms are more/less likely to belong within industries that possess different levels of innovation.

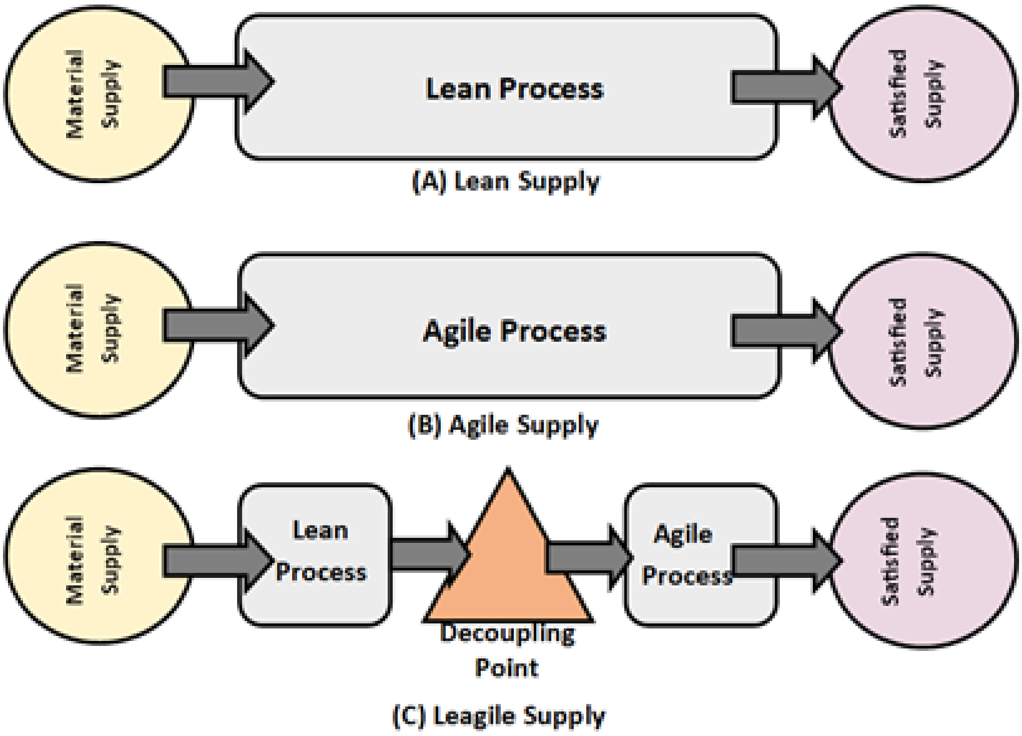
$H_{MCa:}$ Lean firms are more likely to belong to low innovative industries when compared with agile firms.

$H_{MCb:}$ Agile firms are more likely to belong to high innovative industries when compared with lean firms.

3.1.4 Supply Chain Positional Tier

Mason-Jones *et al*. (2000) suggested that SCs, generally speaking, can either be lean, agile or 'leagile' (Drake *et al*., 2013), as depicted in Figure 3.1.3. The leagile SC is a combination of both paradigms encompassing a total SC strategy which involves a decoupling point (Huang *et al.*, 2002). The lean approach is best suited when a market is highly predictable with strong foundations of supply certainty. In contrast, the agile approach is more suitable for turbulent SCs (Drake *et al*., 2013), where customer requirements often change, resulting in unpredictability and the need for innovative products of shorter life-cycles (Cox and Chicksand, 2005). Naylor *et al*. (1999) noted that a lean strategy is not a suitable strategy for all SCs, as SCs have unique demand and supply characteristics that require different ways of working operationally, both internally and externally. Often, it is necessary to implement the 'leagile' approach, as there are decoupling points within particular SCs that require a lean approach at one point and an agile approach at another. Essentially, the decoupling point refers to the point in a SC at which order-driven and forecast-driven orders meet (Hoekstra and Romme, 1992). Mason-Jones *et al*. (2000) suggested that when operating within a 'leagile' SC, lean manufacturing systems are located at the lower levels of the SC and operate upstream, enabling a level schedule in output. In contrast, agile systems are generally located at the top or higher levels of the 'leagile' SC and operate downstream from the decoupling point, ensuring there is an agile response capable of delivering to unpredictable market demand. More recently, Vinodh and Aravindraj (2013) acknowledged that the 'leagile' SC paradigm has been gaining importance within the fields of lean and agile production and that it requires further development.

Figure 3.1.3 – Lean, Agile and 'Leagile' SCs



Source: Adapted from Mason-Jones *et al*. (2000).

Although the literature asserts that ASCs are lean, there are contingencies that may influence the degree to which a particular firm is lean as opposed to agile. For example, OEMs are undoubtedly key players within the ASC, as they control the design, quantity required and the costs of components (Hallavo, 2015). Furthermore, OEMs will typically encourage, or even require, their closest suppliers to also implement lean production, as this will enable them to achieve their desired operational performance (Morris *et al*., 2004). For instance, Marodin *et al*. (2016) suggested that Toyota and Honda developed a collaborative lean relationship with their closest suppliers. Furthermore, first-tier suppliers produce goods that are of more added value relative to firms positioned upstream the ASC, who have to devise a manufacturing strategy that emphasises speed and a broader range of products, i.e. one that is more flexible (Doran, 2004; Boonsthonsatit and Jungthawan, 2015). With this in mind, one may argue that firms positioned upstream the ASC are more agile than lean. Considering this in conjunction with Mason-Jones *et al.*'s (2000) assertions that if a SC, such as the ASC, does encompass both lean and agile systems (i.e. 'leagile'), are lean firms operating upstream and agile firms operating downstream?

There is a limited body of literature that has explored the agile concept relative to different tiers of a SC, although recently, authors have started to acknowledge the importance of lean production relative to different tiers within a SC (Marodin *et al*., 2017a). However, lean literature concerning positional tier (Sezen *et al*., 2012; Garza-Reyes *et al*., 2015; Tortorella *et al*., 2017a, 2017b) has also presented mixed views, signalling the need for clarification in this area. For instance, Marodin *et al*. (2016) found that firms situated in the top tiers of an ASC, closer to the end customer, were more likely to be adopting lean practices relative to those firms located in the lower tiers of an ASC, which supports the findings of Boonsthonsatit and Jungthawan (2015). Tortorella *et al*. (2017a) sided with this, as findings from their study revealed firms positioned closer to the customer implemented lean practices to a greater extent when compared with firms positioned lower down the ASC. On the contrary, Sezen *at al*. (2012) did not find any difference between the degree to which lean production was being adopted between first and second tier suppliers. However, Tortorella *et al*. (2017b) found that firms positioned lower down the SC, i.e. third and fourth tier suppliers, were implementing lean practices to a greater degree than firms positioned at the top of the SC. The authors acknowledged that these results may be anomalous, as firms positioned lower down the Brazilian ASC (the context of their study) are often owned by an oligopoly, leading them to possess a greater degree of bargaining power to influence and drive several aspects of their respective SC. Panizzolo *et al*. (2012) suggested that examination of lean production in developing economy countries should be approached differently than in developed countries, as socio-economic variables may influence managerial decisions in different ways.

In summary, within the ASC, the literature generally sides with lean production being more associated with firms closer to the end customer, whereas firms positioned upstream the ASC are said to be competing on flexibility, hence, they are agile. However, Mason-Jones *et al*. (2000) suggested that 'leagile' SCs consist of lean and agile firms at the top (downstream) and lower tiers (upstream) of the SC respectively.[1] Considering that lean was conceived from the TPS, and that numerous reports and news headlines have continually asserted that other automotive OEMs such as, Ford, and Jaguar Land Rover are successfully implementing lean practices (Rosen, 2011), the following hypotheses were presented:

H_{PTa}. Lean firms are more likely to be positioned at the lower tiers of a SC when compared with agile firms.

H_{PTb}. Agile firms are more likely to be positioned at the top tiers of a SC when compared with lean firms.

[1] Note: top tiers and low tiers of the ASC refer to firms operating downstream and upstream in the ASC.

Summary

Grounded on CT, this section looked to explore if contextual factors were acting as driving force into whether firms were likely to be lean or agile in nature. As there are mixed views concerning the driving forces behind lean and agile production, it is reasonable to question how agile or adaptable a large firm can be and whether or not the age of a firm is associated with the manufacturing paradigm pursued. Considering the diverse set of manufacturing industries that are needed to produce an automobile, it is viable to assume that different levels of innovation are occurring within different manufacturing industries. Therefore firms may implement different strategies. Furthermore, it is necessary to investigate to what extent the ASC may be leagile in nature, and the respective positions of lean and agile firms in relation to positional tier of the ASC. As there is a sense of ambiguity concerning contextual factors and lean and agile production, and the next section will look to explore if this ambiguity is transferred to the literature surrounding the performance trade-offs between lean and agile production too.

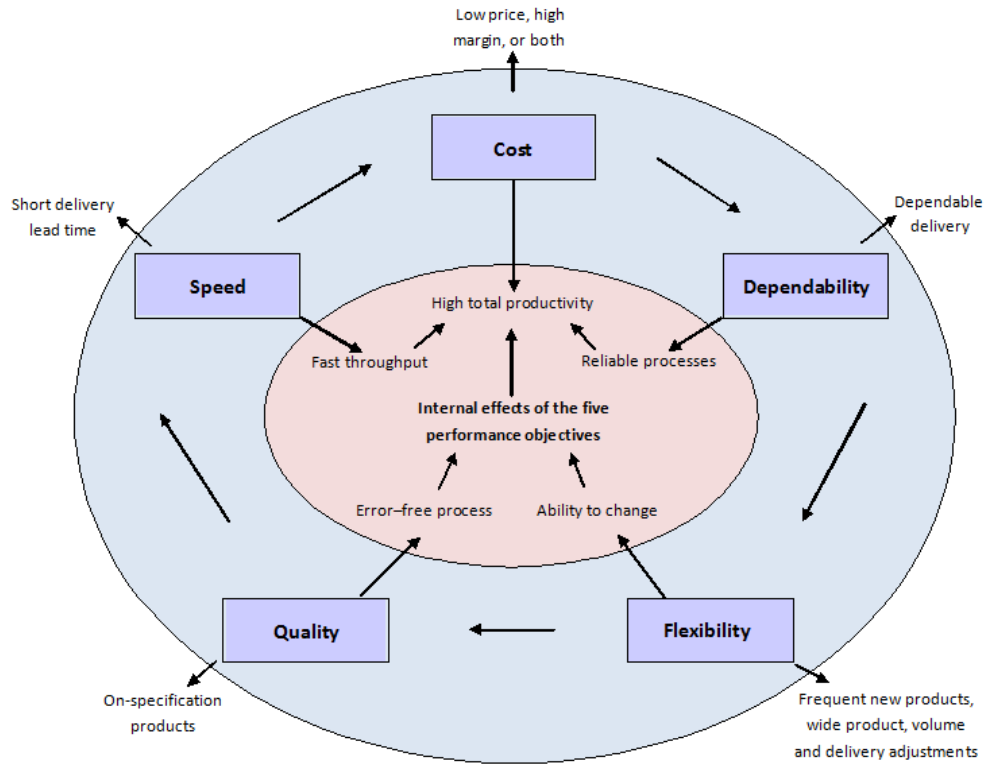
3.2 Performance

This section briefly looks into the measurement of performance. A key assertion within OM concerns the relationship between practice and performance (Slack, 1994). A consensus view within the literature identified that an effective operations strategy can lead to competitive advantages, which in turn enhances business performance (Ibid.).

Although lean and agile production have been associated with improving business performance, building on Skinner's (1969) assertion, as well as the 'trade-off law', it is crucial to incorporate a range of performance measures in order to clarify the trade-offs concerning the manufacturing concepts in question.

Performance has been defined as the degree to which an operation fulfils five performance objectives, namely: quality; dependability; speed; flexibility and cost (Narasimhan and Jayaram, 1998; Flynn and Flynn, 2004; Slack *et al.,* 2010). It would be inadequate to involve the use of a single performance measure when assessing performance, as an organisation or manufacturing strategy may have strengths in different areas of performance. Involving the use of a broad range of performance variables will not only increase the rigour of results, as will be discussed in the methodology chapter, but provide a more well-rounded insight into the strengths and weakness affiliated with each of the manufacturing strategies. The five performance measures are depicted in Figure 3.2.1, and are each broken down into multiple, smaller, sub-variables. Although studies have highlighted innovation as a means in capturing performance, this was not included within this study as certain dimensions of flexibility (see section 4.5.3), are in line with innovative objectives. For instance, Balachandra and Friar (1997) and Zhou and Wu (2010) have ascribed certain levels of innovation with the generation of new products (new product flexibility). Each of the variables and sub-variables are outlined in more detail within the Methodology Chapter.

Figure 3.2.1: Five Performance Measures



Source: Adapted from Slack *et al*., (2010, p. 52)

As mentioned throughout this study, one of the key aims of this thesis is to capture reliable data, therefore, acquiring numerical data is crucial in order for this goal to be achieved. For instance, "*When you can measure what you are speaking about, and express it in numbers, you know something about it…[otherwise] your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in thought advanced to the stage of science*". (Lord Kelvin, 1824-1907Cited in Neely *et al.,* 1995). More information concerning this is outlined in Chapter 4.

3.3 Lean Performance

The first stage of the review process focussed on the effects of lean implementation in relation with performance measures. Each of the studies dealing with this topic are presented in chronological order within Table 3.1.1, which not only reports on the main findings, but also outlines the sample size and mode of analysis within each respective investigation. Acknowledging the variety of TPRCs commonly associated with lean production as detailed in Table 3.1.1, the majority of those studies did not appear to examine all dimensions of lean, instead typically narrowing their focus on particular elements such as JIT (e.g., Inman and Mehra, 1993; and Fullerton and McWatters, 2001) or inventory leanness (e.g., White, 1993; Norris *et al*., 1994; Droge and Germain, 1998; and Shah and Ward, 2003). Although concepts such as JIT and inventory leanness are by all means a part of lean production, they are not synonymous with it. With this in mind, there is a need for studies to incorporate a more 'well rounded' notion of practices affiliated with lean production. Table 3.1.1 also reveals that existing studies predominantly consisted of using either correlations, regressions and SEM modelling as their choice of analysis, and highlighted that the majority of studies which looked to determine the effects of lean production portray consistent findings. Whether measured financially (Inman and Mehra, 1993; Callen *et al*., 2000; Fullerton and McWatters, 2001; Kinney and Wempe, 2002; Fullerton *et al*., 2003; and Yang *et al*., 2011) or captured operationally (Shah and Ward, 2003; Ward and Zhou, 2006; Matsui, 2007; Eroglu and Hofer, 2011; Demeter and Matyusz, 2011; Chavez *et al*., 2013; Fullerton *et al.,* 2014) lean production evidently asserts positive effects on overall firm performance.

Table 3.3.1: Lean Manufacturing Performance Studies

Reference	N & Methodology	Findings
Inman and Mehra (1993)	N = 114 Regression	The implementation of lean benefits firm performance.
Norris *et al.* (1994)	N = 48 Percentage	The implementation of lean benefits plant performance.
Balakrishnan *et al*. (1996)	Literature search N = 46 × 2 T-test	Lean production entails higher inventory turnover than firms that do not. However, there was no significant difference in ROA.
Biggart (1997)	Literature search N = 106 Regression	The implementation of lean does not significantly improve ROA.
Callen *et al.* (2000)	N = 100 Regression	Lean techniques lead to greater profitability and lower total costs.
Fullerton and McWatters (2001)	N = 95 ANOVA	Greater implementation of lean leads to greater profitability.
Kinney and Wempe (2002)	Literature search N = 201 × 2 Regression	The implementation of lean improves both: profitability and return on assets.
Shah and Ward (2003)	N = 1575 Regression	Plant size influences implementation of lean; however, effects of unionisation on implementing lean is less clear. Also, lean bundles have a large impact (23%) on operating performance (speed, quality and costs)
Fullerton *et al.* (2003)	N = 253 Regression	Lean production has a positive effect on firm performance.
Ward and Zhou (2006)	N = 1,757 Regression	Implementing lean/JIT practices reduces lead-times and lean/JIT practices mediates the influence of IT integration on lead-time performance.
Matsui (2007)	N = 46 Correlation	JIT production systems contribute to competitive performance outcomes such as lower manufacturing costs.
Jayaram *et al.* (2008)	N = 57 SEM	The implementation of lean does not significantly impact firm performance.
Taj (2008)	N = 60 Percentage breakdown	Lean production is positively associated with performance and competitiveness.
Rahman *et al.* (2010)	N = 187 CFA	Lean is positively related with operational performance. JIT has a higher level of significance in LEs compared with SMEs, whereas for waste minimization there is a higher level of significance for SMEs compared with Les.
Eroglu and Hofer (2011)	N = 1600 Regression	In essence, inventory leanness is impacting firm performance, but too inventory lean is negatively impacting firm performance.

Demeter and Matyosz (2011)	N = 711 Correlation	Positive correlation between lean practices and inventory turnover. However other contextual factors, such as product type, also were related.
Yang *et al.* (2011)	N = 309 SEM	The implementation of lean production related to environment practices, market performance and financial performance.
Hofer *et al* (2012)	N = 229 Regression	Results showed that the implementations of lean are related to financial performance.
Chavez *et al.* (2013)	N = 228 Regression	Lean practices and quality, delivery, flexibility and cost were found to be positive and significant.
Dora *et al.* (2013)	N = 35 Percentage	The implementation of lean resulted in improved operational performance, especially productivity.
Belekoukias *et al.* (2014)	N = 140 SEM	Lean (JIT & automation) have positive significant relationship with operational performance, but kaizen, TPM and VSM possess less clear, or negative relationship.
Fullerton *et al.* (2014)	N = 244 SEM	Lean manufacturing was directly found to be related with operations performance.

Demeter and Matyusz's (2011) investigation was one of the only studies which did not only prioritise JIT or inventory leanness when exploring the effects of lean practices. Incorporating the use of univariate tests, this investigation also found levels of raw materials, work-in-process and finished goods to be lower within organisations implementing lean practices, which go hand-in-hand with the concepts of JIT and inventory leanness. However, before praising the notion of inventory leanness and high performance, the findings presented by Eroglu and Hofer (2011) must also be acknowledged, as they found inventory leanness to be positively affiliated with performance; a relationship which was observed to be concave in nature, suggesting that if a firm were to be 'too' lean in term of inventory, they would experience a negative relationship with performance. Even though low levels of inventory may be deemed as efficient, *"it does not admit the possibility of some processes always being intrinsically less than totally reliable*" (Slack *et al.,* 2010, p. 442). For instance, if firms allowed small quantities of high uncertainty inventory to be present around the process stage, it can enforce some protection or insurance in case of sudden changes. This idea of keeping small quantities of high uncertainty inventory can also be applied to JIT delivery between organisations. Even the likes of Toyota have faced severe consequences when holding too little inventory between plants, as disasters such as the Kobe earthquake and fires within Toyota's suppliers have resulted in Toyota shutting down main factories for several days due to shortages of certain products (Slack *et al.,* 2010). This demonstrates that even highly regulated networks may not be able to accurately predict what is ahead, and that keeping a small quantity of inventory may be used as a form of insurance for when the unpredictable does occur. Therefore, in order for firms to be able to perform at their best firms must be lean, but not 'too' lean.

In summary, the majority of studies suggested that lean production has direct operational and financial benefits. Only two studies (Biggart, 1997; Jayaram *et al*., 2008) were found to have no statistical significant relationship between lean production practices and firm performance. Before disregarding these studies as being anomalies, these results do side with certain findings within Belekoukias *et al*.'s (2014) and Balakrishnan *et al.'s (*1996) investigations. For instance, even though Belekoukias *et al*. (2014) identified JIT and automation as positively impacting operational performance, their study also found Kaizen, TPM and VSM having little and even negative relationships with cost, dependability, flexibility, quality and speed. Furthermore, Balakrishnan *et al. (*1996) also found lean initiatives as having no direct relationship with return on assets. The majority of studies which investigated the effects of lean production seem to, at best, touch on flexibility performance indicators. For this reason, as well as mixed opinions, the lean literature may need further development and clarification.

3.4 Agile Performance

The next stage of the review process focussed on the effects of agile implementation in relation with performance measures. Once again, each of these studies are presented in chronological order within Table 3.4.1 and the sample size, mode of analysis and main findings of each of these respective investigations are outlined.

The earliest study in Table 3.4.1, conducted by Sharp *et al*. (1999), conceptualised the enablers (core competence management, virtual enterprise, rapid prototyping, concurrent engineering, multi-skilled teams, continuous improvement, change management, IT, team working, employee empowerment) of agile manufacturing into a similar list as to what was presented in Table 2.4.1, and found that leading UK manufacturing organisations valued each of these in terms of generating competitive advantage. Even though certain studies within Table 3.4.1 attempted to investigate a well-rounded notion of the agile production concept, others (Yusuf *et al*., 2004; Dowlatshahi and Cao, 2006; Zain *et al.,* 2005; Inman *et al.* 2011) within this table did not seek investigate a broad range of agile manufacturing practices, instead focusing on particular elements such as IT (driven enterprise), virtual enterprise and JIT. Although these are certainly parts of agile production, they do not portray a holistic view of the concept given the abundance of other elements outlined in the literature (see Table 2.4.1). Most of the studies illustrated in Table 3.4.1 involved statistical techniques such as SEM modelling, regression analysis or correlation analysis as their choice of analytical methodology.

Table 3.4.1: Agile Performance Studies

Reference	N & Methodology	Findings
Sharp *et al.* (1999)	N = 42 Percentages	Results illustrated manufacturing organisations were valuing agility capabilities.
Brown and Bessant (2003)	N = 6 Case Studies	Agility and mass customization can lead to competitive advantage. However, advantages will depend on abilities to leverage factors such as quality, inventory, process technology and human skills.
Ren *et al*. (2003)	N = 105 ANN	Agility is related with speed, cost, quality, innovation, flexibility, proactivity (in this order).
Elkins *et al.* (2004)	Descriptive spreadsheet model	Agile systems leads to rapid and cost-effective response to new (unplanned) product model introductions and dynamic capacity allocation.
Yusuf *et al.* (2004)	N = 600 Regression	Supply chain integration is a vital tool for competitive advantage.
Cao and Dowlatshahi (2005)	N =102 T-Tests	Virtual enterprise and information technology have a positive association with business performance.
Dowlatshahi and Cao (2006)	N = 102 ANOVA	IT and VE positively impacted business performance.
Zain *et al.* (2005)	N = 329 SEM	Technology usage had a direct positive relationship with organisational agility which in turn enhanced performance.
Vazquez-Bustelo *et al.* (2007)	N = 283 SEM	Turbulent market identified as driver for agility. Agility positively associated with cost, quality, flexibility, delivery, service and environment). Greatest impact on market performance (i.e. responsiveness to change)
Swafford *et al.* (2008)	N = 131 SEM	IT integration directly impacts supply chain flexibility, which then results in higher supply chain agility and business performance.
Khan *et al.* (2009)	N = 128 Regression	Collaborative distribution, order commitment, distribution flexibility and inventory management identified as key SCM distribution practices associated with agile supply chains and all had significant impact on organisational performance.
Inman *et al.* (2011)	N = 96 SEM	JIT purchasing positively associated with agile manufacturing whilst JIT production had negative correlation. Agile manufacturing had positive association with marketing, financial and operational performance.
Roberts and Grover (2012)	N = 110 Regression	Customer agility was positively associated with firm performance.
Yusuf *et al.* (2014)	N = 137 Correlation	Agility was positively associated with delivery, proactivity, dependability, quality, flexibility, cost innovation and speed. Greatest significance within speed and innovations. Surprisingly, agility way not associated with customisation.
Gligor *et al.* (2015)	N = 283 SEM	Firm supply chain agility positively impacts financial measures via customer effectiveness and cost efficiency. However, no direct link was found between agility and financial performance.

The majority of studies which looked into the effects of agile production generally portrayed consistent findings. For instance, whether financially/business measured (Yusuf and Adeleye, 2002; Cao and Dowlatshahi, 2005; Dowlatshahi and Cao, 2006; Inman *et al.,* 2011; Roberts and Grover, 2012) or operationally captured (Brown and Bessant, 2003; Ren *et al*., 2003; Elkins *et al.,* 2004; Zain *et al.,* 2005; Vazquez-Bustelo *et al*., 2007; Khan *et al*., 2009; Inman *et al*., 2011; Yusuf *et al*., 2014; Gligor *et al*., 2015), similar to lean production, agile manufacturing is identified to be impacting the firm in a positive way.

Even though multiple studies have investigated the effects of agile production in relation with performance outcomes, few studies (Swafford *et al*., 2008; Gligor and Holcomb, 2012) have looked to assess the firm supply chain agility (FSCA) with regards to firm performance. For instance, multiple studies (Christopher, 2000; Holsapple and Jones, 2005) have asserted the linkage between agility and effectiveness but little empirical evidence has been presented to support it, highlighting the need for greater development. More recently, in an attempt to fill this gap Gilgor *et al.* (2015) investigated agility with customer effectiveness, cost efficiency and financial performance. Interestingly, findings from their study both complemented and contradicted received views. For instance, they found a positive linkage between FSCA and cost efficiency and customer effectiveness, but found no direct association between FSCA and financial performance. Even though received findings from Swafford *et al*. (2008) found a linkage between supply chain agility and financial performance, Gilgor *et al*.'s (2015) investigation failed to support this view. Furthermore, Yusuf *et al*. (2004) previously claimed that SC integration is crucial for completive advantage and more recently Yusuf *et al.* (2014) conducted a study within the oil and gas industry to determine if SC agility is linked with competitive objectives. With findings corroborating those of Dubois and Fredriksson (2008), Yusuf *et al*. (2014) overall found a direct positive linkage between SC agility and competitive objectives (proactivity, quality, innovation, delivery and speed), however, more importantly, they also went on to assert that at best there is only a weak correlation between agility and dependability, flexibility and cost reduction.

In summary, literature surrounding agile production generally suggest that there is a positive association with this concept and business/financial and operational benefits (Yusuf and Adeleye, 2002; Cao and Dowlatshahi, 2005; Dowlatshahi and Cao, 2006; Inman *et al.,* 2011; Roberts and Grover, 2012). However, as mentioned previously there is little empirical evidence investigating the effects of SC agility on firm performance (Swafford *et al*., 2008; Gligor and Holcomb, 2012; Gilgor *et al*., 2015), urging the need for greater development.

Overall, findings revealed that when analysed individually, the literature does suggest similarities in performance strengths between each manufacturing strategy, which has arguably led to therecent confusion between lean and agile manufacturing. For instance, the majority of findings from the literature (see Table 3.3.1 and Table 3.4.1) suggested that lean and agile manufacturing strategies are positively associated with operational and business performance, leading to the question of what the performance trade-offs are. Therefore, in order to distinguish each manufacturing strategy in terms of performance, it is crucial to examine studies that have incorporated both lean and agile manufacturing simultaneously within one study, as comparisons can directly be made by observing the levels of association between strategy and performance measures. With this in mind, the following section will look to review the literature which has explored lean and agile production simultaneously.

3.5 Lean and Agile Performance Trade-offs

Literature which has involved assessing lean and agile manufacturing in accordance with performance have also incorporated a third manufacturing strategy known as a lean and agile 'hybrid' strategy. In simple terms, a hybrid strategy revolves around the notion use of both manufacturing strategies in accordance with one another. However, this investigation does not involve the use of analysing 'hybrid as a manufacturing strategy, given that there is already confusion between the two concepts of lean and agile production, and the fundamental aims of this study is to examine the trade-offs between each of these approaches. Nonetheless, this thesis does acknowledge the idea that lean and agile firms may be operating within a singular SC, therefore the SC and process may in fact be 'leagile' in nature, as discussed in section 3.1.4. Even though similar, the literature reveals that lean and agile manufacturing are fundamentally different and emphasise different priorities. For instance, lean manufacturing is affiliated with efficiency, whereas agile manufacturing is ascribed with adaptability. In order to investigate these assertions further, the next stage of the review involved examining previous studies which looked into the trade-offs between lean and agile systems in accordance with performance, which are outlined in Table 3.5.1. Table 3.5.1 illustrates ten studies in chronological order which looked to examine performance levels within lean and agile systems as well as SC performance. Lean production is generally identified as being more efficient in terms of cost performance in comparison with agile manufacturing systems (Cagliano *et al.,* 2004; Agarwal *et al.,* 2006; Narasimhan *et al*., 2006; Hallgren and Olhager, 2009; Qi *et al.,* 2009). In contrast, studies within Table 3.5.1 suggest that the strengths associated with agile production are within flexibility and speed performance levels (Agarwal *et al.*, 2006; Narasimhan *et al*., 2006;

Hallgren and Olhager, 2009; Sukwadi *et al*., 2013; Qrunfleh and Tarafdar, 2013; Purvis *et al.,* 2014).

Table 3.5.1: Lean and Agile Performance Studies

Reference	N & Methodology	Results
Yusuf and Adeleye (2002)	N = 109 Correlation	Firms focussing on all competitive capabilities (agile) demonstrated greater business performance measure. Lean firms who focused mainly, or largely, on cost and quality were not performing as well as agile systems.
Cagliano *et al* (2004)	N = 284 ANOVA	Lean production was found to impact operational performance, cost performance, collaboration, and information sharing and flexibility levels to a greater extent in comparison to agile manufacturing.
Agarwal *et al.* (2006)	N = Research Group Case Study	Cost and quality were more positively associated with lean systems. Agile systems had a greater association with the level of service and lead-times.
Goldsby *et al*. (2006)	Case Study	Order-to-ship time and cost efficiency (outbound logistics) associated with lean. Inventory was lower under agile conditions. Costs were similar, agile slightly more cost effective in manufacturing and considerably more effective in inventory. Agile significantly less cost effective in terms of outbound logistics
Narasimhan *et al*. (2006)	N = 224 ANOVA	Results indicated that agile manufacturing is superior to lean manufacturing concerning quality, reliability, speed, new product flexibility and process flexibility. However, lean manufacturing was superior in terms of cost performance.
Hallgren and Olhager (2009)	N = 211 SEM	Lean manufacturing is having a greater impact on cost, quality, delivery speed and delivery reliability in comparison to agile manufacturing. Agile manufacturing is having a greater impact on volume flexibility and product mix flexibility.
Qi *et al.* (2009)	N = 406 ANOVA	Results revealed that lean manufacturing is empirically having a greater impact on financial performance, customer service and operating costs in comparison with agile manufacturing.
Sukwadi *et al*. (2013)	N = 160 CFA & SEM	Agility was found to have significantly improve SC performance and business performance. Flexibility was found to be as crucial when looking to improve SC performance. Lean strategy was not found to improve SC performance.
Qrunfleh and Tarafdar (2013)	N = 205 SEM	Agile supply chain strategy contributes significantly to building supply chain responsiveness, and in turn performance. In contrast, lean supply chain strategy does not contribute to supply chain responsiveness or performance.
Purvis *et al.*	N = 2	Agile manufacturing has high levels of vendor flexibly

(2014)	Case Study	and sourcing flexibility. Lean has low for both. Two more scenarios leagile with vendor flexibility and leagile with sourcing flexibility.

Before praising the notion that lean production is more affiliated with cost efficiency levels and agile manufacturing is more associated with flexibility and speed, it is important to note that this was not found within certain studies. For instance, in terms of costs, Goldsby *et al*. (2006) found that the levels of cost performance were similar between both manufacturing approaches, yet a closer examination of this investigation identified agile production to be marginally more effective in terms of manufacturing costs, and significantly more effective in terms of inventory costs and warehousing costs. Taking this into account, it could be proposed that agile production is superior to lean production, however, results from Goldsby *et al.*'s (2006) study also revealed that agile systems were drastically less cost effective in terms of outbound logistics, which is why overall similarities were found in terms of costs between both concepts. The reasoning why higher outbound logistics costs were affiliated with agile production can be explained by small-quantity shipments which were each dispatched directly to customers. Goldsby *et al*. (2006) suggested that if agile firms were more conscious of their outbound costs, and waited for dispatch containers/lorries to be closer to capacity before dispatch, then they would most likely be more cost effective in comparison with lean systems. However, the longer order-lead time may come with trade-offs, such as costs in the long-run.

With a sample of 284 firms, Cagliano *et al.* (2004) discovered that lean production was more greatly associated with collaboration and information sharing than agile manufacturing, a finding which contradicts the literature given that acting within a collaborative environment which regularly shares information with other organisations (i.e. a virtual enterprise) is largely considered to be one of the fundamental pillars of agile production. Cagliano *et al*. (2004) also went on to conclude that lean production was superior to agile manufacturing in most levels of performance (operational and flexibility). Even though findings from this study generally supported lean production as being favourable to agile production, they did reveal agile production to be positively correlated with performance, and although this correlation was lower than the one with lean, this difference between the two concepts was not deemed greatly significant.

Contrary to Cagliano *et al*.'s (2004) findings, Yusuf and Adeleye (2002) found that organisations focussing on agility generally displayed higher mean scores on business performance measures relative to lean practices, as lean firms prioritising cost and quality were not performing as well as agile systems. Even though findings have previously suggested that lean production is strongly affiliated with high quality levels, in an attempt to disentangle each manufacturing approach using a sample of 224 organisations, Narasimhan *et al*. (2006) identified three clusters within the manufacturing industry, namely: low performers; lean performers; and agile performers. Mean performance levels of lean manufacturers were all above the sample mean in terms of cost efficiency, conformance in quality, and design quality. Narasimhan *et al*. (2006) identified lean production as being significantly and marginally more cost effective in comparison with low and agile performers respectively. Furthermore, they found lean production's largest weakness to be associated with flexibility levels. Their findings revealed agile production to possess the highest cluster mean in every performance capability except for cost efficiency, where cost efficiency was only marginally higher than the overall sample mean. Even though agile production was superior to lean production in terms of design quality, conformance quality, delivery reliability, delivery speed, new product flexibility, and process flexibility, the largest differences were observed within delivery and flexibility dimensions, whilst quality levels were more similar between the two manufacturing strategies.

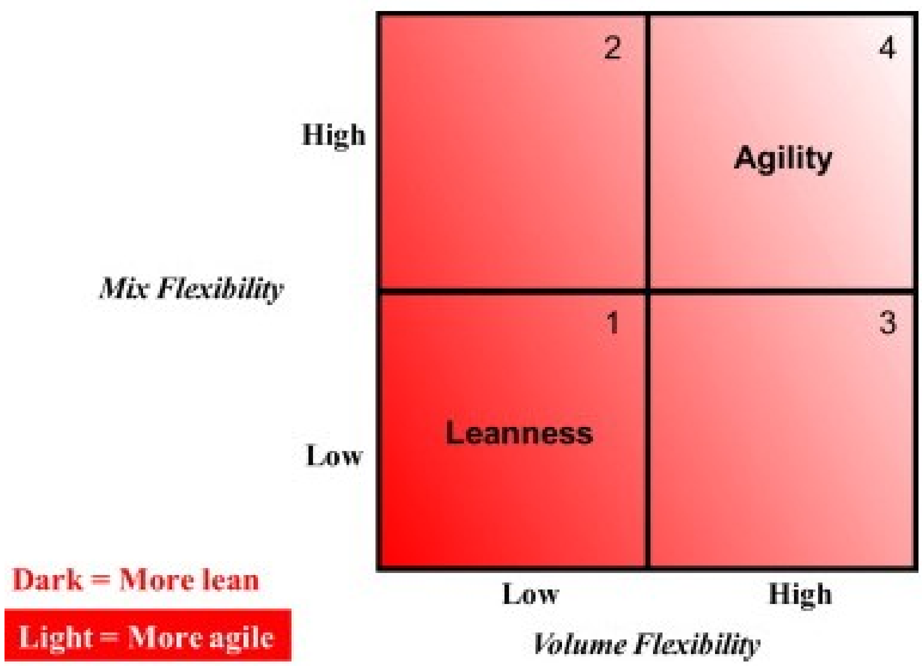
Narasimhan *et al*.'s (2006) findings were contended by Hallgren and Olhager (2009), who based upon a sample of 211 firms actually found lean manufacturing to illustrate a greater positive affiliation with cost, quality, delivery speed and delivery reliability than agile manufacturing. Findings from that study found lean manufacturing to have a significant impact on cost performance (whereas agile manufacturing does not), and that agile production illustrates a greater association with volume as well as product mix flexibility in comparison with lean manufacturing. However, it is important to note that lean manufacturing was found to significantly impact flexibility too, but this was not as strong as the impact observed in relation to agile production. Furthermore, they went on to assert that both lean and agile manufacturing approaches significantly impacted quality, delivery speed and delivery reliability. Hallgren and Olhager's (2009) finding contented those of Narasimhan *et al*. (2006), as agility was found to have slightly higher impact on quality performance, and the impact on delivery speed and reliability were fairly similar for each of the manufacturing approaches. Despite the differences, there are also notable similarities between these two studies as for instance, Hallgren and Olhager's (2009) main findings suggest that that lean production has a significantly stronger impact on cost, with agile production having a stronger impact on flexibility measures, in line with Narasimhan *et al*.'s (2006) assertions.

More recently Sukwadi *et al*. (2013) and Qrunfleh and Tarafdar (2013) investigated each approach in relation to the SC context and with both studies reporting similar findings. Sukwadi *et al*. (2013) found that agility was required in order to improve both business performance and SC performance, and concluded that flexibility was key when looking to improve SC performance. On the other hand, results from their study did not support lean production with business performance or SC performance. These assertions were complemented by Qrunfleh and Tarafdar (2013), whose findings also suggested that implementing agile strategies via the establishment of a responsive SC this would significantly impact performance. Once again, a lean SC strategy was not found to be significantly affiliated with ether SC responsiveness or performance.

Studies (Narasimhan *et al*., 2006; Gunasekaran *et al.,* 2008) have continually asserted that one of the most significant performance characteristic in distinguishing lean and agile manufacturing concepts is flexibility, with speed and responsiveness being fundamental (Reichhart and Holweg, 2007). Lean manufacturing places a large emphasis on the elimination of waste in order to increase efficiency (Shah and Ward, 2003), whilst agile manufacturing requires high levels of flexibility in order to accommodate sudden changes in the market environment. Agile manufacturing systems acquire vast capabilities for reconfiguration where as much waste as possible may be eliminated (Naylor *et al*., 1999) while in contrast, lean manufacturing is a process which removes all non-value adding activities, which in turn produces an efficient SC which is as flexible as required. Flexibility is not a prerequisite in order to become lean, although the elimination of waste is a prerequisite when becoming agile (Naylor *et al.*, 1999). For agile manufacturers, high flexibility may create large internal and external variances concerning factors such as volume, variety, delivery and supplier capabilities. In contrast, lean manufacturers seek to gain competitive advantage by becoming as efficient as possible which in turn reduces the internal and external variances of the same factors. In summary, flexibility, speed and responsiveness are repeatedly associated with agile manufacturing (Yusuf *et al*., 2003), while cost and efficiency are consistently associated with lean manufacturing (Womack, 2002).

Naylor *et al.* (1999) focused on the demand for variability of production (volume flexibility) and the demand for variety of production (mix flexibility) as a means of distinguishing between the lean and agile concepts, which is illustrated in Figure 3.5.1. The darker areas represent leaner systems and, in contrast, the lighter areas represent more agile systems. Shading on the y-axis implies that lean manufacturing systems can acquire high levels of mix flexibility, resulting in the capability to produce a large range of products. However, the shading variability on the x-axis is not as clear, suggesting lean systems cannot cope with large volume fluctuations. By contrast, agile systems can cope with both high levels of mix flexibility and high levels of volume flexibility according to this matrix.

Figure 3.5.1: Demand Distinguishing Lean and Agile Manufacturing Systems



Source: Purvis *et al.* (2014) adapted from Naylor *et al.* (1999, p.112)

Recent discussion surrounding flexibility has focussed on suppliers and the SC context, as it has been argued that examining individual firm flexibility levels is too narrow a view (Pujawan, 2004; Sanchez and Perez, 2005; Swafford *et al*., 2006; Stevenson and Spring, 2007), so firms are now seeking to examine partners and linkages within their SC (Swaminathan, 2001). Many observers have asserted that supply chain flexibility (SCF) is in early stages of development, with its full application yet to be discovered (Bernardes and Hanna, 2009; Malhotra and Mackelprang, 2012).

Lean proponents assert the need to create close long-term relationships between buyers and suppliers (Lamming, 1993; Handfield and Bechtel, 2002; Abdollahi *et al.,* 2015), ensuring the elimination of waste by reducing internal and external variances. As the principles of lean thinking encompass long-term relationships between buyers and suppliers, one may suggest power levels of interdependence. On the contrary to this view, Cox (2004) suggested that lean may actually only work when the buyer has a dominance over their suppliers, and these suppliers would have no choice but to pass value to the buyer. Nellore *et al*., (2001) also suggested that firms with large buying power are far less likely to devote their time to developing relationships with their suppliers, and simply enforce the lean model.

As the global automotive industry has recently witnessed fluctuating trends, firms have placed greater emphasis on agility (Brooke, 2008, Elmoselhy, 2013). Agile thinking revolves around the formation of temporary network of suppliers which are needed when producing goods of short life-cycles. With this in mind it may be suggested that agile systems possess imbalanced power levels between buyers and suppliers. This view is supported by Camarinha-Matos *et al*. (2001) who suggested it is critical for a firm to act as a leader within the enterprise, however, this was contended by Jagdev and Thoben (2001) who advocated that the structure of agile systems is non-hierarchical in nature. Regardless of how power may play a role in the debate between lean and agile systems, agile firms are theoretically expected to have higher flexibility and SCF levels in comparison to lean firms.

Summary

In summary, even though lean and agile manufacturing share certain practices and attributes, the literature states that each paradigm acquires strengths in separate domains. Agile manufacturing uses market knowledge and virtual cooperation to exploit new opportunities, which enables agile firms to be more effective than lean firms in terms of speed and flexibility. In contrast, lean manufacturing requires the elimination of waste in order benefit from the market, therefore in theory, lean manufacturing should be more effective than agile manufacturing in terms of cost and dependability. It is interesting to note that both manufacturing paradigms emphasise quality as being market qualifiers. The similarities and differences between lean and agile production are summarised in Table 3.5.2.

Table 3.5.2: Similarities and Differences between Lean and Agile Supply Chains

Attributes	Lean	Agile
Market Demand	Predictable	Volatile
Product Variety	Low	High
Product Life Cycle	Long	Short
Customer Drivers	Cost	Lead-Time & Availability
Profit Margin	Low	High
Purchasing Policy	Buy Goods	Assign Capacity
Lead Time Compression	Essential	Essential
Eliminate Muda	Essential	Desirable
Rapid Reconfiguration	Desirable	Essential
Robustness	Arbitrary	Essential
Quality	Market Qualifier	Market Qualifier
Cost	Market Winner	Market Qualifier
Lead-Time	Market Qualifier	Market Qualifier
Service Level	Market Qualifier	Market Winner

Sources: Naylor *et al.* (1999), Mason-Jones *et al.* (2000), Olhager (2003).

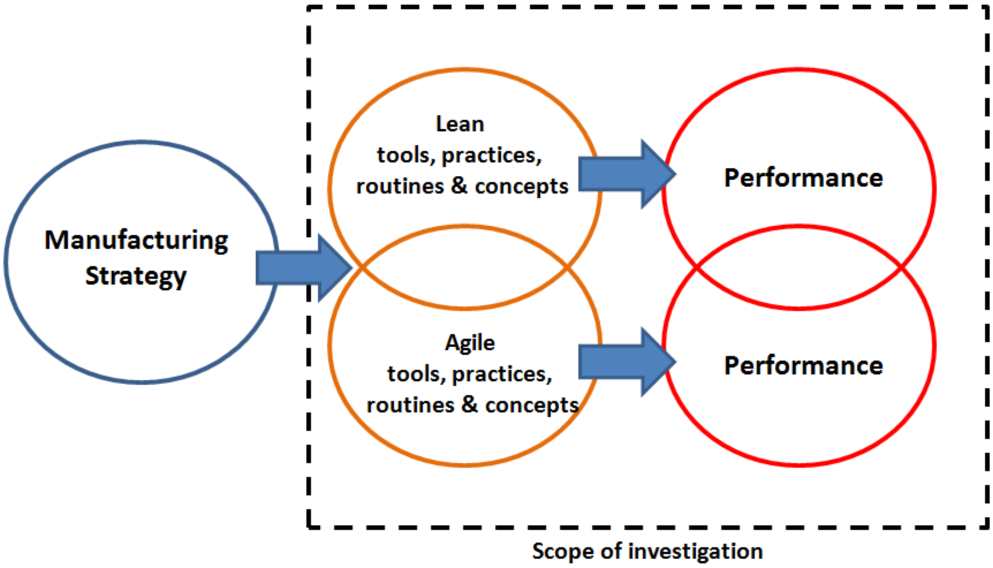
3.6 Research Gap

As discussed in sections 3.3 and 3.4 there is no doubt that in terms of performance, the literature concerning lean and agile production separately is well developed. However, in terms of exploring both paradigms simultaneously, this chapter revealed that only a handful of studies actually looked into the performance trade-offs associated with the two concepts. Furthermore, studies (Goldsby *et al*., 2006; Narasimhan *et al.*, 2006; Hallgren and Olhager, 2009; Qi *et al.,* 2009) that have investigated the performance trade-offs associated with cost, dependability, quality, speed and flexibility, have generally measured a limited number of variables. For instance, considering the literature has repeatedly suggested that flexibility can distinguish each manufacturing strategy, and considering that flexibility literature in itself is well developed, it is necessary to question why more studies have not focussed on measuring a broad set of flexibility dimensions. Narasimhan *et al*., (2006) measured two sub-variables of flexibility (process flexibility and product mix flexibility), as did Hallgren and Olhager (2009) (volume flexibility and product mix flexibility), and even though Hallgren and Olhager (2009) found volume flexibility to be more strongly associated with agile manufacturing, their results also asserted that lean operations can cope with volume flexibility, as although this sub-variable was more affiliated agile manufacturing, it was only to a marginal extent. Arguably both Narasimhan *et al.'s* (2006) and Hallgren and Olhager's (2009) studies did not investigate flexibility in great depth, as neither looked into measures such as supplier/vendor flexibility or sourcing flexibility, which Purvis *et al.,* (2014) cited as a key flexibility measure separating lean and agile manufacturing systems, but even though Purvis *et al*. (2014) investigated lean and agile flexibility in depth, they did not measure any other performance variables. In summary, previous studies (Naylor *et al.*, 1999; Narasimhan *et al.*, 2006; Hallgren and Olhager, 2009; Purvis *et al*., 2014) which have assessed flexibility measures within lean and agile systems only limited dimensions of flexibility have been investigated, highlighting the need for further research in this domain.

Furthermore, researchers within the field of both OM and SCM have often operationalised performance measures via the use of perceived measures, rather than factual data, using case studies or opinion-based, Likert Scale-type questions. With this in mind, one of the aims of this study was to provide a rigorous understanding of the trade-offs between lean and agile systems. As measuring performance has been defined as "*the process of quantifying action, where measurement means the process of quantification and the performance of the operations is assumed to derive from actions taken by its management*" (Slack *et al*., 2010, p. 606), there is an urgent need to capture factual data, as opposed to perceived levels in order to develop understanding of these paradigms. Although lean and agile literatures are widely incorporated into the fields of OM and SCM, only a handful of studies have looked to explore the performance trade-offs simultaneously within a singular study, and those studies that have investigated the trade-offs have generally acquired mixed results concerning costs, dependability and quality, highlighting the need for greater clarity. Therefore, the main sub-research question proposed was:

RQ (b): What are the trade-offs in performance between lean and agile production?

Figure 3.6.1: Theoretical Model



In accordance with Skinner's (1969) assertion that no firm can compete on all aspects of performance which is complemented by findings from this chapter, Figure 3.6.1 illustrates the theoretical framework for this study. As lean and agile firms can be distinguished based upon the bundled set of TPRCs identified in Table 2.4.1, and considering that some of these are employed within both manufacturing concepts, Figure 3.6.1 suggests there may be overlapping strengths between each of the production strategies. However, as they both also involve distinct TPRCs as presented throughout this chapter, one production concept will be stronger or weaker when compared with the other.

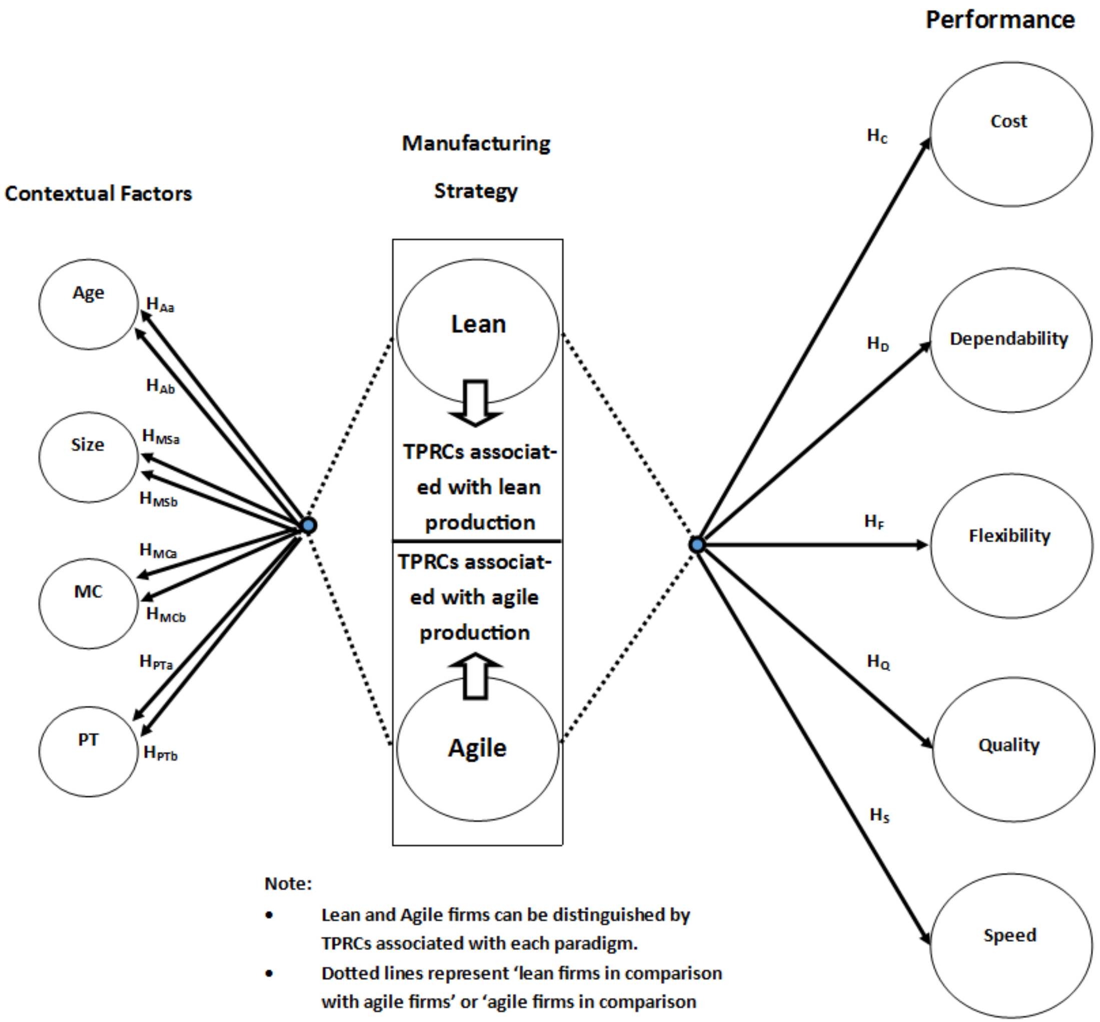
3.7 Conceptual Framework

Figure 3.7.1 highlights the conceptual model used within this study in order to test the theoretical assumptions highlighted earlier. However, before conceptualising the strengths associated with each manufacturing concept, it is important to note the method used to distinguish lean and agile firms (see middle section of Figure 3.7.1). As mentioned in Chapter 2 (section 2.1), trade-offs can be explained due to the different TPRCs implemented within organisations. Therefore, depending on a firm's manufacturing strategy, they will acquire the relevant resources (RBV perspective) in order to achieve their performance objectives, and as such these collections of resources can be used as the basis by which to establish whether firms are implementing lean or agile production to a greater extent. As discussed in Chapter 2, the review of the literature identified that lean firms will be generally implementing 15 TPRCs, namely: Elimination of Waste, Continuous Improvement, 5S, Zero Defects, Production Smoothing, Line Balancing, Value Stream Mapping, Total Productive Maintenance, Cellular Manufacturing, Just-in-Time, Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment and SMED. In addition, the review of the literature found 13 TPRCs ascribed with agile manufacturing, namely: Just-in-Time; Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment, Setup Reduction (SMED), Virtual Enterprise, Core Competence Management, Knowledge Driven Enterprise, Reconfiguration, Rapid Prototyping, Concurrent Engineering and IT Driven Enterprise. Even though there are commonalities between some of the TPRCs, there are also key differences which ultimately lead to different strengths in performance. In essence, prior to testing any trade-offs, lean and agile firms were distinguished based upon which set of the bundled practices they were implementing to the greatest degree.

Furthermore, before examining any conceptualised performance trade-offs it is important to remember the hypotheses presented earlier on in this chapter. As contextual factors can play a role in the choice to implement lean or agile practices, it was deemed necessary to investigate contextual factor trade-offs too (see left hand-side of Figure 3.7.1). For instance, as CT suggests that firms compete on strategies based upon contingent factors, such as firm age, firms size, manufacturing classification of industry and SC positional tier, the following hypotheses: H_{Aa}; H_{Ab}; H_{MSa}; $H_{MSb;}$ H_{MCa}; H_{MCb}; H_{PTa} and $H_{PTb,}$ were established in order to investigate the trade-offs concerning each of these points with respect to lean and agile firms.

Bearing in mind the scarcity in studies and that results illustrated mixed views, the majority of findings from the literature review conducted in this chapter which examined the trade-offs between each manufacturing concept, did reveal lean manufacturing to be more affiliated with cost and dependability (Cagliano *et al.,* 2004; Agarwal *et al*., 2006; Narasimhan *et al*., 2006; Hallgren and Olhager, 2009) than agile manufacturing, and in contrast agile production to be largely related with flexibility and speed (Agarwal *et al*., 2006; Narasimhan *et al*., 2006; Hallgren and Olhager, 2009; Purvis *et al*., 2014) in comparison with lean production. In terms of quality, both manufacturing strategies revealed similar performance levels. Taking this into account, the following hypotheses were conceptualised (see right-hand side of Figure 3.7.1), namely: H_C; H_D; H_F; H_Q; and H_S. As this study is interested in the trade-offs between lean and agile manufacturing firms, the dotted lines in Figure 3.7.1 represent either 'lean firms in comparison with agile firms' or ‘agile firms in comparison with lean firms’, depending on the hypothesis under investigation. The bold lines represent the likelihood and relationship concerning each of the proposed hypotheses occurring.

Figure 3.7.1: Conceptual Framework



RQ (a): what are the trade-offs in contextual factors between lean and agile manufacturing firms?

H_{Aa}. Lean firms are more likely to be older in age when compared with agile firms.

H_{Ab}. Agile firms are more likely to be younger in age when compared with lean firms.

H_{MSa}. Lean firms are more likely to be large in size when compared with agile firms.

H_{MSb}. Agile firms are more likely to be small in size when compared with lean firms.

H_{MCa}: Lean firms are more likely to belong to low innovative industries when compared with agile firms.

H_{MCa}: Agile firms are more likely to belong to high innovative industries when compared with lean firms.

H_{PTa}. Lean firms are more likely to be positioned at the lower tiers of a SC when compared with agile firms.

H_{PTb}. Agile firms are more likely to be positioned at the top tiers of a SC when compared with lean systems.

RQ (b): what are the performance trade-offs between lean and agile manufacturing firms?

RQ (c): Is flexibility the most significant performance level in with which to differentiate lean and agile systems?

H_C: Lean firms are more likely to attain higher cost performance levels when compared with agile firms.

H_D: Lean firms are more likely to attain higher dependability levels when compared with agile firms.

H_F: Agile firms are more likely to attain higher flexibility levels when compared with lean firms.

H_S: Lean firms are likely to attain similar quality levels when compared with agile firms.

H_S: Agile firms are more likely to attain higher speed levels when compared with lean firms.

Note:

- **Lean and Agile firms can be distinguished by TPRCs associated with each paradigm.**
- **Dotted lines represent 'lean firms in comparison with agile firms' or 'agile firms in comparison with lean firms.**

Even though the focal point of this study is to test the trade-off law based on Skinner's (1969) assertion, arguably, if the proposed hypotheses looking into performance trade-offs (H_C; H_D; H_F; H_Q; and H_S) are accepted, the way in which lean and agile firms can be distinguished, and potentially compete, goes hand-in-hand with Porter's (1985) competitiveness assertions. Porter (1985) suggested that fundamentally there are three ways in which a firm can compete, namely: Cost leadership, with an emphasis on the importance of costs whereby firms streamline their operations and strive to become low-cost producers; Differentiation, where firms compete by avoiding direct competition by differentiating their products or possessing the resources in order to be perceived as a purveyor of unique products; and Focus, where organisations gear their focus to a particular market segment. However, these three competitive stances can be reduced to two, as an organisation must fundamentally choose whether to focus on cost or differentiation (Kotha and Orne, 1989; Ward and Duray, 2000; Hallgren and Olhager, 2009). It can therefore be asserted that this study seeks to extend Porter's (1985) assertions on competiveness, as cost focus and differentiation strategies relate to lean and agility respectively.

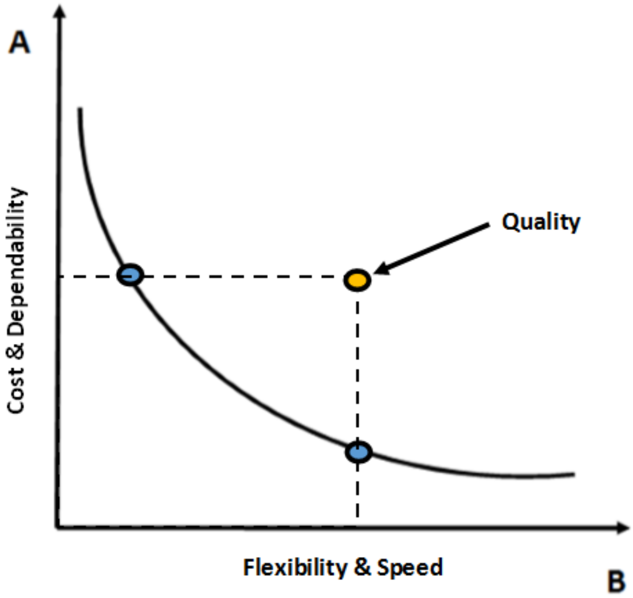
3.8 Conclusion

In conclusion, even though each of these manufacturing concepts share similarities, building on Skinner's (1969) assertion, this chapter looked to explore the trade-offs between each manufacturing strategy in relation with performance. Surprisingly, although both lean and agile manufacturing concepts have widely been explored within the realms of OM and SCM, only a handful of studies have looked to explore the performance trade-offs simultaneously within one study. Furthermore, the studies that have investigated the trade-offs between each manufacturing concept have presented mixed views concerning certain performance measures such as cost, dependability and quality, highlighting the need for clarification and further research. Nevertheless, the majority of findings from the limited literature revealed lean production to be more affiliated with costs and agile manufacturing to be more ascribed with flexibility. Considering that flexibility has repeatedly been asserted as a mode of distinguishing each of the manufacturing paradigms, the studies which did look into the performance trade-offs only included a limited number of flexibility dimensions, urging the need for further research.

A conceptual framework was presented within this chapter, which not only included the performance trade-offs, but also incorporated the conceptualised hypotheses from the previous chapter in order to test trade-offs in terms of contextual factors.

In essence, Figure 3.8.1 provides a simplistic visualisation into the expected trade-offs between lean and agile manufacturing strategies. For instance, lean firms are expected to hold strengths in costs and dependability levels, whereas agile firms are expected to be superior in terms of flexibility and speed. As both concepts highlight quality, similar levels of quality levels are expected between each of the two approaches.

Figure 3.8.1: Hypotheses in Association with Trade-Off Model



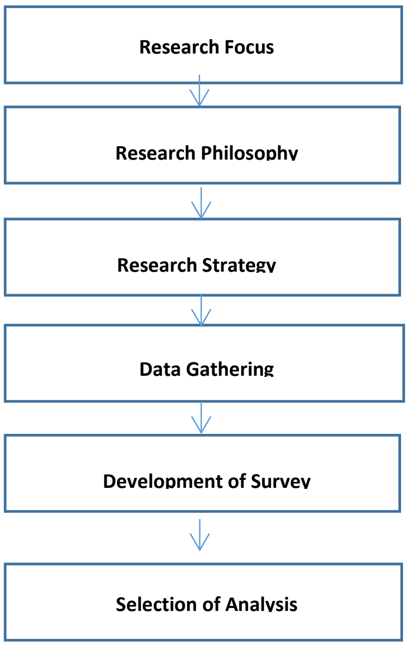
Source: Adapted from Da Silveira and Slack (2001, p. 951)

Furthermore, the majority of studies that have looked into concerns similar to those addressed in this research have measured performance levels via the through the use of case studies or opinion-based, Likert Scale-type questions. The motivation for this study was to seek greater clarity between each of the manufacturing approaches by gathering more rigorous empirical data in comparison to previous studies. The following chapter will illustrate the choice and rationale of methodology employed, as well as a detailed description into each of the performance variables and sub-variables under investigation.

CHAPTER 4 - METHODOLOGY

This chapter will detail the selection of the methodology considered most suitable for this investigation. This chapter is divided into seven sections. First, this chapter will begin by introducing the selection of research focus and justification of the research questions. Second, this chapter will provide a brief introduction to research philosophy. Third, the research strategy deemed most appropriate will be presented. Fourth, the data collection method will be described. Fifth, the selection of variables used to distinguish lean and agile manufacturing organisations and assess each of the performance measures are detailed. Sixth, the selection of main method of analysis is outlined. Finally, this chapter illustrates a more detailed conceptual framework used to answer the main over-arching research question. Figure 4.1.1 depicts the order in which this chapter proceeds.

Figure 4.1.1: Chapter Overview



Before moving on to the research focus, research questions and selected research strategy, it is useful to mention the importance of research design. Research design is a critical factor regarding any form of research, as there are a vast range of different strategies, methodologies and data gathering strategies, each of which has strengths and weaknesses. Some strategies will be more suitable than others in addressing particular research topics, questions and aims. Taking this into account, the research question must first be formulated, which leads to a series of decision-making steps to guide the researcher in identifying the most suitable design and method to effectively answer that question.

4.1 Research Focus & Research Question

Having reviewed the literature, it was apparent that many studies have examined lean manufacturing and agile manufacturing respectively, uncovering the significant impact that they each may have on performance; however only a handful of studies have investigated the trade-offs between each of these approaches simultaneously, and the ones that did comprised of mixed findings. Overall, there is an 'unclear' and 'confused' understanding of the practices employed within each concept, highlighting the need for clarification. With this in mind, with the assumption of the trade-off law (Schmenner and Swink, 1998) and as Da Silveira and Slack (2001) suggested that trade-offs arise due to organisations acquiring different resources and capabilities, the main aims of this research were to: 1) Disentangle the TPRCs associated with each of the concepts; 2) Evaluate the performance trade-offs; and 3) Determine if flexibility is the most critical measure which can be used to differentiate lean and agile systems. Therefore, the main research question is presented as:

RQ: What are the trade-offs between lean and agile manufacturing?

Three sub-research questions were used in order to answer the main research question:

(a) What are the trade-offs in contextual factors between lean and agile manufacturing?

(b) What are the trade-offs in performance between lean and agile manufacturing?

(c) Are flexibility trade-offs the most significant performance level by which to differentiate lean and agile firms?

The automotive industry within the West Midlands (UK) was selected as the industry under investigation as was discussed in Section 1.4.

4.2 Research Philosophy

Research philosophy is a type of belief concerning the way data is collected and analysed (Levin, 1988). In order to truly understand the world there has to be different methods of viewing and analysing facts, ideas and events, and therefore, the social world can be translated and analysed via many avenues of thought. No matter what the situation, in order for a theoretical model to explain anything appropriately, there has to be a suitable relationship between the statements, methods and philosophical routes positioned to inform the methods (Abbott, 1988). There are many different choices regarding the management of research, and Saunders *et al.* (2009) have depicted these choices via an illustration known as the 'research onion' (see Figure 4.2.1). Before moving on to the choice of methodology employed in this study, it is important to look into epistemology and ontology, as these both can play a pivotal role in the overall research philosophical stance, i.e. positivism, realism, interpretivism, pragmatism, constructivism and critical theory (Healy and Perry, 2000; Saunders *et al*., 2009) and methodology that a researcher may take within their investigation.

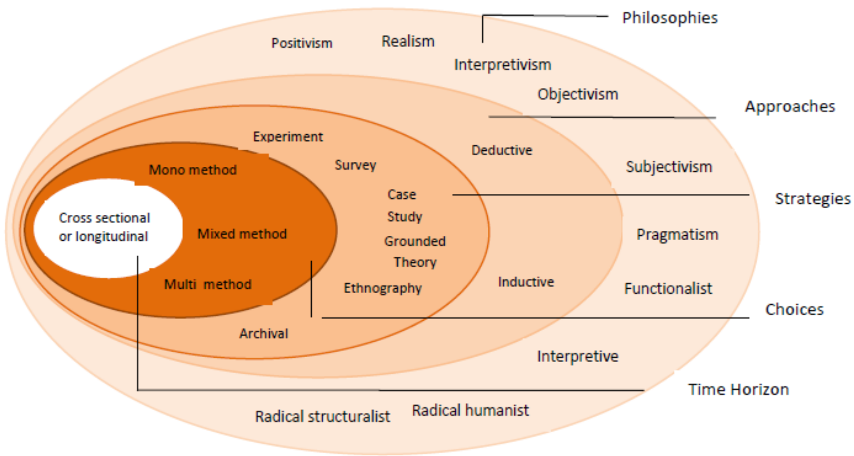
Epistemology is defined as something that embodies adequate knowledge in a given field of study. With regards to epistemology, Saunders *et al.* (2009) suggested that there are two views, namely: the ‘resources’ researcher and the ‘feelings’ researcher. Within a manufacturing setting, the ‘resources’ researcher considers data on resources, such as objects or processes, as crucial to the formation of knowledge, and are inevitably more likely to align their thinking with the natural sciences. On the other hand, within the same setting, the ‘feelings’ researcher would be more likely to be interested in the feelings and attitudes of the workers in the formation of knowledge. In this sense, the ‘resources’ researcher would be more likely to adopt a positivist approach, when seeking to develop knowledge. On the contrary, the ‘feelings’ researcher is more likely to adopt an interpretivist perspective. More information regarding the positivist approach will be explored within section 4.3.

Ontology refers to the reality that researchers investigate. Saunders *et al*. (2009) suggested that in terms of raising questions regarding the research surrounding, ontology plays a larger role in comparison with epistemology. Essentially, there are two aspects to ontology, namely objectivism and subjectivism. Objectivism, “*portrays the position that social entities exist in reality external to social actors concerned with their existence*” (Saunders *et al*., 2009, p.10), whereas subjectivism suggests that “*social phenomena are created from the perceptions and consequent actions of those social actors concerned with their existence*”

(Saunders *et al*., 2009, p.10). Both of these ontological positions have been widely accepted as a means of generating valid knowledge.

Finally, a methodology is a body of knowledge that is critical in assisting researchers to analyse and evaluate certain methods. The methodology is used to indicate many factors within different methods such as limitations, presumptions and consequences (Miller, 1983). The methodology is crucial to any form of research, as different research paradigms, types of data and collection methods can have significant implications for research findings. Therefore, it is vital that the researcher evaluates each of these points thoroughly in order to ensure that they select the most suitable method and overall design regarding their individual research project. As will be discussed, this thesis uses an experimental approach that involves quantitative data via a constructed survey, the justification for which is provided within the upcoming sections.

Figure 4.2.1: The Research Onion



(reproduced with permission from Research Methods for Business Students by Mark Saunders, Philip Lewis and Adrian Thornhill, Copyright 2007, Pearson Education Limited).

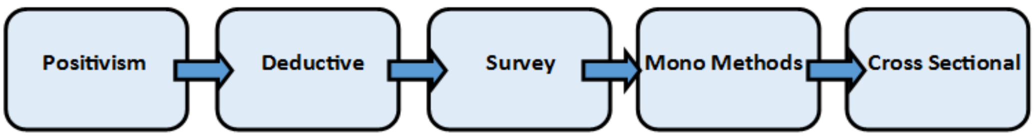
Source: Saunders *et al.* (2009)

4.3 Research Strategy

In terms of epistemology, this thesis builds on the knowledge acquired within OM and SCM in association with the effects of varying manufacturing strategies. Building on Skinner's (1969) theoretical assertion that no manufacturing strategy can compete on all indicators of performance, this study assumes that trade-offs will be apparent, as different organisations will be implementing varying bundles of TPRCs, which can be used to separate lean and agile manufacturing firms. However, the focal point of this study was to investigate the performance trade-offs in greater detail and *more* objectively than previous studies. This required collecting data that was methodologically, *more* rigorous than previous studies.

Using the research onion as a guide to the research choices available, in accordance with the main research question, the research philosophy employed within this investigation took a positivist stance that is deductive in nature. Considering the research question can be answered in numerical form, and as this study looked to obtain *more* objective performance indicators, the research strategy consisted of gathering primary quantitative data via the use of cross-sectional gatherings from a constructed survey. Figure 4.3.1 clearly indicates the chosen steps regarding each of the points. The aim of the following section was to outline the rationale into why each of these choices were selected.

Figure 4.3.1: Research Strategy



As the main objective of this research was to highlight the performance differentials between each of the manufacturing concepts in question, and as this research took a 'value free' stance, where the role of the researcher was to primarily be an observer of a current situation, it was decided that this research is in line with a positivist approach. As mentioned previously, there are two views within epistemology, namely: the 'resources' researcher, and the 'feelings' researcher. As the 'resources' researcher considers data on resources as crucial to the formation of knowledge, and considering this investigation sought to explore the performance effects of two manufacturing strategies which were distinguished based upon the TPRCs employed within organisations, as opposed to investigating the feelings and attitudes of individuals working within these organisations, a positivist stance was deemed appropriate. With regards to positivism, the role of the researcher is identified as an observer of the system, which can indeed be measurable. Positivist research is generally more likely to accompany a deductive approach, which includes testing theory via the use of hypotheses. Although a positivist approach is appropriate for this research, a positivist stance may not be appropriate when approaching certain topics within social sciences such as human behaviour, real-life experiences, treating respondents independently and non-reflective objects (Healy and Perry, 2000). However, as these factors were not explored within this investigation, they were not deemed a threat. Positivism is generally associated quantitative research, whilst the other paradigms have a high relevance with qualitative studies.

As this research sought to determine 'what' the performance trade-offs are between each of the manufacturing concepts in question, rather than determining 'why' this might be occurring, a deductive approach was adopted. As mentioned previously, deductive research is closely linked with positivism and occurs when the researcher applies general information to a specific project. The deductive approach has been labelled the 'top-down' approach because initially the researcher begins with a broad concept and works their way down to a specific conclusion. This occurs when a researcher begins with a theory within their chosen topic and narrows their way down to a specific hypothesis that can be tested, and ultimately accepted or rejected. "*A deductive approach is concerned with developing a hypothesis (or hypotheses) based on existing theory, and then designing a research strategy to test the hypothesis*" (Wilson, 2012, p.7). As this investigation built on existing received wisdom to test a range of performance hypotheses that deduce conclusions based on theoretical propositions, a deductive approach was deemed most suitable.

As the research questions can largely be answered in numerical form, as opposed to descriptive, it was most appropriate to use a survey instrument which could capture quantitative data. Quantitative research is an approach that places a large emphasis on numerical data which is used to determine relationships between theory and research, and is viewed as the most traditional form of enquiry. Denzin and Lincoln (2005) stated that research only involving positivist quantitative methods are commonly perceived as the most prestigious achievements of Western civilisation as truth can easily be verified without any significance of the researcher's opinion. Even though quantitative research has been argued to present results which are unbiased in line with the researcher's opinion, it has been criticised as only measuring the relationship between the variables under investigation, as it does not consider the cause of these results (Ibid.). Neuman (2013, p.168) claimed that "*In a quantitative study, we usually try to verify or falsify a relationship or hypothesis we already have in mind. We focus on an outcome or effect found across numerous cases. The test of a* *hypothesis may be more than a simple true or false answer; frequently it includes learning that a hypothesis is true for some cases or under certain conditions but not others".* In essence, a quantitative approach is appropriate when a researcher is seeking to test the relative importance of a range of causes concerning a social phenomenon (Bryman, 2015). As quantitative findings are defined by statistics, final results can often be applied and generalised to a larger population other than just the sample investigated.

Reliability has been defined as the extent to which the results obtained by the researcher are consistent over a given time and capture an accurate representation of the total populations under investigation (Saunders *at al.*, 2009). Furthermore, Kirk and Miller (1986) advocated that in order to ensure reliability, the researcher must consider the extent to which a measurement, given repeatedly, remains the same. With this in mind, as will be discussed in section 4.5, performance was captured numerically and did not involve the use of subjective Likert-Scale based questions. Furthermore, validity is described as whether the research truly measured what it intended to measure (Saunders et al., 2009). The concept of validity is embedded within a positivist approach (Golafshani, 2003), justifying why a positivist approach was more suitable in comparison with other philosophical stances. Even though it has been acknowledged that positivists "*ignores their ability to reflect on problem situations"* (Robson, 1993, p.60) due to their inability to obtain deep, meaningful results, as this study's ultimate focus was to rigorously measure and distinguish lean and agile performance trade-offs it was essential to capture information that was both, reliable and valid; concepts which go hand-in-hand with the positivist approach. As previously mentioned, Denzin and Lincoln (2005) have criticised quantitative research as only measuring the relationship between the variables under investigation. With this in mind, and by using the findings presented in Chapter 3 (section 3.2), in terms of validity, the survey instrument also included questions corresponding to contextual factors such as firm size, firm age, manufacturing classification and positional tier, all which have been ascribed within the literature as factors that can potentially impact the generalisability of results.

In summary, this investigation takes a positivist stance, as the researcher takes an objective view of as 'observer' of a 'reality' (lean and agile firms) which is measurable. Furthermore, this research follows a deductive approach as it heavily involves the use of scientific testing via the use of multiple hypotheses. Hypotheses investigated in this study are developed from existing theory/laws, as highlighted in Chapter 4 (section 4.6).

4.4 Data Gathering

As the information this study wanted to obtain was not readily available, a survey was developed as the means of data collection. Data was obtained from Managing Directors/Operational Directors via the use of a questionnaire which was distributed by email. Involving the use of a representative sample of participants (see section 4.4.1), the main aim of the survey was to discover if there were any existing relationships between the variables examined, in this case between manufacturing strategy and performance, which can be then be applied to a generalisable statement for the object of study. However, survey research only provides a 'snapshot' of a situation in a certain point in time, which can be argued as verifying little information on the underlying meaning of the data. Even though case study research can provide greater insights and discoveries regarding a subject, it is arguably a poor method when objectively verifying a hypothesis, as it may entail some bias with the researcher's views. As the main aim of this study was to determine 'what' the performance trade-offs were corresponding to lean and agile manufacturing strategies, as opposed to ‘why’ they were happening, a case study was not deemed appropriate. Furthermore, Garity and Sanders (1998, p.60) advocated that “*surveys can accurately document the norm, identify extreme outcomes, and delineate associations between variables in a sample*”. Considering the aims of this study were to investigate the differences between lean systems and agile systems as a whole, the survey approach was deemed acceptable. In terms of deductibility, surveys have been deemed superior to case study investigations, for instance, Vidich and Shapiro (1995, p.31) claimed that “*without the survey data, the observer could only make reasonable guesses about his area of ignorance in the effort to reduce bias*." Furthermore, Jick (1979) argued that survey research can lead to reliable findings, where individuals have greater confidence with findings, hence, more are likely to make generalisations based on the results in comparison to case study research.

4.4.1 Sampling

Kumar (2011, p.193) defined sampling as *“the process of selecting a few (a sample) from a bigger group (the sampling population) to become the basis for estimating or predicting the prevalence of an unknown piece of information, situation or outcome regarding the bigger group”.* Sampling within quantitative research should be unbiased and representative of the original population. The main purpose of sampling within quantitative research is to draw conclusions from the investigated group, which can then be generalised for a larger population. In addition, emphasis is placed on the size of the sample, as studies seeking to investigate policies, test associations/relationships and establish the impact of certain factors arguably acquire greater validity when the sample size is large in nature. Furthermore, randomisation also plays a crucial part in quantitative research, as it is used to ensure that the researcher has avoided any possibility of bias when selecting participants. There are many sampling techniques the researcher may employ concerning both qualitative and quantitative research, however, as this study is seeking to obtain primary quantitative results, the three most popular and relevant sampling techniques are: simple random sampling, stratified random sampling and cluster sampling. Simple random sampling involves randomisation, as each participant within the population is given an independent and equal chance of selection, however, as populations contain different groups one must consider stratified random sampling. Stratified random sampling is built upon the philosophy that the accuracy of the estimate is largely dependent on the extent of variability of the original population. For instance, stratified random sampling occurs when the researcher attempts to stratify the original population in such a way that the population within each stratum is homogenous and has a strong correlation to what is actually under investigation (Kumar, 2011). In essence, stratified random sampling is built on the fact that if heterogeneity within the original population can be reduced for a given sample size, results can be argued to be more precise and hold greater validity when making generalisations. Simple random and stratified sampling techniques require the researcher to separate and distinguish each element and stratums within a given population. However, if the population is extremely large, it is rather difficult to identify and distinguish each sampling unit. If this is the case, then it may be more appropriate for the researcher to use cluster sampling, which occurs when the researcher deems the population too large and thus divides the sampling population into different groups, which may be based on visibility or identifiable characteristics. These groups are referred to as clusters and the researcher then extracts a viable sample within each cluster using simple random sampling. Once a researcher identifies the relevant clusters, as these clusters may contain large variations in the size of each of the populations, they may use proportionate random sampling, which involves selecting the same percentage of population amongst all clusters.

FAME Bureau Van Dijk is a database that covers approximately 9 million firms within the UK and Ireland (FAME, 2016). Using this, approximately 15,000 manufacturing organisations operating within the West Midlands region were identified. Figure 3.1.2 illustrated the diverse range of components required when manufacturing a motor vehicle, so taking this into account it is no surprise that many firms producing products for the automotive industry may actually be classified under different manufacturing SIC codes as opposed to just the SIC *29. Manufacture of motor vehicles, trailers and semi-trailers.* Therefore, understanding the limitations of using Standard Industry Classification (SIC) codes the researcher of this study investigated all 15,000 manufacturing organisations through their company websites in order to determine if they were involved in the automotive industry. In summary, in order to formulate a generalisable sample of firms operating within the West Midlands automotive industry, not only did this study include firms listed and coded under the SIC code *manufacture of motor vehicles,* but incorporated automotive suppliers who may not have typically been classified within this category.

Table 4.4.1 indicates the number of actual firms that were identified as being involved within the automotive industry across a range of different manufacturing industries. In total, 1,710 firms were identified as operating within the West Midlands manufacturing sector, producing products for the automotive industry. Analysing table 4.4.1 it is clear that the initial population of firms belonged to a range of different industries, which in turn belonged to different clusters within the original population. This study then sought to determine a viable sample size. Due to time constraints and resource limitations, this study decided that a viable sample size would consist of approximately one quarter (25%) of the original population. In order to conduct regression analysis approximately 100 responses were required, and considering the piloting stage acquired a response rate of 22% in order to obtain approximately 100 reposes at such a response rate, 450 firms would need to be contacted.

Table 4.4.1: Manufacturing Classification Response Rate

Manufacturing Classification (SIC Code)	Number of identified firms	Number of contacted firms		Number of surveys returned	Response Rate
29. Manufacture of motor vehicles, trailers and semi-trailers	446	115	25.8%	41	36%
15. Manufacture of leather and related products	16	6	37.5%	3	50%
19. Manufacture of coke & refined petroleum products	18	5	27.7%	2	40%
22. Manufacture of rubber & plastic products	276	75	27.1%	22	29%
23. Manufacture of other non-metallic mineral products	35	10	28.6%	3	30%
24. Manufacture of basic metals	104	30	28.8%	12	40%
25. Manufacture of fabricated metal products, except machinery	265	70	26.4%	20	29%
27. Manufacture of electrical equipment	151	44	29.1%	16	36%
26. Manufacture of computer, electronic & optical products	48	15	31.3%	3	20%
32. Other Manufacturing	302	80	26.5%	18	23%
Total	1710	450	26.3%	140	31%

As there were apparent differences between the numbers of firms within each industry operating within the automotive industry, it was deemed appropriate to use proportionate random sampling. Therefore, rather than randomly contacting 450 firms from the original population as the sample, in order to obtain results which were representative of the automotive manufacturing industry as a whole, this study contacted approximately 25% of firms within each of the identified manufacturing industries. All firms within each of the industries was coded with a number. Next, a computer programme was used to generate random numbers until 25% of firms within each industry had been selected.

In summary, the sampling methodology process consisted of using elements of both cluster sampling and proportionate random sampling, as firms were catgeorised based upon their manufacturing classification (SIC) first, and randomly but proportionally contacted depending on the size of each manufacturing group via emails and the use of LinkedIn, however it is important to stress that LinkedIn was only used as a source of communication once the sampling stage had passed. Furthermore, Managing Directors and Operations Directors were contacted only, given that the survey consisted of providing sensitive information which required their consent.

In total, 450 out of the possible 1,710 organisations were contacted to ask for their participation in this study, having been randomly selected from each of their respective manufacturing groups. Of the 450 firms, 140 organisations agreed to take part and returned the surveys accordingly, revealing an overall response rate of 31%. The response rate within each manufacturing group classification ranged from 20% (*Manufacture of computer, electronic & optical products)* to 50% (*Manufacture of leather and related products*). It could be considered that these proportions vary quite extensively, however it is vital to note that this was more evident from response groups which consisted of a smaller number of firms. Taking a closer look, Table 4.4.1 reveals that most manufacturing groups acquired a response rate similar to the mean response rate of 31%.

4.4.2 Non-Respondent Bias

In order to test to detmine if non-repondent bias may have jeopardised the results, this investgation involved the use of a similar method to Armstrong and Overton's (1977) technique. Full information concerning both the method and results can be found in section 5.1.2.

4.4.3 Piloting Stage

This research incorporated a piloting stage in order to refine the constructed survey. Piloting can: a) enable researchers to preliminary test their proposed hypotheses, which in turn can lead them to develop, replace or delete a hypothesis for more concise results; b) Provide researchers with ideas and approaches which may not have initially been anticipated; c) Allow the researcher to thoroughly test the proposed analytical technique; d) Reduce potential problems by allowing the researcher to simply re-design certain sections of the survey prior to distribution (Saunders et al., 2009). As recommended by Gorard (2003), this research involved the use of a two-stage pre-testing process. Firstly, the initial survey was sent to appropriate academics within the field of OM as well as 10 Managing Directors (MDs) of manufacturing firms. This process entailed receiving general feedback concerning the design of the survey, whilst ensuring the questions could be operationalised. The piloting stage highlighted that slight modifications were required concerning the wording and format of questions, and more specifically the unit of analysis concerning certain items. Even though certain MDs were aware of certain TPRCs affiliated with lean and agile production, they were not sure of the exact names of these practices. With this in mind, a detailed glossary was provided which outlined the definitions of each of the TPRCs. Even though it was not appropriate to conduct regressions with this small sample, the piloting stage did assist the researcher in determining if the survey was going to be of use, as not only were patterns emerging in terms of TPRCs and manufacturing strategies, but performance differences were also becoming apparent. With slight modifications to the original version, the survey was distributed to the selected 450 organisations. The final survey can be found within the appendices.

4.5 Development of Survey

Before discussing the choice of analysis, it is important to discuss the development of the survey as the choice of variables used can significantly impact the choice of analytical technique employed. The main aims of the survey were to: a) Record the contextual factors which may impact the results; b) Identify which manufacturing strategy (lean, agile, hybird) is being implemented to a greater extent. i.e. distinguish between lean, agile and hybrid manufacturing systems; and c) Factually capture cost, dependability, flexibility, quality and speed performance levels. With regards to identifying which firms were lean, agile or hybrid, this is not to say that firms are 100% implementing lean TPRCs or agile TPRCs or hybrid TPRCs, instead a scorecard was designed to illustrate which strategy was being implemented to a greater extent. More information concerning this process is provided in section 4.5.2.

4.5.1 Contextual Factors

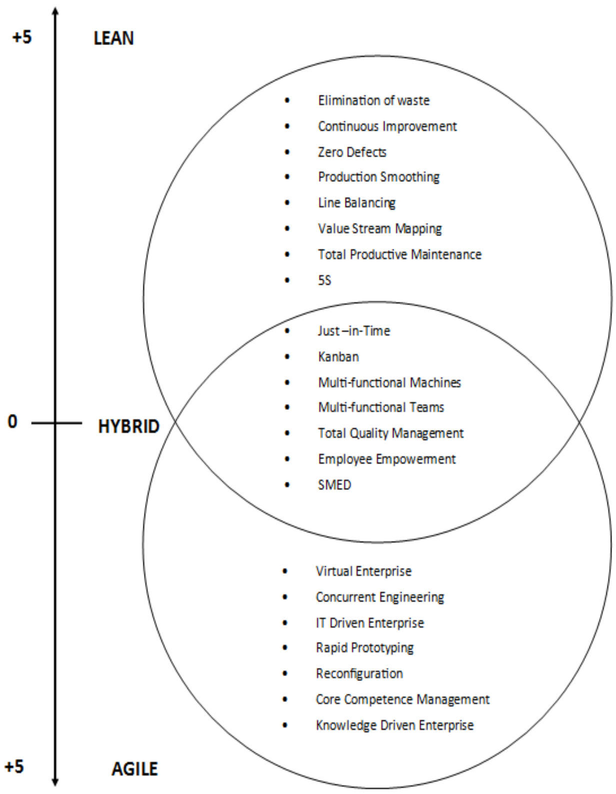
Before discussing the variables which contributed to the main aims of this investigation, it is important to stress that there are particular factors which may impact the validity of this study. Contextual factors such as age, size and product type (industry classification) and positional tier need to be considered, as the literature (Mason-Jones *et al.,* 2000; Bonavia and Marin, 2006; Bhasin, 2012; Sezen *et al*., 2012; Reves *et al*., 2015; Marodin *et al.,* 2016) has found them to impact the results of previous lean and agile studies. Each contextual factor may account for a certain degree of influence and implementation of manufacturing strategy, which eventually impacts performance. In order to increase the validity of this research, each contextual factor has to be recorded, controlled and analysed before any findings may be asserted. Furthermore, seasonal trends may have also been a factor that could have contributed to varying levels of performance. In order to overcome the issue of seasonal trends, the survey employed investigated lean, agile and performance questions over the whole of the 2014 financial year as this ensured any large fluctuations were averaged throughout the year.

4.5.2 Distinguishing Lean & Agile Firms

Multiple practices such as JIT, Kanbans, Multi-Functional Teams and Machines, TQM and SMED are associated with both lean and agile manufacturing practices, which leads to the question of how to distignuish lean and agile manufacturing firms. Firstly, in order to distiguish lean and agile manufacturing organisations, respondents were simply asked which manufacturing strategy was being used to a greater extent within their firm. However, to refine the analysis and test the validity of whether respondents were answering this question accurately, a scorecard was developed based on the findings presented in Chapter 2 (section 2.4), which suggested that there were 22 TPRCs related to lean and agile production (see Table 2.4.1). Each of these variables were measured on a Likert-Scale ranging from 1 (zero levels) to 5 (high levels), with 3 being moderate levels.

Building on Table 2.4.1, Figure 4.5.1 illustrates how the scorecard was used to distinguish lean and agile systems. Practices that have repeatedly been affiliated with lean manufacturing (Elimination of Waste, Continuous Improvement, 5S, Zero Defects, Production Smoothing, Line Balancing, Value Stream Mapping, Total Productive Maintenance, Cellular Manufacturing, Just-in-Time, Kanban, Multifunctional Teams/Machines, Total Quality Management; Employee Empowerment, SMED) are represented in the the lean circle and practices that have been repeatedly associated with agile manufacturing (Just-in-Time; Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment, Setup Reduction (SMED), Virtual Enterprise, Core Competence Management, Knowledge Driven Enterprise, Reconfiguration, Rapid Prototyping, Concurrent Engineering, IT Driven Enterprise) are represented in the agile circle. Furthermore, practices (Just-in-Time, Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment, SMED) associated with both manufacturing concepts are identified in the middle group of both circles and were labelled as 'hybrid'.

Figure 4.5.1: Distinguishing Lean and Agile Practices



The mean values from the Likert-Scale were caculated between each of these groups of TPRCs, and depending which mean group scored the highest, firms were distinguished as lean, agile or hybrid. For example, this can be shown by analysing Table 4.5.1. For instance, firms A, B and C scoring 3.8, 4.2 and 4.6 respectively amongst lean practices. As these averages were higher than hybrid and agile practices they were deemed as being lean. Firms D and E scored an average of 4.1 and 4.6 respectively amongst agile practices, and as these averages were higher than lean and hybrid practices they were deemed as being agile.

Table 4.5.1: Example of Distinguishing Process

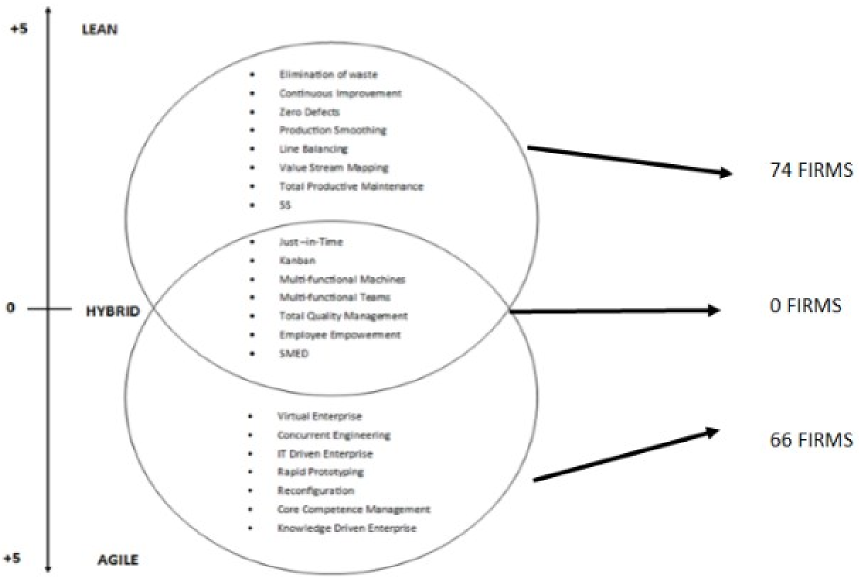
Firm	Lean Practices (mean score)	Hybrid Practices (mean score)	Agile Practices (mean score)
1	3.8	2.8	3.1
2	4.2	2.6	3.3
3	4.6	2.2	2.8
4	3.2	1.5	4.1
5	3.8	3.1	4.6

Krishnamurthy and Yauch (2007) proposed that there are three general postions occupied by lean and agile academics. Firstly, there is a group who consider lean and agile manufacturing concepts to be distinct from one another and are unable to co-exist with one another (Harrison, 1997). Secondly, those (McCullen and Towill, 2001; Naylor *et al*., 1999; Gunasekaran *et a*l., 2008) who take the view that lean and agile strategies can co-exist as they are mutually supportive of one another. Finally, there are those who see agile manufacturing as a strategy which has evolved from lean manufacturing where lean must have been the precursor (Hormozi, 2001). Importantly, the investigation of firms implementing a hybrid stratgey was excluded. More information concerning the exclusion of the hybrid manufacturing group is outlined below.

The scorecard was developed to distinguish lean agile and hybrid organisations. The rationale behind this is simple; firms implementing lean resources (TPRCs) to the greatest extent would lead to lean capabilities (performance), and firms implementing agile resources (TPRCs) to the greatest extent would lead to agile capabilities (performance). Finally, firms implementing 'hybrid' capabilities to the greatest extent, would lead to capabilities (performance) affiliated with both lean and agile production concepts.

Although the distinguishing approach used within this study can also imply that all firms are only partially lean, agile or hybrid, identifying firms as 'totally' implementing a production strategy such as lean or agile can be considered to be a dated approach (Bamford *et al*., 2015). In essence, depending on which collection of bundled TPRCs was being implemented to the greatest, firms were distinguished as lean, agile and 'hybrid'.

Figure 4.5.2: Lean & Agile Practices Employed by Organisations



Manufacturing Strategy	N
Lean	74
Agile	66

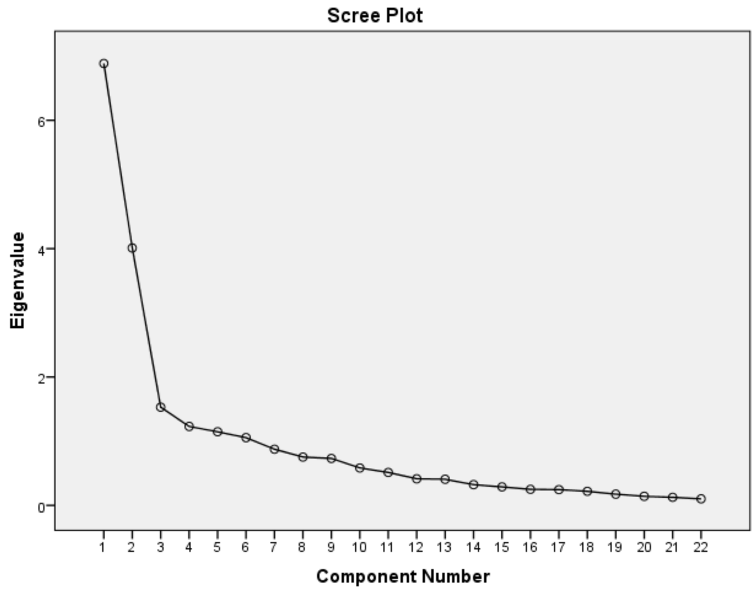
As mentioned previously, firstly, in order to distiguish lean, agile and hybrid manufacturing organisations, respondents were simply asked which manufacturing strategy was being used to a greater extent within their firm. The scorecard was then used to test whether or not initial responses to either being lean, agile or hybrid were in fact correct.

The scorecard revealed that a total of 74 organisations were implementing lean manufacturing systems and 66 organisations were implementing agile manufacturing systems, which was 96% consistent with initial responses. There are a group of academics (Sukwadi *et al*., 2013; Elmoselhy, 2013) who have suggested that both strategies can co-exist and support one another, this study takes the view that lean and agile firms can co-exist within a SC, thus, the SC process is considered to be ‘leagile’. However, organisations operating within the ‘leagile’ process can still be individually identified as being either lean or agile without involving the use of the term ‘hybrid’.

Furthermore, as the scorecard failed to identify firms implementing ‘hybrid’ TPRCs. In order to test the validity of using two factors (lean and agile) as opposed to three factors (lean, agile and hybrid), this study made use of confirmatory factor analysis (CFA). Kaiser (1960) suggested that the number of factors should depend on the number of factors with eigenvalues greater than one. Results from the CFA are highlighted below.

Figure 4.5.3 and Figure 4.5.4 illustrate the CFA screen plot concerning the eigenvalues when examining all TPRCs as well as just lean and agile TPRCs respectively. Although results from the CFA analysis in Figure 4.5.3 revealed that there were three factors (lean, agile and hybrid) which had eigenvalues greater than one, it is important to note that the third factor's (hybrid) eigenvalue was only marginally over the value of 1.

Figure 4.5.3: Eigenvalue Screen Plot of All TPRCs



Considering the two factor solution accounted for 69% of the variance, as opposed to 75% with the three factor solution, it was deemed appropriate to exclude the examination of a third factor. With the exclusion of 'hybrid' TPRCs, the eigenvalue for the third factor dramatically deceases; justifying the decisionto discontinue the analysis of 'hybird' firms. Furthermore, Table 4.5.2 outlines the factor loadings concerning each of the TPRCs affiliated with lean and agile production.

Figure 4.5.4: Eigenvalue Screen Plot of Lean and Agile TPRCs

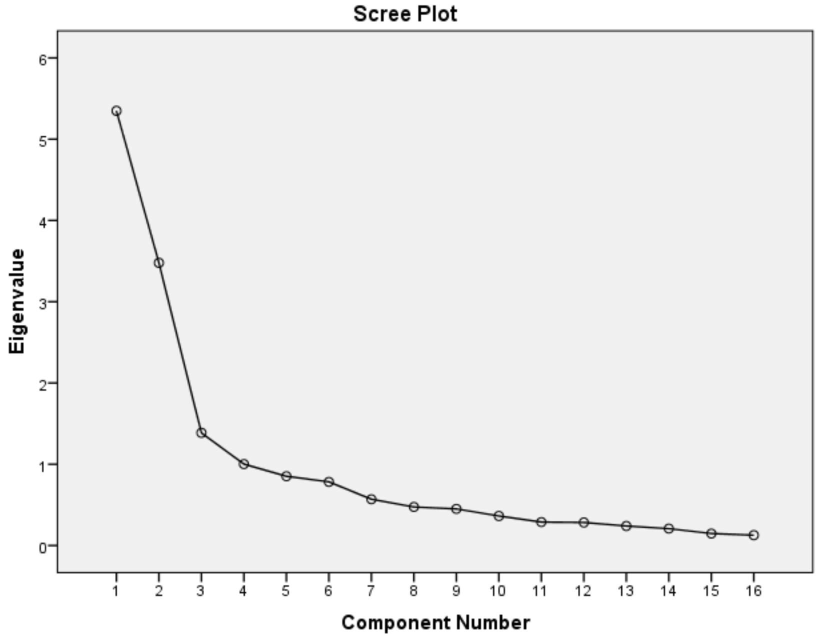


Table 4.5.2: Rotated 2 Factor Loading

	Component	
	1 (Agile)	2 (Lean)
Elimination of waste		.483
Continuous improvement		.778
Zero defects		.741
Production smoothing		.613
Line balancing		.526
Value stream mapping		.702
Total productive maintenance		.689
5S		.559
Cellular manufacturing		.590
Virtual enterprise	.765	
Concurrent engineering	.751	
IT driven enterprise	.863	
Rapid prototyping	.724	
Capability for reconfiguration	.803	
Core competence management	.829	
Knowledge driven enterprise	.783	

Extraction method: Principal component analysis (2 components extracted KMO .819)

As the technique by which lean and agile firms were distinguished involved a scorecard consisting of Likert-scale questions, it is important to test the reliability of these constructs.

For instance, Hair *et al*. (1998, p.118) stated that "*any summated scale should be analysed for reliability to ensure its appropriateness before proceeding to an assessment of its validity"*. With this in mind, this investigation involved the use of Cronbach's alpha when testing the internal consistency reliability amongst the degree to which each of the TPRCs were implemented within organisations, and which in turn was used to distinguish lean and agile manufacturing systems. Cronbach's alpha is widely used in the social sciences when determining levels of inter-reliability amongst a range of items. Cronbach's alpha ranges from 0 to 1.0; however, Vogt (1999) suggested that values greater than 0.70 actually suggest that the sub-items are measuring the same construct.

Table 4.5.3: Testing the Reliability of TPRCs Associated with Lean and Agile Production

Manufacturing Strategy	Number of Items	Cronbach's Alpha
Lean	15	0.72
Lean excluding hybrid TPRCs	8	0.82
Hybrid	7	0.73
Agile	13	0.70
Agile excluding hybrid TPRCs	7	0.92

Table 4.5.3 demonstrates that all of the TPRCs that are ascribed with lean production acquired a Cronbach's alpha score of 0.72; however, with the exclusion of TPRCs associated with both lean and agile production, the Cronbach's alpha score increased to 0.82. The TPRCs associated with agile production acquired a Cronbach's alpha score of 0.70, and with the exclusion of TPRCs affiliated with lean production, this Cronbach's alpha score increased to 0.92. Even though the Cronbach's alpha score for the hybrid strategy was also above the threshold criteria, this was only marginally above the threshold. Furthermore, as no firm scored highest within the hybrid strategy and considering that CFA analysis found that lean and agile TPRCs accounted for 69% of the variance, as opposed to 75% for three factors (lean, agile, hybrid) once again it was not deemed necessary for the inclusion of the hybrid

strategy. As both lean and agile manufacturing TPRCs scored well above the 0.70 threshold, it is viable to assert that the named TPRCs were internally consistent and reliable.

In summary there are four fundamental reasons why hybrid was not included: a) no firm suggested that they were most strongly implementing a hybrid strategy: b) no firm scored highest within the hybrid bundled TPRCs; c) CFA analysis found that lean and agile TPRCs (two factors) accounted for 69% of the variance, as opposed to 75% for three factors (lean, agile, hybrid), therefore it was not deemed necessary to include a third factor for just 6% more explanation in the variance; d) With the exclusion of hybrid TPRCs both lean and agile TPRCs scored well above the 0.70 threshold, whereas the hybrid group of TPRCs was only marginally above the threshold criteria.

4.5.3 Performance

As mentioned in Chapter 3, a key assertion within OM concerns the relationship between manufacturing practice and performance (Slack, 1994). Even though the literature from Table 3.3.1 and Table 3.4.1 concerning lean and agile firms individually shows that they have been associated with improving business performance, building on Skinner's (1969) assertion, it is necessary to consider a range of performance dimensions in order to determine the trade-offs between the two concepts.

Slack *et al*. (2010, p.606) asserted that "*performance measurement is the process of quantifying action, where measurement means the process of quantification and the performance of the operations is assumed to derive from actions taken by its management*", and went on to state that performance is defined as the degree to which an operation fulfils the five performance objectives: quality, dependability, speed, flexibility and cost. It would be inadequate to involve the use of a single performance measure when assessing performance, as the performance strengths of an organisation or manufacturing strategy may lie in different domains. Using a broad range of performance variables will ultimately increase the rigour of results therefore each of these performance measures are further broken down into multiple smaller measures, which will be discussed in turn.

Cost

Costs are a fundamental factor concerning the commercial competitiveness of an organisation as it can enable firms to survive in the market environment. Organisations that are competing directly on price alone will heavily monitor costs as they are almost synonymous with the firm's major operational objectives. The following table outlines the sub-variables that used in this research to account for the cost variable.

Table 4.5.4: Operationalisation of Cost

Cost Items	Unit	Description	Source
Sales	(£)	Total revenue	Beamon (1999)
Profit	(£)	Total sales minus any expenses.	Pohlen and Coleman (2005); Swafford *et al.* (2008); Carvalho *et al*. (2012).
Manufacturing cost	(£)	Total costs of manufacturing (labour, maintenance, re-works).	Goldsby *et al*. (2006); Cai *et al*. (2009); Carvalho *et al*. (2012).
Inventory cost	(£)	Total costs associated with held inventory.	Goldsby *et al*. (2006); Cai *et al*. (2009); Martin and Patterson (2009); Carvalho *et al*. (2012).
Distribution cost	(£)	Total costs of distribution (handling, transportation).	Goldsby *et al*. (2006)

In total, five measures (sales, profit, manufacturing cost, inventory, distribution) were operationalised to assess the cost performance of organisations. Of these, sales and profit are asserted as financial measures of performance, whereas the remaining measures are concerned with the operations of the manufacturing plant itself. Importantly, profit margin, manufacturing cost, inventory cost and distribution cost were later converted into percentages relative to total sales, in order to minimise the variances between small and large firms, whilst simultaneously allowing for direct comparisons to be made. In essence, the higher the profit margin the greater the performance, and the lower manufacturing cost (%), inventory cost (%) and distribution costs (%) relative to total sales, firms were deemed as being the more cost effective. This will be explained in further detail in Chapter 6.

Dependability

Dependability revolves around the philosophy of providing a service in time for customers when they are required or needed (Slack *et al*., 2010). The dependability of an operation can only be judged after the operation has been carried out and where the product has reached the end customer. At first, dependability may not effect customers, however, as time progresses, if an organisation gains a reputation of negative dependability, it can override all other criteria. Dependability can be measured by examining how reliable an organisation is when delivering a product. Firms with high internal dependability are considered most effective as this can help to save time and money, and enforce stability within their organisation (Slack *et al*., 2010). In order to obtain a well-rounded grasp of dependability as a performance measure, this research operationalised dependability into four constructs, namely: delivery reliability, lateness of orders, wrong deliveries and stock levels, which are detailed in the table below.

Table 4.5.5: Operationalisation of Dependability

Dependability Items	Unit	Description	Source
Delivery reliability	%	Percentage of late orders in the year	Hallgren and Olhager (2009); Soni and Kodali (2009); Carvalho *et al.* (2012).
Lateness of orders	Time (days/hours)	Average elapsed time between order expected and received by customers	Beamon (1999); Lodding *et al*. (2014).
Wrong deliveries	%	Percentage of wrong deliveries made in the year	Damme & Amstel (1996); Zschorn *et al.* (2004)
Stock	%	Average percentage of products in stock ready to distribute stock in relation orders	Sheffi and Rice (2005); Golsby *et al*. (2006); Carvalho *et al.* (2012).

Soni and Kodali (2009) asserted that dependability can be operationalised by assessing the number/percentage of orders which were sent out late by the respective firm (delivery reliability). However, this investigation also acknowledges that an order one day late is not as an order 10 days late, therefore, this study also looked into the duration in which goods were sent out late. After the piloting stage, surprisingly, many respondents stated that it would be useful to examine the number/percentage of wrong deliveries made by organisations, as this was actually more frequent than may be imagined. Many (Sheffi and Rice, 2005; Golsby *et al*., 2006) have contended the notion that firms holding low levels of stock will ultimately be more efficient, which will in turn impact upon their performance as this stock can prevent orders from being late. With this in mind, this study asked organisations to state the average percentage of stock which was readily available to distribute in relation with total orders.

Quality

Slack *et al*. (2010, p.40) stated that "*quality is consistent conformance to customers' expectations*". In essence, quality concerns doing things the right way, however this may vary in accordance with the type of operation being conducted. As quality is observed to be something that is extremely transparent, it is proposed that the majority of firms will hold quality as an important factor. This transparency of quality is reflected by customers, as they will find it relatively easy to make judgements about the quality of a firm's products. In turn, quality becomes a key factor relating to customer satisfaction and dissatisfaction rates. It is essential to analyse customer satisfaction rates as organisations can use them as indicators to determine whether or not customers are likely to buy from them again. Furthermore, it has been suggested that high quality levels within an organisation can lead to lower costs and an increase in dependability levels. In order to operationalise quality as a performance measure, a range of sub-items were used, which are reported in the table below.

Table 4.5.6: Operationalisation of Quality

Quality Items	Unit	Operationalisation	
Defects	%	Percentage of defects in relation to total output	Wang *et al*. (2004); Kumar *et al*. (2006); Carvalho *et al*. (2012
Customer complaints	%	Percentage of customer complaints in relation to customer orders	Cai *et al*. (2009); Soni and Kodali (2009); Carvalho *et al*. (2012).
Warranty claims	%	Percentage of warranty claims in relation to customer orders	Upadhye *et al*. (2010); Psomas *et al.* (2014).
Scrap levels	%	Percentage of scrap levels in relation to total output	Biswas and Sarker (2008)

Quality can be assessed by looking at what happens on the factory floor or by researching customer service levels. Multiple authors (Wang *et al*., 2004; Kumar *et al*., 2006; Carvalho *et al*., 2012) have advocated that the percentage of defects is a way of assessing quality levels. Even though products may be considered as defects, if they are only considered defective to a minor degree they may still be salvageable. However, if these defective products are scrapped, it can be argued the level of defects is considerably high. Therefore, this investigation asked firms to state the average percentage of products that were scrapped having been considered defective. Customer satisfaction rates can also provide an interesting insight, as they can be used as indicators of whether or not customers are likely to buy from a firm again (Cai *et al*., 2009; Soni and Kodali, 2009). This study therefore incorporated the measurement of quality levels by asking organisations to state the percentage of customer complaints and warranty claims.

Speed

In terms of performance, speed refers to the elapsed time between customers making and receiving their order (Slack *et al*., 2010). The quicker an organisation performs its operation, the quicker the customers receive their orders, in turn increasing the likelihood of them placing another order. Authors have asserted that speed can reduce costs within an organisation, as efficient and fast operations ultimately lead to reduced handling time of materials, which may inevitably reduce inventory costs. Speed can also reduce risk, e.g. forecasting for the short-term is far less risky than forecasting for the long-term. If an organisation possesses the ability to conduct operations quickly, they are regarded as moreable to accommodate any sudden changes in the market environment. The following table illustrates the sub-variables which used within the survey in order to determine speed as a performance measure.

Table 4.5.7: Operationalisation of Speed

Speed Items	Unit	Operationalisation	Source:
Order-lead time	Time (days/hours)	Average elapsed time between receiving an order and customer receiving product	Naylor *et al*. (1999); Cai *et al*. (2009); Carvalho *et al.* (2012).
Frequency of deliveries	Number	Average number of deliveries per month.	Goldsby *et al*. (2006)
Delivery speed	Time (days/hours)	Average elapsed time during distribution.	Hallgren and Olhager (2009); Soni and Kondali (2009); Amas *et al*. (2013).
Manufacturi ng speed	Time (days/hours)	Average elapsed time during manufacturing process.	Goldsby *et al*. (2006)
Customer service	Time (days/hours)	Average elapsed time between a customer query and response made.	Wheeler (2013)

As highlighted in Table 4.5.5, literature (Naylor *et al*., 1999; Cai *et al*., 2009) reveals that the performance measure of speed can be assessed based upon the time elapsed between customers making an order and receiving the product (order-lead time). However, in order to determine which factors contribute to high or low speed performance levels, it is vital to include the assessment of different operational stages which comprise the total order-lead time. With this in mind, this research incorporated four additional sub-items within the construct of speed, namely: frequency of deliveries, delivery speed, manufacturing speed and customer service speed. Investigating these will determine where speed strengths and weaknesses may lie within an organisation.

Flexibility

Flexibility concerns the ability of organisations to adjust or change their operation in some way. These changes may involve the following: what the operations does, how long it takes for the completion of a task and when the operation occurs (Slack *et al*., 2010). Flexibility can be categorised into two groups: Internal Flexibility (IF) and External Flexibility (EF) (Oke, 2005), however, Stevenson and Spring (2007) as well as Purvis *et al.* (2014) have also emphasised the importance of a third category, Supply Chain Flexibility (SCF). IF refers to flexibility that can occur within systems, EF refers to flexibility that can be observed by external customers and SCF refers to the ability of a firm to reconfigure the SC. This study does not examine IF levels, as lean and agile were distinguished involving the use of a collection of bundled practices (see Figure 4.5.1) which in turn serve as a mode of evaluating levels of IF within organisations. Rather, this study is interested in the effects of these practices (internal processes) on EF and SCF levels. Involving multiple dimensions of flexibility increases the validity and rigor of results with regard to this performance measure.

Literature within the broad realms of manufacturing flexibility has rarely operationalised flexibility constructs (Gerwin, 1993), and has rarely been explored within lean, agile and flexibility literature. The aim of this investigation was not to present an exhaustive list of flexibility measures, but rather to investigate those key flexibility measures which have repeatedly been associated with lean and agile literature. When deciding which dimensions of EF to investigate, this research built upon Gerwin's (1993) seven dimensions of flexibility, namely; volume flexibility, materials flexibility, mix flexibility, modification flexibility, changeover flexibility, rerouting flexibility, and flexibility responsiveness. D'Souza and Williams (2000) narrowed down these categories into four groups: (1) volume flexibility; (2) variety flexibility; (3) process flexibility; (4) materials handling flexibility, where (1) and (2) belong within EF and (3) and (4) are part of IF. Previous studies have also advocated that delivery can also be used to differentiate between lean and agile systems (Cagliano *et al.,* 2004; Hallgren and Olhager, 2009). It is also important to mention that each dimension of flexibility comprises of range and mobility. Therefore, three groupings (volume, variety, delivery) are categorised within EF, whereas the range and mobility of delivery flexibility are captured within SCF and EF respectively. In terms of SCF, the lean and agile literature has focused significantly on supplier flexibility (Purvis *et al.*, 2014), with some researchers advocating logistic flexibility, which can be argued as the range of delivery flexibility. In terms of supplier flexibility, supplier base flexibility was classified as the range for this measure and both sourcing flexibility and supplier offering flexibility were suggested as the mobility of supplier flexibility. As flexibility has only been previously explored to a limited depth, the following section provides a detailed description into the way in which flexibility levels were captured.

Table 4.5.8: Operationalisation of Flexibility

EF/ SCF	Flexibility	Range	Mobility	Operationalisation	Source
EF	Volume	**Volume flexibility**	-	Range in volumes in which firm can be profitable.	Sethi and Sethi (1990); Beamon (1999); Carter (1986); Mishra *et al.* (2017).
			Volume flexibility cost	Cost of doubling the output of the system	
	Variety	**Mix flexibility**	-	Number of unique products.	Gerwin (1987)
		-	**New product flexibility**	Time required to introduce new products	Sethi and Sethi (1990); Beamon (1999); Cai *et al.* (2009); Mishra *et al.* (2017).
	Delivery	See Logistic Flexibility	**-**	-	-
			Delivery flexibility	Time in which delivery can be reduced.	Beamon (1999); Gosling *et al.* (2010); Mishra *et al.* (2017).
SCF	Supplier	**Supplier base flexibility**	-	Number of alternative suppliers that are readily available.	Gosain *et al.* (2004); Sheffi and Rice (2005); Carvalho *et al.* (2012) ; Mishra *et al.* (2017).
		-	**Sourcing flexibility**	Time required when sourcing alternative suppliers.	Sánchez and Pérez (2005); Carvalho *et al.* (2012); Mishra *et al.* (2017).
		-	**Supplier offering flexibility**	Change in output suppliers are able to accommodate.	Gosain *et al.*, 2004; Stevenson and Spring, 2007.
	Delivery	**Logistic flexibility**		Number of logistic organisations readily available when delivering products.	Cai *et al*. (2009); Gosling *et al.*, 2010; Mishra *et al.* (2017).
		-	See Delivery Speed Flexibility		

Volume Flexibility Demand (F_v)

Volume flexibility concerning demand is commonly associated with the range of volumes in which a firm is profitable over a given time period (Sethi and Sethi, 1990). Data was collected which measured the highest (D_{max}) and lowest (D_{min}) volume of goods ordered (demanded) in each respective month over a 12-month period. The total volume of goods produced (D_T) in the 12-month period was also documented, which when divided by 12 represented the average volume of goods demanded (D_A) each month (1). The standard deviation was then calculated which illustrated the standard deviation of orders each month from the mean. However, as standard deviations varied quite sharply between each firm, the coefficient of variance (CV) was used when making comparisons (2).

(1) $D_T / 12 = D_A$
(2) $CV = SD / D_A$
(3) $F_v = CV (t)$

The CV generally ranges from 0 to 1 and measures the uniformity of the data. The greater the uniformity of the data, the closer the CV will be to the value of 0. In contrast, the closer CV is to 1 or greater than 1, the greater the flexibility (dispersion) of demand. In summary, in order to calculate volume flexibility demand, the survey asked the following questions:

- Total demand volume for the last financial year
- Lowest volume of goods ordered in a month corresponding to the last financial year
- Highest volume of goods ordered in a month corresponding to the last financial year

Volume Flexibility Cost (F_{vc})

Carter (1986) suggested that in order to measure the mobility of volume flexibility one must observe the total costs required when doubling the output volume. Therefore, respondents were asked to state the average percentage of total costs saved when doubling the volume of goods produced within the respective year.

(4) $F_{vc} = \Delta\%$ cost savings when doubling volume output.

Product Mix Flexibility (F_m)

The range concerning variety flexibility can be measured by product mix flexibility, which identifies the range of individual product types that can be manufactured over a certain period of time (Slack, 1991).

(5) $F_m = N(t)$

This study decided to measure product mix flexibility in terms of different products produced over a given time period, where N (t) represents the total number of different types of products that can be manufactured within the time period t (12 months). Therefore, mix flexibility represents the total number of different (unique) products produced over 12 months.

New Product Flexibility (F_n)

The mobility of variety flexibly can be measured by new product flexibility, which is defined as the ease with which a firm can introduce new products (Beamon, 1999). New product flexibility can either be assessed by the time required to produce a new product or the excess cost required to set up a new product (Sethi and Sethi, 1990). As speed and responsiveness have repeatedly been affiliated with differentiating between lean and agile, speed was used as the unit of measurement. This can be illustrated by examining equation (6), where F_n (new product flexibility) is simply equal to the time (T_n) required for the development of the new product.

(6) $F_n = T_n$ (t)

As flexibility is observed over one year, organisations were asked the average time spent (days) when introducing new products over a 12-month period.

Delivery Speed Flexibility (F_{ds})

Slack *et al*. (2010, p.46) define delivery flexibility as "*the operation's ability to change the timing of the delivery of its services or products*". Beamon (1999) also acknowledges that the ability to adjust planned delivery dates forward is an important factor regarding flexibility as it enables the organisation to accommodate special and urgent orders. Beamon (1999) expressed delivery flexibility as the percentage of slack time by which a certain delivery time can actually be reduced. The range in which delivery flexibility was measured was based upon the ability to change delivery dates (Gosling *et al.*, 2010). With this mind, delivery flexibility was measured as the total delivery time that can be reduced when an order is processed as urgent.

(7) $F_d = T_d$ (t)

Therefore, delivery flexibility (F_d) was measured by asking organisations to state the total average delivery time (days) that was reduced when orders were processed as urgent within the year under investigation.

Supplier Base Flexibility (F_{sb})

Tachizawa and Thomsen (2007) acknowledged that sourcing flexibility should heavily involve the use of a large supplier base in order to reconfigure the SC depending on demand. Arguably flexible sourcing will inevitably result in a firm acquiring a large supply base when re-structuring the SC, therefore, in order to measure the range of supplier flexibility respondents were asked to state the average number of alternative suppliers readily available.

(8) $F_{sb} = N_s (t)$

In essence, supplier base flexibility can be empirically captured by observing the total number of suppliers that are readily available to the respective firm. Therefore, N_s represents the total average number of different suppliers that were readily available in the SC in the annual time period (t).

Sourcing Flexibility (F_s)

The mobility of supplier flexibility can be measured using sourcing flexibility, which refers to the ease with which an organisation may change SC partners when accommodating changes within the business environment (Gosain *et al.,* 2004; Sánchez and Pérez, 2005). It has been argued that the sourcing of suppliers is undoubtedly linked with firms gaining a competitive advantage, as it can have large effects on flexibility and speed (Abdollahi *et al.*, 2015). With this in mind, sourcing flexibility can be measured by either recording the costs associated with switching suppliers or the time required when sourcing different suppliers. As time has previously been used as unit of analysis, time was also used when measuring new product flexibility, which is represented in equation (9).

(9) $F_s = T_s (t)$

Once again, as this study involved collecting information over an annual period, respondents were asked to state the average time (days) spent when sourcing new suppliers.

Supplier Offering Flexibility (F_o)

In order to measure the mobility of supplier flexibility, supplier offering flexibility, also known as offering flexibility (Gosain *et al.*, 2004), was also measured, which refers to the capability of a SC linkage to support changes in product in conjunction with current partners. However, as this study seeks to examine the offering flexibility suppliers can accommodate to the firm in question, this study labels this flexibility measure as supplier offering flexibility.

(10) $F_o = \Delta\%\ \text{output}\ (t)$

An individual organisation's flexibility may inevitably be restricted based upon its suppliers, therefore, in an attempt to capture supplier offering flexibility, this study asked respondents to state the total average percentage change in output (Δ%) suppliers were able to accommodate within 2014 (t).

Logistical Flexibility (F_l)

Finally, in order to investigate the range of delivery flexibility, the ability to change delivery dates, this study incorporated the use of measuring logistic flexibility. Logistic flexibility refers to the number of logistics organisations readily available when delivering products.

(11) $F_l = N_l\ (t)$

Logistic flexibility is captured in equation (11), where N_l represented the total average number of different distributors readily available within the annual time period (t).

In summary, the main objectives for the survey were to:

(1) Record the contextual factors which may impact the results.

(2) Identify which manufacturing strategy between lean, agility and hybrid is being implemented to a greater extent. i.e. distinguish lean and agile firms.

(3) Capture cost, dependability, flexibility, quality and speed performance levels in a 'more' objective manner in comparison with previous studies.

In addressing each of these aims the survey consisted of 5 items looking into contextual factors (manufacturing classification, size, age, positional tier, type of automotive product), 22 items assessing the degree of lean or agile implementation, and 27 items assessing levels of performance. Performance was measured via 5 constructs, namely: cost, dependability, flexibility, quality and speed, where each of these constructs consisted of 5, 4, 9, 4 and 5 items respectively.

4.6 Selection of Analysis

As the main aim of this thesis was to seek performance differences between each of the manufacturing concepts, and in order to obtain objective results which were reliable, there was a need to obtain numerical data. As the theoretical underpinning for this research was set upon the trade-off debated, multinomial logistic regressions were identified as the most suitable regression for analysing the collected data, which are advantageous as each test (model) can test the effects of one choice of manufacturing strategy when compared with the other. Multinomial logistic regressions are utilised when predicting the probability of categorical placement or category membership via maximum likelihood estimations concerning a dependent variable based upon multiple independent variables, where the independent variables can either be dichotomous (binary) or continuous (interval). Multinomial logistic regressions are simply an extended form of binary logistic regressions, which allow multiple categories to be placed within the dependent outcome. Logistic regressions need to consider the sample size and assessment of outliers, and more importantly multicollinearity. Schwab (2002) stated that in order for results to be accurate, logistic regressions require the data to be formatted in order that each independent variable consists of a minimum of 10 responses within each group. Logistic regressions often require researchers to use this technique for analysis, as this model does not assume normality, linearity or homoscedasticity. Even though it can be argued that logistic regressions have limited assumptions, they do entail the assumption of independence amongst the dependent variables (Hausman-McFadden, 1984). In addition, logistic regressions also involve the assumption related to non-perfect separation. For instance, if categorical groups are perfectly distinguished based upon their predictors, this will ultimately lead to the development of unrealistic estimated coefficients which in turn will produce exaggerated results.

In essence, logistic regressions are used to measure the relationship between the dependent variable, which is categorical in nature, and one or more independent variables. This is achieved by estimating the probability using a logistic function. The independent variable within this study is manufacturing strategy pursued, where firms will simply be coded as lean or agile. Even though the survey captured continuous empirical data concerning the independent variables (cost, dependability, flexibility, quality, speed), these were then categorized into binary variables of low (1), medium (2) and high (3). Categorizing continuous data may raise questions with regard to the accuracy of data actually captured, however, as each of the items within each of the five performance domains contain varying quantitative results, and in some cases varying units, categorization aids in making basic comparisons. Furthermore, categorizing each sub-variable means that a whole mean value for the performance measure in question could be assigned, which was then once again coded into binary values.

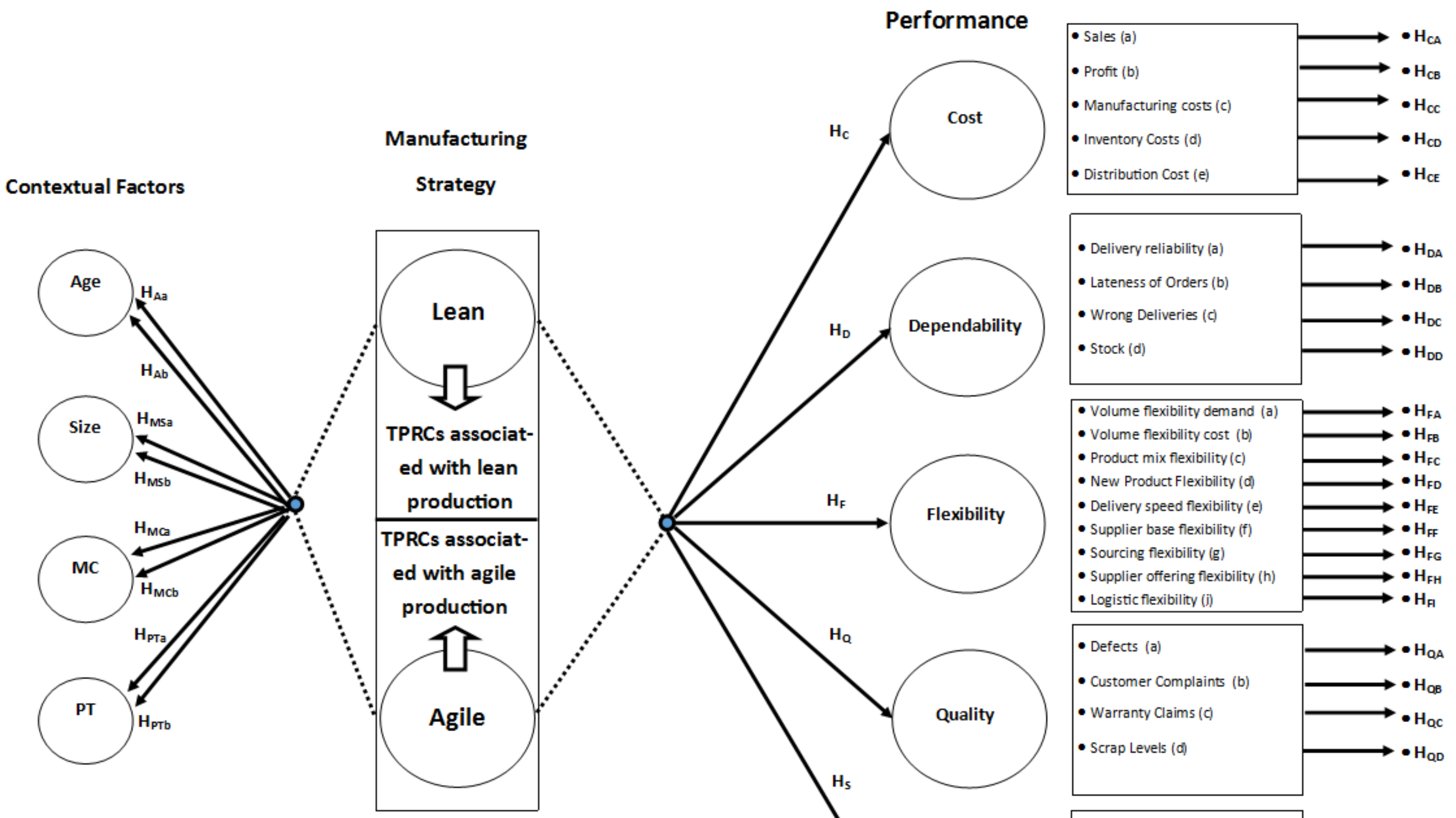
In summary, firms were distinguished as either being lean or agile based upon which practices were implemented to the greatest degree within each respective organisation. Therefore, the independent variable is the strategy pursued; as such firms will be either lean or agile. The independent variables consisted of five performances (cost, dependability, flexibility, quality, speed), and each of these variables in turn are comprised of multiple sub-variables, which are categorised into three groups: low, medium and high. The parameters by which each item is identified as being low, medium or high are outlined prior to each regression within the upcoming analysis chapters. Initially, multinomial logistic regressions were performed for each of the sub-variables, as conducting each regression individually enables the identification of trade-offs between lean and agile systems and each of the performance items. The mean was then calculated for each of the five performance constructs, with Table 4.6.1 illustrating how this was achieved. The example in this table illustrates an organisation as achieving mean scores of 2.0 (medium), 1.75 (medium), 2.0 (medium), 2.60 (high) and 1.33 (low) within cost, dependability, flexibility, quality and speed respectively. In addition, contextual factors such as age, size and product type were investigated to determine if they influence performance results. If contextual factors are observed to be impacting the results, they will be included within the regressions as controlled variables. However, if these contextual factors do not appear to influence the results, they will be discarded from the regressions. Greater detail concerning the choice of analysis and description of regression is provided within the analysis chapters. The conceptual framework from Chapter 3 is further developed in order to clearly portray how each of the regressions contributes to answering the main research question.

Table 4.6.1: Example of Mean Performance Calculation

Performance			LOW (1)	MED (2)	HIGH (3)	
Cost						
Sales	(£)	Total revenue	X			1
Profit	(£)	Total sales minus any expenses.		X		2
Manufacturing cost	(£)	Total costs of manufacturing (labour, maintenance, re-works).		X		2
Inventory cost	(£)	Total costs associated with held inventory.			X	3
Distribution cost	(£)	Total costs of distribution (handling, transportation).		X		2
Mean Cost Performance (Parameters: Low (1-1.74); Medium (1.75 – 2.49) High (2.49-3.00))				**X**		**2**
Dependability						
Delivery reliability	%	Percentage of late orders in the year		X		2
Lateness of orders	Time	Average elapsed time between order expected and received by customers	X			1
Wrong deliveries	%	Percentage of wrong deliveries made in the year		X		2
Stock	%	Average percentage of products in stock ready to distribute		X		2
Mean Dependability Performance (Parameters: Low (1-1.74); Medium (1.75 – 2.49) High (2.49-3.00))				**X**		**1.75**
Quality						
Defects	%	Percentage of defects in relation to total output		X		2
Customer complaints	%	Percentage of customer complaints in relation to customer orders		x		2
Warranty claims	%	Percentage of warranty claims in relation to customer orders	X			1
Scrap levels	%	Percentage of scrap levels in relation to total output	X			1
Mean Quality Performance (Parameters: Low (1-1.74); Medium (1.75 – 2.49) High (2.49-3.00))				X		2
Speed						
order-lead time	Time	Average elapsed time between receiving an order and customer receiving product		X		2
Frequency of deliveries	No.	Average Number of orders delivered per month.			X	3
Delivery speed	Time	Average elapsed distribution time		X		2
Manufacturing speed	Time	Average elapsed time spent on manufacturing only.			X	3
Customer service	Time	Average elapsed time between a customer query and response made.		X		3
Mean Speed Performance (Parameters: Low (1-1.74); Medium (1.75 – 2.49) High (2.49-3.00))					**X**	**2.6**
Flexibility						
Volume Flexibility Demand	CV	Range of volumes in which a firm is profitable over a given time period.	X			1
Volume Flexibility Cost	%	Total costs saved when doubling the output volume.	X			1
Product Mix Flexibility	No.	Number of unique products manufactured.	X			1
New Product Flexibility	Time	Time required to produce a new product.		X		2
Delivery Speed Flexibility	Time	The time in which delivery can be reduced.	X			1
Supplier Base Flexibility	No.	Number of suppliers readily available in order to reconfigure the supply chain.		X		2
Sourcing Flexibility	Time	ease with which an organisation may change SC partners when accommodating changes	X			1
Supplier Offering Flexibility	%	The percentage change in output suppliers were able to accommodate.	X			1
Logistic Flexibility	No.	Number of logistic organisations readily available when delivering products.		X		2
Mean Flexibility Performance (Parameters: Low (1-1.74); Medium (1.75 – 2.49) High (2.49-3.00))			**X**			**1.33**

4.7 Conceptual Framework & Hypotheses

Figure 4.7.1: Detailed Conceptual Framework



Note:

- Lean and Agile firms can be distinguished by TPRCs associated with each paradigm.
- Dotted lines represent 'lean firms in comparison with agile firms' or 'agile firms in comparison with lean firms.

As each of the constructs and items have been outlined, Figure 4.7.1 provides a detailed illustration of the conceptual framework used within this investigation. Multinomial logistic regressions were used to test each of the five constructs of performance, as well as each of the sub-variables within the five performance measures. In total 27 hypotheses are tested, where 5 belong to each of the five performance measures as a whole and 22 belong to each sub-performance item. Each of these hypotheses are listed below:

H_C: Lean firms are more likely to attain higher cost performance levels when compared with agile firms.

H_{Ca}: Lean firms are more likely to attain higher sales when compared with agile firms.

H_{Cb}: Lean firms are more likely to attain higher profit margins when compared with agile firms.

H_{Cc}: Lean firms are more likely to attain higher manufacturing cost efficiency levels when compared with agile firms.

H_{Cd}: Lean firms are more likely to attain higher inventory cost efficiency levels when compared with agile firms.

H_{Ce}: Lean firms are more likely to attain higher distribution cost efficiency levels when compared with agile firms.

H_D: Lean firms are more likely to attain higher dependability levels when compared with agile firms.

H_{Da}: Lean firms are more likely to attain higher order reliability levels when compared with agile firms.

H_{Db}: Lean firms are more likely to attain higher lateness of order dependability levels when compared with agile firms.

H_{Dc}: Lean firms are more likely to attain higher wrong deliveries dependability levels when compared with agile firms.

H_{Dd}: Lean firms are more likely to attain higher stock levels when compared with agile firms.

H_F: Agile firms are more likely to attain higher flexibility levels when compared with lean firms.

H_{Fa}: Agile firms are more likely to attain higher volume flexibility demand levels when compared with lean firms.

H_{Fb}: Agile firms are more likely to attain higher volume flexibility cost levels when compared with lean firms.

H_{Fc}: Agile firms are more likely to attain higher product mix flexibility levels when compared with lean firms.

H_{Fd}: Agile firms are more likely to attain higher new product flexibility levels when compared with lean firms.

H_{Fe}: Agile firms are more likely to attain higher delivery speed flexibility levels when compared with lean firms.

H_{Ff}: Agile firms are more likely to attain higher supplier base flexibility levels when compared with lean firms.

H_{Fg}: Agile firms are more likely to attain higher sourcing flexibility levels when compared with lean firms.

H_{Fh}: Agile firms are more likely to attain higher supplier offering flexibility levels when compared with lean firms.

H_{Fi}: Agile firms are more likely to attain higher logistic flexibility levels when compared with lean firms.

H_Q: Lean firms are likely to attain similar quality levels when compared with agile firms.

H_{Qa}: Lean firms are likely to attain similar defect levels when compared with agile firms.

H_{Qb}: Lean firms are likely to attain similar customer complaint levels when compared with agile firms.

H_{Qc}: Lean firms are likely to attain similar warranty claim levels when compared with agile firms.

H_{Qd}: Lean firms are likely to attain similar scrap levels when compared with agile firms.

H_S: Agile firms are more likely to attain higher speed levels when compared with lean firms.

H_{Sa}: Agile firms are more likely to attain higher order-lead time levels when compared with lean firms.

H_{Sb}: Agile firms are more likely to attain higher frequency of deliveries levels when compared with lean firms.

H_{Sc}: Agile firms are more likely to attain higher delivery speed levels when compared with lean firms.

H_{Sd}: Agile firms are more likely to attain higher manufacturing speed levels when compared with lean firms.

4.8 Conclusion

Multiple aspects of the research design and methods have been discussed within this chapter. First, this chapter recapped the research question and the reasons why the automotive industry was selected as the research focus. Second, using Saunders *et al*. (2009) 'research onion', a step-by-step guide outlined the strategy and methodology employed to tackle the main, over-arching research question. As this investigation is particularly interested in 'what' the performance outcomes of two manufacturing strategies are, a positivist philosophical stance and deductive approach was implemented. As quantitative research goes hand-in-hand with deductive research, and a constructed survey was used to collect data via cross-sectional gatherings. Third, as the automotive industry consists of a range of sub-manufacturing industries in itself, aspects of both cluster sampling and stratified random sampling were incorporated in order to obtain a generalizable sample. Fourth, the steps taken to determine if non-response bias played a part in impacting the validity of this study were outlined. Fifth, the process of developing of the survey instrument was described, which involves the use of a scorecard developed from literature; a section which clearly stated how lean and agile firms were initially distinguished. Following this, a detailed description demonstrated how each of the performance constructs and sub-items were captured. As flexibility has scarcely been explored, this chapter provided a thorough outline into the operationalisation of this performance measure. Sixth, the justification for using multinomial logistic regressions to analyse the data was discussed. Finally, this chapter outlined a detailed illustration of the conceptual framework, which incorporated all of the sub-performance items and hypotheses. With all of this in mind, the following three chapters' report on the results of the analysis. Chapter 5 determines if there are relationships between lean and agile firms in relation with contextual factors, Chapter 6 looks to explore the trade-offs in terms of cost, dependability, quality and speed, while Chapter 7 evaluates the flexibility trade-offs between each of the manufacturing approaches, with a particular focus on external flexibility and supply chain flexibility.

CHAPTER 5 – ANALYSIS: CONTEXTUAL FACTORS

The primary aim of this chapter is to investigate the contextual factors potentially affecting the firms taking part in this study, and in turn answer the RQ (a): *what are the trade-offs in contextual factors between lean and agile manufacturing?* For instance, firm size, manufacturing classification, type of products manufactured and organisational positional tier within the ASC will be discussed. With this in mind, this chapter is designed to determine whether or not the factors named above have a relationship with lean and agile manufacturing systems via the use of logistic regressions where appropriate. This chapter is formed of six sections. Initially, this chapter will report on the response rate and determine if non-respondent bias influenced the results. Second, third, fourth and fifth this chapter will investigate if firm age, manufacturing size, manufacturing classification and positional tier within the ASC were related with each of the manufacturing strategies respectively. Sixth, a summary of the results will be outlined with respect to the contextual hypotheses; thus, this chapter will pave the way in determining whether or not contextual factors needed to be controlled prior conducting each of the trade-off tests.

5.1 Overview

5.1.1 Response Rate

As mentioned in Chapter 4, 450 out of the population of 1,710 organisations were contacted asking for their participation in this research, having been randomly selected from each of their respective manufacturing groups. In total, 140 organisations agreed to take part in this study and returned the surveys accordingly, revealing an overall response rate of 31% (see section 5.4.1).

5.1.2 Non-Respondent Bias

Data was collected over a six-month period and was obtained for the 2014 calendar year, eliminating the influence of any seasonal economic trends. Initially, 42 organisations returned the survey within the first two months and a further 64 organisations returned the survey after receiving a reminder email during months 2-4. Finally, a further 34 firms returned the survey, having received a second reminder during months 4-6. Both of the latter groups may have been non-respondents if it were not for the follow-up reminder emails. In order to test for non-respondent bias, using Armstrong and Overton's (1977) technique, late respondents were considered as a surrogate for non-respondents. With this in mind, the first 30 surveys received were compared to the last 30 surveys received. T-Tests were conducted using firm size and sales, and results indicated that there were no significant differences between the responses. Therefore, organisations were deemed as representative of the West Midlands's automotive industry, suggesting no significant non-respondent bias.

5.2 Age

As age has previously been noted as a factor that can potentially impact the choice of manufacturing strategy (Osterman, 1984; Shah and Ward, 2003), this study looked to examine if there were apparent differences between lean and agile systems and firm age. Based on Shah and Ward's (2003) suggestions, firms were grouped into three age categories, namely: firms operating for less than 10 years; firms operating between 10 and 20 years; and firms operating over 20 years. For convenience, these age categories were coded as 'young', 'established' and 'mature' respectively. The proportion of lean and agile organisations with respect to these classifications are reported in Table 5.2.1.

Table 5.2.1: Lean and Agile Firms Based Upon Age

	Lean		**Agile**		**Total**	
	Number of firms	% of firms	Number of firms	% of firms	Number of firms	% of firms
0-10	11	15%	14	21%	25	18%
10-20	14	19%	17	26%	31	22%
20+	49	66%	35	53%	84	60%
Total	74	100%	66	100%	140	100%

Although both the lean and agile paradigms have varying proportion of firms within each of the three age categories, results from Table 5.2.1 suggest that there are similar trends between both concepts. For instance, both lean and agile manufacturing systems have an increasing proportion of firms operating at the older levels in comparison with the younger levels. However, Table 5.2.1 does not provide the grounds to suggest that the age of the firms is impacting upon the choice of manufacturing strategy employed. Regardless, in order to statistically test whether there was a significant relationship between firm age and manufacturing strategy, this study incorporated the use of multinomial logistic regressions. Lean and agile firms were assigned binary variables and the ages of organisations were categorised into three levels, namely: young; established; and mature. In summary, the independent variable was the choice of manufacturing strategy (lean/agile) and the dependent variables were related to firm age (young/established/mature). The models in Table 5.2.2 incorporated young firms as the reference category, whereas the models in Table 5.2.3 used mature firms as the reference category. In essence, results in Table 5.2.2 are in comparison with young firms and results in Table 5.2.3 are in comparison with mature firms.

Table 5.2.2: Firm Age Regression Results (a)

Model 1

Firm Size	L/A	B	Sig	Exp (B)
Established	L (1)	.047	.931	1.048
	A (0)	.	.	.
Mature	L (1)	.627	.173	1.872
	A (0)	.	.	.

Ref category is young & agile is base.

Model 2

Firm Size	L/A	B	Sig	Exp (B)
Established	A (1)	-.047	.931	.954
	L (0)	.	.	.
Mature	A (1)	-.627	.173	.534
	L (0)	.	.	.

Ref category is young & lean is base.

Results from model 1 in Table 5.2.2 identified the B coefficient as being positive for both established and mature organisations when agile (0) firms were used as the base point. Therefore, using the Exp (B) column, probabilities were calculated. For instance, lean firms in comparison to agile firms were (1.048-1=4.8) 4.8% more likely to be established relative to being young, and lean firms in comparison to agile firms were (1.872-1=.872) 87.2% more likely to be mature relative to being young. Results from model 2 in Table 5.2.2 illustrated the B coefficient as being negative for both established and mature categories when lean firms (0) were the base category. Therefore, agile firms in comparison with lean firms were (1-.931=.069) 6.9% less likely to be established relative to being young, and agile firms in comparison with lean firms were (1-.534-1=.466) 47% less likely to be mature relative to being young. Even though results go hand-in-hand with the notion that lean firms are more likely to be older in age when compared with agile organisations, as each of these results acquired P values above the threshold criteria of significance, hypothesis $\mathbf{H_{Aa}}$ was rejected.

REJECT- H_{Aa}. Lean firms are more likely to be older in age when compared with agile firms.

Table 5.2.3: Firm Age Regression Results (b)

Model 1

Firm Size	L/A	B	Sig	Exp (B)
Young	A (1)	.627	.173	1.872
	L (0)	.	.	.
Established	A (1)	.580	.171	1.786
	L(0)	.	.	.

Ref category is mature & lean is base.

Model 2

Firm Size	L/A	B	Sig	Exp (B)
Young	L (1)	-.627	.173	.534
	A (0)	.	.	.
Established	L (1)	-.580	.171	.560
	A (0)	.	.	.

Ref category is mature & agile is base.

Next, the regressions in Table 5.2.3 were conducted in order to determine if agile firms were more likely to be younger in age when compared with lean organisations. Results from model 1 in Table 5.2.3 identified the B coefficient as being positive for both young and established categories when lean (0) firms were used as the base reference. Therefore, using the Exp (B) results, probabilities were calculated. For instance, agile firms in comparison to lean firms were (1.872-1=.872) 87.2% more likely to be young relative to being mature, and agile firms in comparison to lean firms were (1-1.786=.786) 78.6% more likely to be established relative to being mature. Furthermore, when agile (0) firms were used as the baseline for comparison, results from model 2 in Table 5.2.3 suggested that lean firms in comparison with agile organisations were (1-.534=.466) 46.6% less likely to be established relative to being young, and (1-.560=.440) 44% less likely to be mature relative to being young. Once again, even though results suggested that agile systems are more likely to be younger in age when compared with lean systems, these statements were not of significance as the P value was greater than the threshold criteria, therefore hypothesis $\mathbf{H_{Ab}}$ was rejected.

REJECT - H_{Ab}. Agile firms are more likely to be younger in age when compared with lean firms.

5.3 Manufacturing Size

This study then looked to investigate if there were apparent differences between lean and agile systems and firm size. According to Bhasin (2012), larger organisations are more likely to adopt lean manufacturing practices across all of their activities in comparison with small organisations, explained by the fact that larger firms are more likely to benefit from standardisation and economies of scale by pursuing this strategy. However, this ultimately results in these organisations being rather rigid and resistant to change. On the other hand, Cohen and Klepper (1992) suggested that due to the nature of agile manufacturing, firms seeking to predominantly adopt this strategy are more likely to welcome change and would generally consist of smaller organisations. With this in mind, Table 5.3.1 illustrates the size of organisations in relation to whether they are adopting lean or agile practices.

Table 5.3.1: Lean and Agile Size of Organisations

	Lean		**Agile**		**Total**	
	Number of firms	% of firms	Number of firms	% of firms	Number of firms	% of firms
Small	27	37%	22	33%	49	35%
Medium	32	43%	34	52%	66	47%
Large	15	20%	10	15%	25	18%
Total	74	100%	66	100%	140	100%

Firms were distinguished as being either small, medium or large by using a technique previously deployed by Bhasin (2012). Organisations were categorised as small when employing equal to or less than 50 employees, medium when employing greater than 50 but equal to or less than 250 employees and as large when employing greater than 250 employees. A total of 49 (35%) organisations were identified as small, 66 (47%) firms were medium-sized, and 25 (18%) were large firms. Considering that the majority of manufacturing firms within the West Midlands region are SMEs, it is no surprise that over 80% of organisations involved in this study were classified as SMEs. Even though there are differences between the size of organisations and number of lean and agile firms, the percentages of small, medium and large firms are fairly similar between lean and agile systems. For example, 37% of lean firms were small and 33% of agile firms were small; 43% of lean firms were medium-sized and 52% of agile firms were medium-sized; and 20% of lean firms were identified as large firms and 15% of agile firms were large. Overall, results from Table 5.3.1 portray fairly consistent proportions between the size of the firm and manufacturing strategy employed. Even though there are a greater number of lean firms who were large in comparison with agile firms, there are also a larger number and proportion of firms who are small and lean in comparison with agile and small firms. In conclusion, a descriptive summary of the size of firms within Table 5.3.1 does not provide the grounds to suggest that the size of the firm is impacting upon whether firms choose to pursue a lean or agile strategy. However, in order to statistically test whether there was a significant relationship between firm size and manufacturing strategy, this study incorporated the use of multinomial logistic regressions. Lean and agile firms were assigned binary variables and the size of organisations were categorised into three levels, namely; small, medium, large. In summary, the independent variable was the choice of manufacturing strategy (lean/agile) and the dependent variables consisted of firm size (small/medium/large). The models in Table 5.3.2 incorporated small firms as the reference category, whereas the models in Table 5.3.3 used large firms as the reference category. In essence, results in Table 5.3.2 are in comparison with small firms and results in Table 5.3.3 are in comparison with large firms.

Table 5.3.2: Firm Size Regression Results (a)

Model 1

Firm Size	L/A	B	Sig	Exp (B)
Medium	A (1)	.265	.483	1.304
	L (0)	.	.	.
Large	A (1)	-.201	.688	.818
	L (0)	.	.	.

Ref category is small & lean is base.

Model 2

Firm Size	L/A	B	Sig	Exp (B)
Medium	L (1)	-.265	.483	.767
	A (0)	.	.	.
Large	L (1)	.201	.688	1.222
	A (0)	.	.	.

Ref category is small & agile is base.

Results from model 1 in Table 5.3.2 shows that the B coefficient is positive for medium and negative for large when lean (0) is the base category. Using the Exp (B) results, probabilities can also be calculated. With this in mind, agile firms in comparison to lean firms are (1.304-1=30%) 30% more likely to be medium-sized relative to being small, and agile firms in comparison to lean firms are (1-.818=18%) 18% less likely to be large relative to being small. Results from model 2 in Table 5.3.2 illustrate the B coefficient as being negative for medium-sized and positive for large when agile (0) is the base category. Therefore, lean firms in comparison to agile firms are (1-.767=23%) 23% less likely to be medium-sized relative to being small, and lean firms in comparison to agile firms are (1.222-1=22%) 22% more likely to be medium-sized relative to being small.

Table 5.3.3: Firm Size Regression Results (b)

Model 1

Firm Size	L/A	B	Sig	Exp (B)
Small	A (1)	.201	.688	1.222
	L (0)	.	.	.
Medium	A (1)	.466	.328	1.594
	L (0)	.	.	.

Ref category is large & lean is base.

Model 2

Firm Size	L/A	B	Sig	Exp (B)
Small	L (1)	-.201	.688	.818
	A (0)	.	.	.
Medium	L (1)	-.466	.328	.627
	A (0)	.	.	.

Ref category is large & agile is base.

Results from model 1 in Table 5.3.3 shows that the B coefficient is positive when lean (0) is the base category. Therefore, agile firms in comparison to lean firms are (1.222-1=22%) 22% more likely to be small relative to being large, and agile firms in comparison to lean firms are (1.594-1=59%) 59% more likely to be medium-sized relative to being large. Furthermore, results from model 2 in Table 5.3.3 illustrate the B coefficient as being negative when agile (0) is the base category. Therefore, lean firms in comparison to agile firms are (1-.818=18%) 18% less likely to be small relative to being large, and lean firms in comparison to agile firms are (1-.627=37%) 37% less likely to be medium-sized relative to being large.

Overall, results from both tables demonstrated a positive association between lean systems and large organisations, and a positive association between agile systems and small organisations. However, as the P values are not less than 0.05 in either of the regressions, these statements are not of significance. For this reason, generalisable conclusions cannot be made and both hypotheses, $\mathbf{H_{MSa}}$ and $\mathbf{H_{MSb}}$, were rejected.

REJECT - ***H_{MSa}. Lean firms are more likely to be smaller in size when compared with agile firms.***

REJECT - ***H_{MSb}. Agile firms are more likely to be smaller in size when compared with lean firms.***

5.4 Manufacturing Classification

Acknowledging that neither firm age nor firm size proved to be significantly related with either of the manufacturing approaches, the next step involved investigating manufacturing classification. Both Figure 5.4.1 and Table 5.4.1 illustrate the manufacturing classification relating to each of the 140 participating firms. In total, this study incorporated 10 manufacturing classification groups within the West Midlands automotive industry. Unsurprisingly, the manufacture of motor vehicles received the highest number of participants, totalling 41 organisations. The manufacture of rubber and plastic products and the manufacture of basic metals received the second and third largest number of participants, with 22 and 20 firms respectively. The smallest number of participants belonged to the manufacture of coke and refined petroleum products with only 2 participating organisations. The second smallest number of participating firms belonged to three classifications; the manufacture of leather and related products, the manufacture of other non-metallic mineral products and the manufacture of computer, electronic and optical products, all of which had 3 participating organisations.

Figure 5.4.1: Manufacturing Classification of Organisations

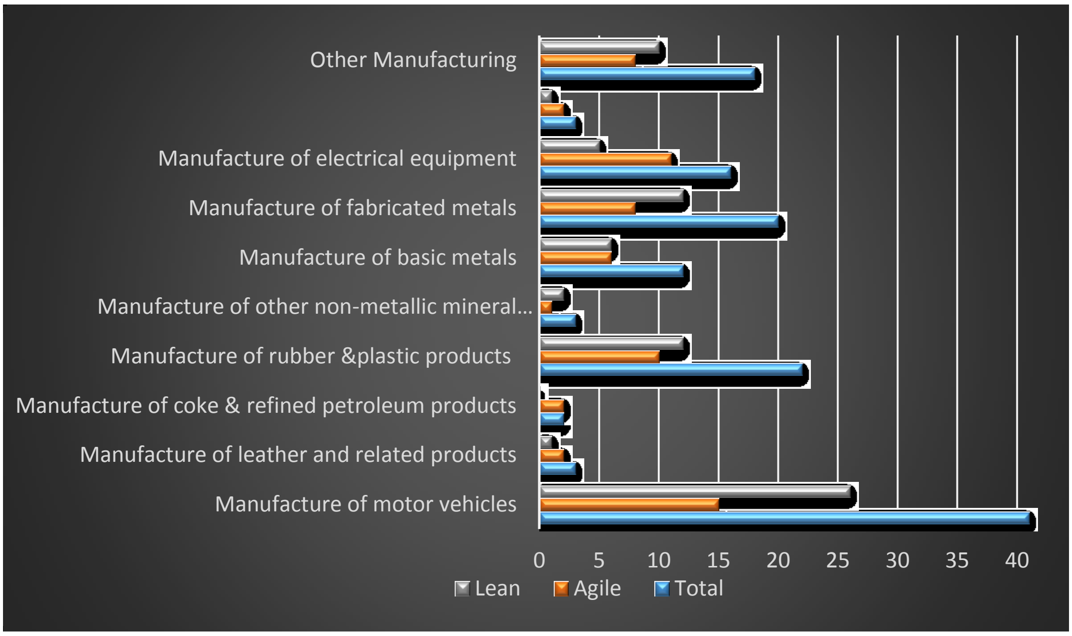


Table 5.4.1: Manufacturing Classification of Organisations

Manufacturing Classification	**Agile**		**Lean**		**Total**
Manufacture of motor vehicles	15	37%	26	63%	41
Manufacture of leather and related products	2	67%	1	33%	3
Manufacture of coke and refined petroleum products	2	100%	0	0%	2
Manufacture of rubber and plastic products	10	45%	12	55%	22
Manufacture of other non-metallic mineral products	1	33%	2	67%	3
Manufacture of basic metals	6	50%	6	50%	12
Manufacture of fabricated metals	8	40%	12	60%	20
Manufacture of electrical equipment	11	69%	5	31%	16
Manufacture of computer, electronic and optical products	2	67%	1	33%	3
Other Manufacturing	9	44%	10	66%	18
Total	66	47%	74	53%	140

Table 5.4.1 also highlights the percentage of lean and agile respondents within each manufacturing category, which could be used as a starting point to determine if each of the different manufacturing sub-categories is related with lean or agile production. The manufacture of leather and related products, manufacture of coke and refined petroleum products, manufacture of other non-metallic mineral products and the manufacture of computer, electronic and optical products all have large percentage differences between the proportion of firms that were lean or agile. However, the large proportional differences

in responses may be explained by the small number of respondents within each category, hence making it difficult to make assumptions with regard to whether or not firms are likely to be lean or agile within each of these sub-manufacturing categories. In contrast, firms who were classified under the manufacture of motor vehicles and the manufacture of electrical equipment also portray large percentage differences, but these categories have a relatively larger number of respondents which makes it more plausible to draw conclusions. For instance, the manufacture of motor vehicles acquired a total number of 41 respondents in which 15 firms (37%) were identified as agile and 26 (63%) firms as lean, and the manufacture of electrical equipment had a total number of 16 respondents, where 11 (69%) firms were identified as agile and 5 (31%) firms as lean. Taking this into account, these findings may suggest that manufacturing classifications may play a part and are likely to influence whether firms are pursuing a lean or agile strategy. On the other hand, the manufacture of rubber and plastic products, the manufacture of basic metals, the manufacture of fabricated metals and other manufacturing have a total number of respondents within each category of 22, 12, 20 and 18 respectively. Each of these industries acquired responses from a similar proportion of lean and agile firms suggesting that each of the manufacturing sub-categories does not draw clear differences in determining whether firms are likely to be lean or agile. Furthermore, in conjunction with Adam's (2011) *The Distribution of Innovation Activity Across UK Industry* report, organisations were classified as either low or high innovators depending on their manufacturing SIC code. For example, if a firm was identified as belonging to an industry that appeared on this report's list of innovative industries, then they were ranked as high innovators. On the other hand, if a firm belonged to an industry that did not be appear on this report then were categorised as operating in a low innovative industry. Table 5.4.2 and Table 5.4.3 report on the manufacturing industries classified as high or low innovators and the number and percentage of lean and agile firms identified as operating within these groups respectively.

Table 5.4.2: High and Low Innovative Manufacturing Industries

Manufacture of motor vehicles	*High*
Manufacture of leather and related products	*Low*
Manufacture of coke and refined petroleum products	*Low*
Manufacture of rubber and plastic products	*Low*
Manufacture of other non-metallic mineral products	*Low*
Manufacture of basic metals	*High*
Manufacture of fabricated metals	*High*
Manufacture of electrical equipment	*High*
Manufacture of computer, electronic and optical products	*High*
Other Manufacturing	*Low*

Table 5.4.3: Lean and Agile Firms Distinguished Based upon High/Low Levels of Innovation

	Lean		**Agile**		**Total**	
	Number of firms	% of firms	Number of firms	% of firms	Number of firms	% of firms
Low	25	34%	23	35%	49	35%
High	49	66%	43	65%	66	47%
Total	74	100%	66	100%	140	100%

Surprisingly, results from Table 5.4.3 suggest that a relatively even proportion of lean and agile manufacturing firms were operating within low and high innovative industries, and due to acquiring similar figures it was not necessary to conduct regression analysis as results would imply both industries are operating with similar levels of innovation.

In conclusion, even though there are clear disproportionalities in the number of lean and agile firms within selected sub-manufacturing categories, this was not the case for the majority of sub-manufacturing industries that acquired a relative large number of responses. Due to obtaining responses from 140 organisations across 10 sub-manufacturing categories, it was not viable to conduct multinomial logistic regressions or form any real conclusion which holds quantifiable relevance. However, it may be argued that overall, there seemed to be a fairly consistent proportion of firms following a lean (53%) and agile (47%) manufacturing strategy within the range of sub-manufacturing categories forming the ASC. For these reasons it was not possible to conduct regressions in order to test hypotheses $\mathbf{H_{MCa}}$ and $\mathbf{H_{MCa'}}$. Therefore, both hypotheses were rejected.

REJECT- $H_{MCa:}$ Lean firms are more likely to belong to low innovative industries when compared with agile firms.

REJECT- $H_{MCa:}$ Agile firms are more likely to belong to high innovative industries when compared with lean firms.

Even though Table 5.4.1 highlighted each of the sub-manufacturing classifications to which firms belonged, in order to provide more information concerning the type of product created for the automotive industry, this study further categorised firms into seven automotive product manufacturing categories, namely: vehicle, body/main part, electrical, interior, powertrain and chassis, miscellaneous auto parts, and other. In total, this study received results from 3 organisations producing the final vehicle, 23 firms producing products for the body or main part of the car, 13 firms producing electrical products, 16 firms producing goods relating to the interior of a car, 14 firms producing powertrain and chassis products and the remaining firms producing other and miscellaneous automotive products. Table 5.4.4 shows the type of automotive product produced in accordance with each of the manufacturing approaches.

Table 5.4.4: Lean and Agile Automotive Product Type Manufactured

	Lean		Agile		Total	
	Number of firms	% of firms	Number of firms	% of firms	Number of firms	% of firms
Vehicle	2	3%	1	1.5%	3	2%
Body/Main Part	14	18.5%	9	13.5%	23	17%
Electrical	5	7%	8	12%	13	9%
Interior	11	15%	5	8%	16	11%
Powertrain and Chassis	6	8%	8	12%	14	10%
Miscellaneous Auto Parts	22	30%	17	26%	39	28%
Other	14	18.5%	18	27%	32	23%
Total	74	100%	66	100%	140	100%

5.5 Positional Tier

The final contextual factor under investigation concerns positional tier, as it is useful to discuss each of the tiers to which firms belong within the ASC. Contextual factors such as firm age, firm size and manufacturing classification failed to illustrate substantial trends in relation with lean and agile manufacturing organisations. However, a quick look at Table 5.5.1, which reports on the number of lean and agile systems at varying levels of the ASC, suggests a relationship may be apparent in relation to positional tier.

Table 5.5.1: Lean and Agile Systems within the ASC

Positional Tier	Lean		Agile		Total	
	Number of firms	% of firms	Number of firms	% of firms	Number of firms	% of firms
OEM	12	16%	4	6%	16	11%
1ST	26	34.5%	10	15%	36	26%
2ND	17	23%	15	23%	32	23%
3RD	14	18.5%	19	29%	33	24%
4TH & 5th	6	8%	18	27%	23	16%
Total	74	100%	66	100%	140	100%

Observing Table 5.5.1, the columns on the far right illustrate the total number of lean and agile firms located with each tier within the ASC. Out of the possible 140 firms, 16 (11%) firms were Original Equipment Manufacturers (OEMs), 36 (26%) firms were 1st tier suppliers, 32 (23%) firms were 2nd tier suppliers, 33 (24%) firms were 3rd tier suppliers and 23 (16%) firms were 4th and 5th tier suppliers within the ASC. With the exception of OEMs and 4th & 5th tier suppliers, there seems to be a fairly consistent total number of firms who were 1st, 2nd and 3rd tier suppliers within the ASC. Interestingly, results from Table 5.5.1 suggest that the majority of lean organisations seem to be positioned at the higher (top) end of the ASC, as 16% and 34.5% of lean organisations are OEMs and 1st tier suppliers respectively, but further down the SC, the percentage of lean organisations decreases. On the contrary, results from Table 5.5.1 imply that the majority of agile manufacturing organisations appear to be positioned at the lower end of the ASC with 27% and 29% of agile organisations classified as 4th & 5th and 3rd tier automotive organisations respectively. Further up the SC there is a drop in the percentage of agile organisations, and only a cumulative 21% of agile organisations within this study were OEMs & 1st tier suppliers, which is significantly less than the cumulative 50.5% of lean organisations who were OEMs and 1st tier suppliers.

In order to statistically test if lean and agile firms are positioned at different levels of the SC, this study once again incorporated the use of multinomial logistic regressions. As previously, lean and agile firms were assigned binary variables and automotive tiers within the SC were categorised into three levels, namely; top, middle, bottom. The top of the SC consisted of OEMs and 1st tier suppliers, the middle of the SC consisted of 2nd tier suppliers, and the bottom of the SC consisted of 3rd, 4th and 5th tier suppliers. In summary, independent variable was the choice of manufacturing strategy (lean/agile) and the dependent variable consisted of ASC position (top/middle/bottom). The models in Table 5.5.2 incorporated the middle tier as the reference category, therefore are results in this table are relative to the mid-tiered organisations.

Table 5.5.2 – Positional Tier Regression Results (a)

Model 1

SC Position	L/A	B	Sig	Exp (B)
Top	A (1)	-1.025	.010	.359
	L (0)	.	.	.
Bottom	A (1)	1.003	.061	2.727
	L (0)	.	.	.

Ref category is middle & lean is base.

Model 2

SC Position	L/A	B	Sig	Exp (B)
Top	L (1)	1.025	.010	2.787
	A (0)	.	.	.
Bottom	L (1)	-1.003	.061	.367
	A (0)	.	.	.

Ref category is middle & agile is base.

Results from model 1 revealed that when taking lean (0) as the base category, the B coefficient was negative when observing the top of the SC and positive when observing the bottom of the SC. Once again, using the Exp (B) column, probabilities can be calculated. Therefore, agile firms in comparison to lean firms are (1-0.359=64%) 64% less likely to be positioned at the top of the SC relative to the middle of the SC, and agile firms in comparison to lean firms are (2.727-1= 173%) 173% more likely to be positioned at bottom of the SC relative to the middle of the SC. Results from model 2 show that when taking agile (0) as the base category, the B coefficient is positive when observing the top of the SC and negative when observing the bottom of the SC. Therefore, lean firms in comparison to agile firms are (2.787-1= 179%) 179% more likely to be positioned at the top of SC relative to the middle of the SC, and lean firms in comparison to agile firms are (1-0.367= 63%) 63% less likely to be positioned at the bottom of the SC relative to the middle of the SC. However, the P value was less than 0.05 for only two of these findings, therefore it is viable to state that lean firms are significantly more likely to be positioned at the top of the SC relative to the middle of the SC, and agile firms are significantly less likely to be positioned at the top of the SC. Even though results portray agile firms as more likely to be positioned at the bottom of the SC, as the P value (0.061) was slightly above 0.05 this cannot be reported as being of significance. In order to investigate whether lean and agile firms are distinguishable based upon the positional tier to which they belong in the SC, this study conducted two more regressions, where the reference category was changed to top of the SC and the results are reported in Table 5.5.3.

Table 5.5.3 – Positional Tier Regression Results (b)

Model 1 **Model 2**

SC Position	**L/A**	**B**	**Sig**	**Exp (B)**		**SC Position**	**L/A**	**B**	**Sig**	**Exp (B)**
Middle	A (1)	1.025	.010	2.787		Middle	L (1)	-1.025	.010	.359
	L (0)	.	.	.			A (0)	.	.	.
Bottom	A (1)	2.028	.000	7.600		Bottom	L (1)	-2.028	.000	.132
	L (0)	.	.	.			A (0)	.	.	.

Ref category is top & lean is base. Ref category is top & agile is base.

Results from model 1 revealed that when taking lean (0) as the base category, the B coefficient was positive for both middle and bottom categories. Therefore, agile firms in comparison to lean firms are (2.787-1=179%) 179% more likely to be positioned at the middle of the SC relative to the top of the SC, and agile firms in comparison to lean firms are (7.600-1=660%) 660% more likely to be positioned at the bottom of the SC relative to the top of the SC. Results from model 2, show that when taking agile as the base (0) category, the B coefficient was negative for both middle and bottom categories. Therefore, lean firms in comparison to agile firms are (1-0.359=64%) 64% less likely to be positioned at the middle of the SC relative to the top of the SC, and lean firms in comparison to agile firms are (1-0.132= 87%) 87% less likely to be positioned at the bottom of the SC relative to the top of the SC. Furthermore, the P value is less than 0.05 for all of these statements, therefore it is viable to state that lean firms are significantly less likely to be positioned at the middle and bottom of the SC relative to the top of the SC, and agile firms are significantly more likely to be positioned at the middle and bottom of the SC relative to the top of the SC. With these findings, both hypotheses $\boldsymbol{H_{PTa}}$ and $\boldsymbol{H_{PTb}}$ were rejected.

REJECT - H_{PTa}. Lean firms are more likely to be positioned at the lower tiers of a SC when compared with agile firms.

REJECT - H_{PTb}. Agile firms are more likely to be positioned at the top tiers of a SC when compared with lean systems.

5.6 Conclusion

In summary, the aim of this chapter was to determine if contextual factors were related to each of the manufacturing approaches, and in turn answer RQ (a): *what are the trade-offss in contextual factors between lean and agile manufacturing systems?*

Through the use of independent multinomial logistic regressions, this chapter found firm age and manufacturing size to be related with the pursuit of either a lean or agile strategy. Even though these two factors were discovered to be related with the choice in manufacturing strategy, findings were not significant; hence, these variables were not controlled further within the analysis chapters. Furthermore, due to the vast range of manufacturing classifications, it was not viable to conduct regression analysis. The most important finding within this chapter surrounds the discussion of where lean and agile manufacturing firms are located within the ASC. For instance, lean firms were significantly more likely to be operating at the top tiers of the ASC when compared with agile firms. On the contrary, agile firms were significantly more likely to be found operating within the lower levels of the ASC. Taking this into account, both hypotheses were rejected. Importantly, findings surrounding positional tier are in direct opposition with existing views concerning where lean and agile systems are located in a 'leagile' supply chain. Although this finding led to the rejection of the hypotheses conceptualised, importantly, there was a significant relationship between the choice in manufacturing strategy and positional tier within a SC. With this in mind, the upcoming analysis chapters take this into account by controlling for positional tier as a contextual factor within the subsequent regression analysis.

In conclusion, findings from this chapter suggested that when operating within a complex SC, lean firms are operating downstream from the decoupling point and agile firms are operating upstream from the decoupling point. Taking this and literature into account, it may be argued that firms competing on costs and efficiency levels are more likely to be located at the top of the SC. In contrast, firms competing on flexibility and speed measures are more likely to be located at the lower end of the SC. However, before advocating these assertions further, it is necessary to explore the performance strengths affiliated with each of the manufacturing approaches. With this in mind, Chapter 6 and Chapter 7 detail the differences between the two concepts in terms of performance outcomes.

CHAPTER 6 – ANALYSIS: LEAN & AGILE PERFORMANCE TRADE-OFFS

The focal point of this chapter is to provide statistical evidence concerning the performance trade-offs between lean and agile production. With this in mind, the breadth of this investigation was fairly large and due to the size and scope of analysis this chapter will be broken down into five sections, where cost, dependability, quality and speed will be analysed individually. The final section will conclude with a discussion concerning all findings from this chapter. As flexibility has been advocated as key distinguisher (Narasimhan *et al*., 2006; Purvis *et al*., 2014) of lean and agile firms, this dimension of performance will be explored separately in Chapter 7. Before reporting on the regression results, each subsequent section between 6.1 and 6.4 will provide a statistical descriptive overview concerning each performance level measured with regards to the mean, standard deviation and correlations amongst each of the items within each performance construct. In summary, the ultimate aim of this chapter is to answer RQ (b) *what are the trade-offs in performance between lean and agile manufacturing?* However, as flexibility will be discussed within Chapter 7, in order to answer RQ (b) the results from the following chapter must also be taken into account

Prior to analysis, it is important to refer to the categorical development of performance levels and codification of the variables. Similar to the multinomial logistic regressions conducted in Chapter 6, lean and agile systems were coded into binary categories, as either 1-lean 0-agile or 1-agile or 0-lean depending on the hypothesis under investigation. For example, as literature (Cagliano *et al*., 2004; Agarwal *et al*., 2006; Hallgren and Olhager, 2009; Qi *et al*., 2009) has advocated that lean firms are more cost effective in comparison to agile systems, in order to test this assertion, the following hypothesis was constructed $\mathbf{H_C}$: Lean manufacturing systems are more likely to attain higher cost performance levels in comparison with agile systems. As this hypothesis is primarily investigating lean in comparison to agility, lean organisations were coded as 1, as this was the strategy under investigation, and agile systems were coded as 0, and this strategy was used as the baseline for comparison. Following this, and after screening results for outliers and errors, each of the performance (sub-items) variables were categorized into three groups namely; low, medium and high. The parameters by which firms were distinguished as low, medium and high are reported within each subsequent analysis section.

Importantly, organisations may have acquired large numerical values within certain performance variables but this does not necessarily reflect a high performance measure. For instance, when referring to speed, some organisations acquired high levels of order-lead time, which actually demonstrates low levels of speed performance. Therefore, in these cases, performance categories were inversely coded where high levels of performance were affiliated with low numerical values and vice-versa for low levels of performance. In summary, the independent variables within each of the regressions conducted in this chapter refer to the choice of manufacturing strategy employed, i.e. lean or agile, and the dependent variables consist of performance, which are categorised as low, medium or high. Findings from Chapter 6 suggested that contextual factors such as firm age, firm size and manufacturing classification did not illustrate a significant relationship with either lean or agile production, therefore, these external factors were not deemed to jeopardise the results within this chapter. However, as the positional tier within the ASC did illustrate a significant relationship between lean and agile firms, this was controlled in all of the regressions reported in this chapter as well as Chapter 7.

6.1 Cost Analysis

As mentioned previously in Chapter 4, five cost sub-variables were used in order to operationalise the assessment of cost performance. These cost variables consisted of revenue, profit, manufacturing cost, inventory cost and distribution cost. In order to exemplify comparative analysis this study calculated profit, manufacturing cost, inventory cost and distribution cost in relation to the total sales respective to each firm. The mode in which each of these variables were captured are expressed in the five equations below:

- Revenue = Total Sales (£)
- (Total Costs/Total Sales)*100 = profit margin (%)
- (Manufacturing Cost/Total Sales)*100 = manufacturing costs in relation to sales (%)
- (Distribution Costs/Total Sales)*100 = distribution costs in relation to sales (%)
- (Inventory Costs/Total Sales)*100 = inventory costs in relation to sales (%)

Before reporting on the multinomial logistic regression results, this section will begin with a descriptive statistical insight into what was found. Table 6.1.1 reports on the mean and standard deviations found between each manufacturing concept in relation with each of the cost items.

Table 6.1.1 Cost - Lean & Agile Mean Values

Cost Performance	Lean (n=74)		Agile (n=66)	
	Mean	SD	Mean	SD
Profits	11.10	3.98	6.00	2.50
Manufacturing cost	51.00	9.60	65.0	11.05
Distribution cost	4.30	8.32	8.00	4.91
Inventory cost	11.20	1.90	8.80	3.11

With the exception of revenue, all cost variables were calculated as a percentage in relation to the total sales of each respective firm, which are illustrated in Figures 6.1.1, 6.1.2, 6.1.3 and 6.1.4. The red-dashed lines within each of these figures correspond to the mean values concerning lean and agile systems as a whole. Figure 6.1.1 illustrates the profit margin between lean and agile systems, and analysing this graph it is apparent that lean firms are generating higher levels of profit in comparison to agile firms. For instance, on the whole, lean systems acquired a mean profit margin of 11.10%, which was almost twice the value acquired by agile (6.00%) systems. Figure 6.1.2 reports on the percentage of sales which were spent on manufacturing activities in relation to the total sales. Agile firms are observed to be spending a greater percentage of total sales on manufacturing activities in comparisons with lean firms, however, the proportional difference between the total costs being spent on manufacturing is not as great as the proportional difference between profit levels. For instance, the mean percentage of total sales spent on manufacturing within lean organisations was 51.0%, whereas the average percentage of total sales spent on manufacturing within agile organisations was calculated as 65%. Figure 6.1.3 and Figure 6.1.4 illustrate the percentage of total sales spent on distribution costs and inventory costs respectively. On average, lean systems were identified as spending 4.30% of total sales on distribution costs and 11.20% of total sales on inventory costs. On the other hand, agile systems were found to be spending 8.00% of total sales on distribution costs and 8.80% of total sales on inventory costs. Table 6.1.1 also illustrates the standard deviations of each of the four cost variables in relation to lean and agile systems. Lean firms have a greater standard deviation concerning profit levels and distribution costs, whereas agile firms have greater standard deviations in manufacturing costs and inventory costs.

Figure 6.1.1: Profits

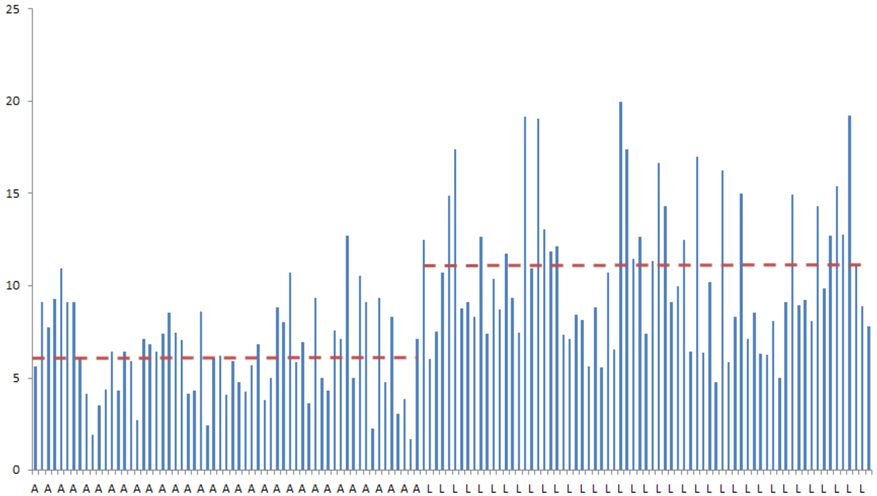


Figure 6.1.2: Manufacturing Costs

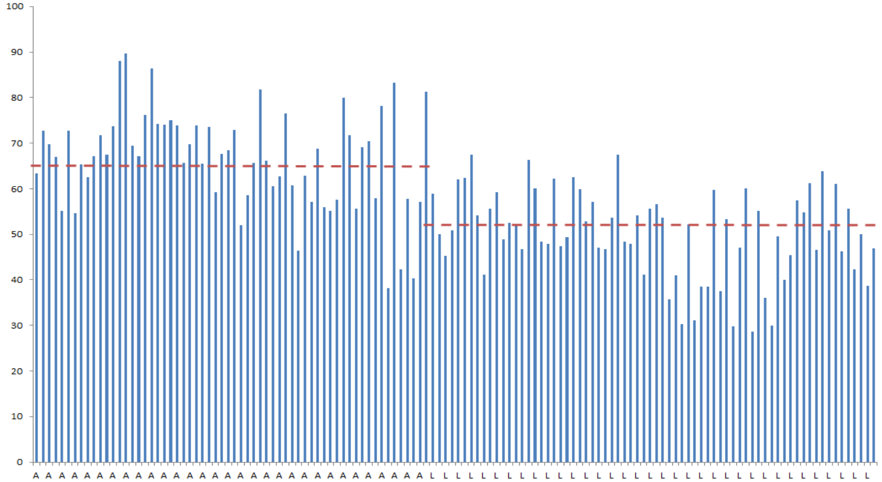


Figure 6.1.3: Distribution Costs

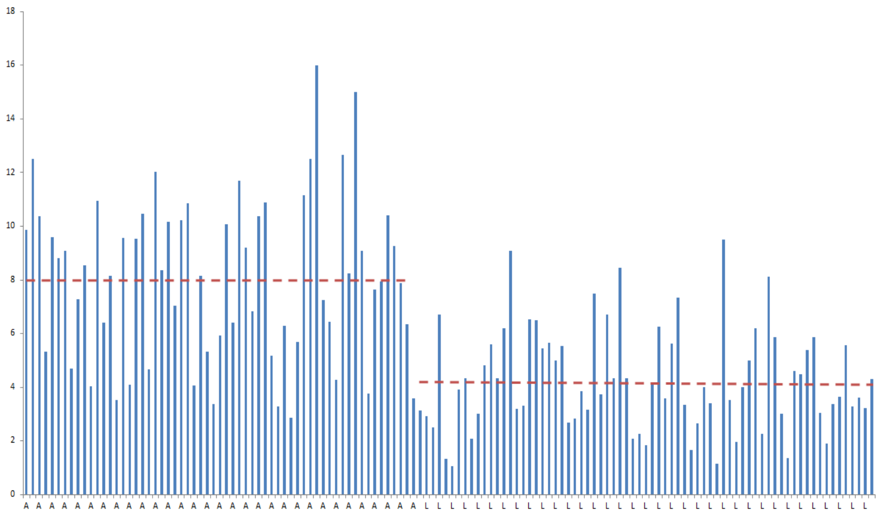
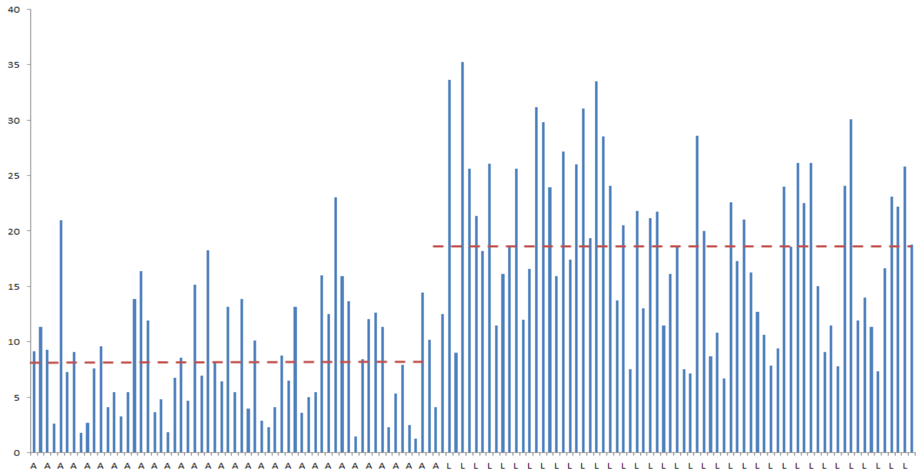


Figure 6.1.4: Inventory Costs



In summary:

- Lean systems (11.10%) were found to acquire higher levels of profit in comparison to agile systems (6.00%).
- In terms of total sales, lean systems (51.00%) were observed to be spending less on manufacturing activities in comparison with agile systems (65.00%).
- In terms of total sales, agile systems (8.80%) were found to be spending less on inventory costs in comparison with lean systems (11.20%).
- In terms of total sales, lean systems (4.30%) were observed to be spending less on distribution costs in comparison with agile systems (8.00%).
- On average, lean firms are spending (51.00 + 4.30 + 11.20 = 66.50%) 66.5% of total sales on manufacturing, distribution and logistics, whereas agile systems (6.00 + 65.00 + 8.00 = 79.00%) are spending 79.0%.

Even though the previous four figures identified clear disparities between lean and agile production and each of the cost variables, the next stage of analysis involved a set of independent T-Tests designed to determine if there are statistical significant differences between the mean values of each cost item relative to each of the manufacturing groups. The results of these tests are presented in Table 6.1.2. The P value was reported as 0.00 in each of the corresponding independent T-Tests, therefore, as these values are below significance criteira of 0.05, there are significanct differences between the mean of each of the cost performance measures in relation with lean and agile manufacturing systems.

Table 6.1.2: Lean & Agile Independent T-Tests

Cost	Sig. (2-tailed)
Revenue	**.000**
Profit	**.000**
Manufacturing Cost	**.000**
Inventory Cost	**.000**
Distribution Cost	**.000**

Overall, results suggest that there are statistical differences between all five cost variables and each of the manufacturing paradigms. However, before moving on to the multinomial logistic regressions, this study investigated whether each of the performance measures were related to one another. Regardless of whether lean or agile, a Pearson correlation test was conducted in order to determine if each of the cost performance measures were related, the results of which are presented in Table 6.1.3.

Table 6.1.3: Pearson Correlations Matrix of Cost Items

	1	2	3	4	5
Revenue (1)	**1**				
Profit (2)	.144	**1**			
Manufacturing Cost (3)	-.057	-.096	**1**		
Inventory Cost (4)	.138	.282**	-.241**	**1**	
Distribution Cost (5)	-.130	-.189*	.300**	-.174*	**1**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Results from Table 6.1.3 suggest that profit levels are negatively correlated with the percentage of total sales spent on manufacturing activities however, the strength of this correlation was relatively weak and not significantly related. In contrast, profit levels were positively and significantly related with inventory costs, and negatively and significantly related with distribution costs at the 0.01 level and 0.05 levels respectively. This implies that firms are likely to generate greater profits when spending more on inventory costs and spending less on distribution costs. Furthermore, results from Table 6.1.3 suggest that manufacturing costs were negatively related to inventory costs and positively related to distribution costs at the 0.01 and 0.05 levels respectively. This suggests that firms which spend more on manufacturing activities are also likely to spend more on distribution costs and spend less on inventory costs. Finally, results also found a negative and significant association between the percentage of sales spent on inventory and the percentage of total costs spent on distribution.

Cost Regression Analysis

Initially, five independent multinomial regressions were conducted in order to determine if lean manufacturing firms acquired higher levels of cost performance in comparison with agile firms. Cost variables were categorised as low, medium and high, and Table 6.1.4 illustrates the parameters of each of these categories. Furthermore, Table 6.1.5 illustrates the frequency of lean and agile firms deemed as performing low, medium and high in association with each respective cost item.

Table 6.1.4: Cost Parameters: Low (1), Medium (2) & High (3)

Costs	1 (Low)	2 (Medium)	3 (High)
Revenue	$0 < x \leq 3.00m$	$3.00m < x \leq 6.00m$	$x > 6.00m$
Profits	$0 < x \leq 5$	$5 < x \leq 10$	$x > 10$
Manufacturing Cost	$x > 60$	$45 < x \leq 60$	$30 \leq x \leq 45$
Inventory Costs	$x > 10$	$5 < x \leq 10$	$x < 5$
Distribution Costs	$x > 6$	$3 < x \leq 6$	$x < 3$
Average Cost	1-1.64	1.65-1.99	2.0-3

Note: Manufacturing cost, inventory cost and distribution costs reverse coded. i.e. smaller values imply greater performance.

Table 6.1.5: Frequency of Categorised Cost Variables

Manufacturing Strategy	Costs	1 (Low)	2 (Medium)	3 (High)
Lean	Revenue	32	16	26
	Profits	7	35	32
	Manufacturing Cost	12	47	15
	Inventory Costs	45	21	8
	Distribution Costs	13	43	18
Agile	Revenue	32	21	13
	Profits	25	32	9
	Manufacturing Costs	33	24	9
	Inventory Costs	27	23	16
	Distribution Costs	30	25	11

The low performance category was used as the reference point when making comparisons. Also, agile firms were selected as the baseline (0) for each of the regressions conducted in this section. In summary, the independent variable was the choice of manufacturing strategy (lean/agile) and the dependent variables consisted of cost performance (low/medium/high). The regression results are reported in Table 6.1.6. In essence, results in Table 6.1.6 correspond to lean manufacturing systems in comparison with agile manufacturing, relative to low performance levels. With this mind, if the B coefficient is greater than zero this means that lean systems, in comparison with agile systems, are more likely to be located in the respective group in relation to the reference (low) category. In contrast, if the B coefficient is less than zero this means that lean systems, in comparison with agile systems, are less likely to be located in the respective group in relation to the reference (low) category. However, each of these assertions were only valid if the P value is below the threshold criteria (0.05).

Table 6.1.6 Multinomial Logistic Regression Results for Cost

Model 1) Revenue	L/A	B	Sig	Exp (B)	Nagelkerke .037
Medium	L (1)	-0.272	.513	.762	
	A (0)	.	.	.	
High	L (1)	0.693	.100	2.00	
	A (0)	.	.	.	
Model 2) Profit	L/A	B	Sig	Exp (B)	Nagelkerke .180
Medium	L (1)	1.363	0.006	3.906	
	A (0)	.	.	.	
High	L (1)	2.541	0.000	12.698	
	A (0)	.	.	.	
Model 3) Manufacturing cost efficiency	L/A	B	Sig	Exp (B)	Nagelkerke .195
Medium	L (1)	1.582	0.000	4.865	
	A (0)	.	.	.	
High	L (1)	1.442	0.007	4.231	
	A (0)	.	.	.	
Model 4) Inventory cost efficiency	L/A	B	Sig	Exp (B)	Nagelkerke .109
Medium	L (1)	0.031	0.939	1.031	
	A (0)	.	.	.	
High	L (1)	-1.041	0.034	0.353	
	A (0)	.	.	.	
Model 5) Distribution cost efficiency	L/A	B	Sig	Exp (B)	Nagelkerke .355
Medium	L (1)	1.379	0.001	3.969	
	A (0)	.	.	.	
High	L (1)	1.329	0.009	3.776	
	A (0)	.	.	.	
Model 6) Mean cost performance	L/A	B	Sig	Exp (B)	Nagelkerke .048
Medium	L (1)	1.211	0.000	2.287	
	A (0)	.	.	.	
High	L (1)	1.651	0.000	2.923	
	A (0)	.	.	.	

Reference category is low and agile used as base.

Results from model 1 (revenue), revealed the B coefficient to be negative (-.272) for the medium category and positive (.693) for the high category. Observing the Exp (B) column allowed for the likelihood of lean firms acquiring different performance levels. For instance, lean (1) firms in comparison with agile (0) firms are (1-0.762=0.238) 23.8% less likely and (2.0-1=1.0) 100% more likely to acquire medium (between £3-£6 million) and high (above £6 million) levels of revenue relative to low (£0-£3 million) levels of revenue. However, both of the P values are greater than the threshold criteria (0.05), therefore, these statements are not of significance. Even though lean firms were identified as more likely to acquire higher levels of revenue in comparison with agile firms, as this finding was not of significance, hypothesis $\mathbf{H_{Ca}}$ was rejected.

The B coefficient was greater than zero for both medium (1.363) and high (2.541) categories concerning model 2 (profit). In addition, the P value was less than 0.05 for both categories, suggesting levels of significance. Therefore, using the Exp (B) column, lean firms (1) in comparison with agile firms (0) are (3.908-1=2.908) 290% and (12.698-1=11.698) 1169%, and significantly, more likely to acquire medium (between 5%-10%) profit levels and high (above 10%) profit levels relative to low (below 5%) levels of profits respectively. Taking this into account, hypothesis $\mathbf{H_{Cb}}$ was accepted.

Model 3 (manufacturing cost efficiency) also illustrated the B coefficient to be greater than zero for both medium (1.582) and high (1.442) categories. Furthermore, the P values are less than 0.05 for each of these categories, implying levels of significance. With this in mind, and using the Exp (B) column, it can be stated that lean systems in comparison to agile systems are (4.865-1=3.865) 387% and (4.231-1=3.231) 323%, and significantly, more likely to acquire medium and high levels of manufacturing cost efficiency levels relative to low levels of manufacturing cost efficiency levels. With this in mind, hypothesis $\mathbf{H_{Cc}}$ was accepted.

Model 4 (inventory cost efficiency) highlighted an interesting finding. For instance, the B value was greater than 0 for the medium (.031) category and less than 0 for the high (-1.041) category. However, only the high category illustrated levels of significance. With this in mind, and using the Exp (B) column, it can be stated that lean (1) firms in comparison to agile (0) firms are (1-1.031=.031) 3.1% more likely to acquire medium levels of inventory cost efficiency levels relative to low levels of inventory cost efficiency. More importantly, lean firms (1) in comparison to agile firms (0) are (1-.353=.647) 64.7% and significantly less likely to acquire high levels of inventory cost efficiency relative to low levels of inventory cost efficiency. As agile firms were found to be significantly outperforming lean firms hypothesis $\mathbf{H_{Cd}}$ was rejected.

Model 5 (distribution cost efficiency) found the B coefficient to be positive for both medium and high categories, and both categories also acquired P values below 0.05. Therefore, lean (1) firms in comparison with agile (0) firms are (3.969-1=2.969) 297% and (3.776-1=2.776) 277%, and significantly, more likely to acquire medium and high levels of distribution cost efficiency levels relative to low levels. Therefore, hypothesis $\mathbf{H_{Ce}}$ was accepted.

In order to calculate an approximate single number to measure overall cost efficiency levels, this investigation assigned a mean value concerning the categorised constructs. For instance, if an individual firm acquired; low (1) levels of revenue, low (1) levels of profits; medium (2) levels of manufacturing cost efficiency levels; low (1) levels of inventory cost efficiency levels; and high (3) levels of distribution cost efficiency levels, they were identified as acquiring a total cost performance score of (1+1+2+1+3=8) 8, which was subsequently divided by 5 to calculate an average cost performance level of 1.60. Firms were then categorised as: low if acquiring a total cost performance value between 1 and 1.64; medium if acquiring a total cost performance value between 1.65 and 1.99; and high if acquiring a total cost performance value between 2.00 and 3.00. In essence, assigning a single value which measured the overall cost performance of a firm allowed for the creation of a single parameter which could distinguish firms as being low, medium or high. A visual representation of this process is available in the Methodology chapter (see section 4.6). An additional regression was conducted which set out to investigate if there were significant differences between levels of performance in relation to lean and agile manufacturing firms. The results for this regression are reported in Table 6.1.6 (model 6). Model 6 (overall cost performance levels) illustrated that the B coefficient was positive for both medium (1.211) and high (1.651) groups respectively. Furthermore, each of these categories acquired a P value less than 0.05, hence, was significant. Therefore, lean systems (1) in comparison with agile systems (0) are (2.287-1=1.287) 129% and (2.923-1=1.923) 192%, and significantly, more likely to acquire medium and high levels of cost performance respectively, relative to low levels. With this in mind hypothesis $\mathbf{H_C}$ was accepted.

Summary

Lean firms when compared to agile firms were found to be more likely to possess high levels of cost performance with regard to profits, manufacturing costs and distribution costs. However, this was not the case with regard to revenue and inventory costs. In fact, agile firms were identified as being significantly more likely to attain high levels inventory cost efficiency levels in comparison with lean firms. In addition, although lean firms were more likely to attain high levels of revenue in comparison with agile organisations, this finding was not of significance. The outcomes concerning each of the proposed cost hypotheses are outlined in Table 6.7.1. Overall this section found, based upon a mean measure of cost performance, lean organisations to be significantly superior to agile firms.

Table 6.1.7: Hypothesis Outcomes for Cost Measures

Hypothesis	**Accept (A)/ Reject (R)**
H_{Ca}: Lean firms are more likely to attain higher cost levels when compared with agile firms.	**A**
H_{Ca}: Lean firms are more likely to attain higher sales when compared with agile firms.	**R**
H_{Cb}: Lean firms are more likely to attain higher profit margins when compared with agile firms.	**A**
H_{Cc}: Lean firms are more likely to attain higher manufacturing cost efficiency levels when compared with agile firms.	**A**
H_{Cd}: Lean firms are more likely to attain higher inventory cost efficiency levels when compared with agile firms.	**R**
H_{Ce}: Lean firms are more likely to attain higher distribution cost efficiency levels when compared with agile firms.	**A**

6.2 Dependability Analysis

Dependability is centred on the philosophy of providing a service in time to customers, when it is required or needed (Slack *et al.*, 2010). With this in mind, dependability levels can only be measured after the operation has been completed, and in order to measure a range of dependability levels four items consisting of delivery reliability, wrong deliveries, stock and lateness of orders were used. The operationalisation of each of these items is as follows:

- **Delivery Reliability**: Total orders that were late (%)
- **Wrong Deliveries:** Total orders that were delivered to the wrong address (%)
- **Stock:** Products available in stock (%)
- **Lateness of orders:** Lateness of orders (day)

The mean dependability levels associated with lean and agile manufacturing systems are illustrated in Table 6.2.1. In terms of delivery reliability, the mean values suggest that lean organisations deliver approximately 7.76% of total orders late, which was well above the mean agile value, with those firms delivering 5.51% of total orders late. Interestingly, mean values from Table 6.2.1 also suggest that despite lean organisations holding greater levels of stock (26.71%) in comparison with agile organisations (18.60%), lean systems still send a greater proportion of orders late. However, results suggest the average lean organisation is likely to send a lower (0.20%) proportion of total orders to the wrong address in comparison with agile manufacturers (0.36%).

Table 6.2.1: Dependability - Lean & Agile Mean Values

Dependability Performance	Lean (n=74)		Agile (n=66)	
	mean	SD	mean	SD
Delivery Reliability (%)	7.86	9.52	5.51	4.57
Wrong deliveries (%)	0.20	0.47	0.36	0.55
Orders in stock (%)	26.71	22.67	18.60	14.70
Lateness of orders (Days)	4.10	3.50	2.19	2.48

Even though there were clear discrepancies between the mean dependability levels within lean and agile systems, these differences were not as evident as with cost performance measures. Next, four independent T-Tests were conducted in order to determine if these differences were of significance, the results of which are presented in Table 6.2.2.

Table 6.2.2: Dependability T-Test

Dependability	Sig. (2-tailed)
Delivery Reliability	**.070**
Wrong Deliveries	**.064**
Orders in Stock	**.014**
Lateness of Orders	**.000**

Unsurprisingly, results from each of the T-Tests did not reveal significant differences between all the sub-variables, however findings did reveal that there was a significant difference between lean and agile in association with orders in stock and the lateness of orders. Taking this into account, it may be argued that lean and agile organisations, with the exclusion of lateness of orders, generally do not exhibit significant differences between dependability levels.

Next, Pearson correlations were conducted to determine if each of the sub-variables were associated with one another, results are presented in Table 6.2.3. Neither of the dependability sub-variables illustrated a significant relationship at the 0.01 level. The percentage of orders that were late (delivery reliability) illustrated a relatively weak but positive and significant relationship with the percentage of orders sent to the wrong address and the lateness of orders, both at the 0.05 level. Also, results illustrated a relatively weak but significant and negative association between the percentage of orders sent to the wrong address and percentage of stock levels. Therefore, it is suggested that firms acquiring higher levels of stock are more likely to ship orders to the correct address.

Table 6.2.3: Pearson Correlations Matrix of Dependability Items

Dependability	1	2	3	4
Delivery Reliability (1)	**1**			
Wrong Deliveries (2)	.190*	**1**		
Stock (3)	.066	-.182	**1**	
Lateness of Orders (4)	.216*	-.043	.008	**1**

*. Correlation is significant at the 0.05 level (2-tailed).

Dependability Regression Analysis

Initially, four independent multinomial logistic regressions were conducted in order to determine if lean manufacturing firms acquired high levels of dependability in comparison with agile firms. The dependability variables were categorised as low, medium and high, and Table 6.2.4 illustrates the parameters by which firms were deemed to be achieving low, medium and high performance levels. Table 6.2.5 details the frequency of lean and agile firms deemed as performing low, medium and high in association with each respective dependability variables.

Table 6.2.4: Dependability Parameters: Low (1), Medium (2) & High (3)

Dependability	1 (Low)	2 (Medium)	3 (High)
Orders Late	$x > 8$	$4 < x \leq 8$	$x < 4$
Wrong Deliveries	$x > 5$	$0 < x \leq 5$	$x = 0$
Orders in Stock	$0 \leq x \leq 15$	$15 < x \leq 30$	$x > 30$
Lateness of Orders	$x > 2$	$1 < x \leq 2$	$x < 1$
Average	1-1.64	1.65-2.29	2.3-3

Note: Orders late, wrong deliveries and lateness of orders reverse coded. i.e. smaller values imply greater performance.

Table 6.2.5: Distinguishing Lean and Agile Based on Dependability Parameters

	Dependability	1 (Low)	2 (Medium)	3 (High)
Lean	Orders Late	22	17	35
	Wrong Deliveries	12	11	51
	Orders in Stock	31	19	24
	Lateness of Orders	51	18	5
Agile	Orders Late	17	15	34
	Wrong Deliveries	20	9	37
	Orders in Stock	32	22	12
	Lateness of Orders	20	27	19

Low levels of dependability amongst each of the sub-variables were used as the reference category and agile (0) firms were used as the baseline. In essence, the independent variable was the choice of manufacturing strategy (lean/agile) and the dependent variables consisted of dependability (low/medium/high). The multinomial logistic regression results are reported in Table 6.2.6.

Table 6.2.6: Multinomial Logistic Regression Results for Dependability

Model 1) Delivery Reliability	L/A	B	Sig	Exp (B)	Nagelkerke .003
Medium	L (1)	-.133	.782	0.876	
	A (0)	.	.	.	
High	L (1)	-.229	.570	0.795	
	A (0)	.	.	.	
Model 2) Wrong Deliveries	L/A	B	Sig	Exp (B)	Nagelkerke .056
Medium	L (1)	.829	.276	2.292	
	A (0)	.	.	.	
High	L (1)	.960	.020	2.612	
	A (0)	.	.	.	
Model 3) Orders in Stock	L/A	B	Sig	Exp (B)	Nagelkerke .031
Medium	L (1)	-.115	.775	0.891	
	A (0)	.	.	.	
High	L (1)	.725	.095	2.065	
	A (0)	.	.	.	
Model 4) Lateness of Orders	L/A	B	Sig	Exp (B)	Nagelkerke .182
Medium	L (1)	-1.342	.001	0.261	
	A (0)	.	.	.	
High	L (1)	-2.271	.000	0.103	
	A (0)	.	.	.	
Model 5) Mean Dependability	L/A	B	Sig	Exp (B)	Nagelkerke .005
Medium	L (1)	-.242	.576	0.785	
	A (0)	.	.	.	
High	L (1)	-.086	.866	0.918	
	A (0)	.	.	.	

Reference category is low and agile (0) is used as the baseline.

Results from model 1 (delivery reliability) found the B coefficient as being negative for both medium (-.133) and high (-.229) categories, which may lead to the belief that lean (1) firms in comparison with agile (0) firms are less likely to acquire medium and high levels of efficiency in late orders. However, this cannot be proposed as both medium and high categories did not portray levels of significance. This may be explained by examining Table 6.2.5, as 17 and 35 lean firms acquired medium and high levels of dependability for orders being late respectively, whereas 15 and 34 agile firms acquired these same performance levels. As these values are relatively similar, regression results were not expected to hold levels of significant differences. In essence, using the Exp (B) column, lean firms (1) in comparison to agile (0) firms are only (1-0.876=0.12) 12% less likely to acquire medium levels of efficiency in late orders relative to low levels of orders being late. Also, lean (1) firms in comparison with agile (0) firms are (1-0.795=0.20) 20% less likely to acquire high levels of efficiency in late orders relative to low levels of efficiency in late orders. These similar levels of probability may help to explain why both categories did not appear to show levels of significance. With these findings, hypothesis $\mathbf{H_{Da}}$ was rejected.

Results from model 2 (wrong deliveries) illustrated the B coefficient as being positive for both medium (0.829) and high (.960) categories. Therefore, using the Exp (B) column, lean firms (1) in comparison to agile firms (0) are (2.292-1=1.29) 129% and (2.612-1=1.612) 161% more likely to gain medium and high levels of wrong deliveries relative to low levels respectively. Although, only the high category gained a P value less than 0.05, as this was of significance hypothesis $\mathbf{H_{Dc}}$ was accepted.

Results from model 3 (orders in stock) revealed the B coefficient as being negative for the medium category and positive for the high category, suggesting lean (1) systems in comparison to agile (0) systems are (1-0.261=0.739) 74% less likely to gain medium levels and (2.065-1=1.065) 107% more likely to gain high levels of orders in stock relative to the low category. However, as the P value was greater than threshold criteria of significance for each group hypothesis $\mathbf{H_{Dd}}$ was rejected.

Model 4 (lateness of orders) found the B coefficient to be negative for both medium (-1.342) and high (-2.271) categories. Also, as the P value was less than 0.05 for each of these categories, statements of significance can be asserted. In conjunction with the Exp (B) column, lean firms (1) in comparison with agile (0) systems are (1-0.261=0.739) 74%, and significantly, less likely to possess medium levels of dependability concerning lateness of orders relative to the low category. In addition, lean systems in comparison to agile systems are (1-0.103=0.897) 90%, and significantly, less likely to acquire high levels of dependability concerning the lateness of orders relative to the low category. As agile firms were found to be superior to lean firms, hypothesis $\mathbf{H_{Db}}$ was rejected.

In order to examine overall dependability levels, this study calculated the mean categorical value concerning each of the sub-variables (refer to overall cost efficiency levels for detailed description into how this was achieved, also see section 4.6). Firms were categorised as: low if acquiring a total dependability performance value between 1 and 1.64; medium if acquiring a total dependability performance value between 1.65 and 2.29; and high if acquiring a total dependability performance value between 2.30 and 3.00. The results for this regression are reported in Table 6.6.2 (Model 5) and revealed that the B coefficient for both medium (-0.242) and high (-0.086) categories was negative, suggesting lean organisations (1) in comparison with agile organisations (0) were less likely to acquire medium and high levels of dependability relative to the low category. However, both categorical groups acquired P values greater than 0.05 suggesting that these findings were not significant. Therefore, using the Exp (B) values, lean firms (1) in comparison with agile (0) firms are 22% and 8% less likely to attain medium and high levels of dependability respectively, relative to the low category. Considering neither medium nor high groups revealed significant differences between each of the manufacturing approaches, hypothesis $\mathbf{H_D}$ was rejected.

Summary

Based on the parameters set in Table 6.2.5, results revealed lean production to be significantly superior to agile production in terms of wrong deliveries. However, in terms of lateness of orders, agile systems were found to be superior. In terms of delivery reliability and orders in stock, neither manufacturing approach were identified as superior or weaker to the other. With this in mind, it is no surprise that there was no significant difference in the final regression which investigated overall dependability levels between lean and agile firms. Table 6.2.7 outlines the hypotheses which were accepted or rejected based on the outcome of this section.

Table 6.2.7: Hypothesis Outcomes for Dependability Measures

Hypothesis	**Accept (A)/ Reject (R)**
H_D: Lean firms are more likely to attain higher dependability levels when compared with agile firms	**R**
H_{Da}: Lean firms are more likely to attain higher order reliability levels when compared with agile firms.	**R**
H_{Db}: Lean firms are more likely to attain higher lateness of order dependability levels when compared with agile firms.	**A**
H_{Dc}: Lean firms are more likely to attain higher wrong deliveries dependability levels when compared with agile firms.	**R**
H_{Dd}: Lean firms are more likely to attain higher stock levels when compared with agile firms	**R**

6.3 Quality

As discussed in the Methodology chapter, this study operationalised the measurement of quality via four sub-variables, namely: defects; scrap levels; customer complaints; and warranty claims. Once again, the techniques by which each of these variables were measured are outlined below:

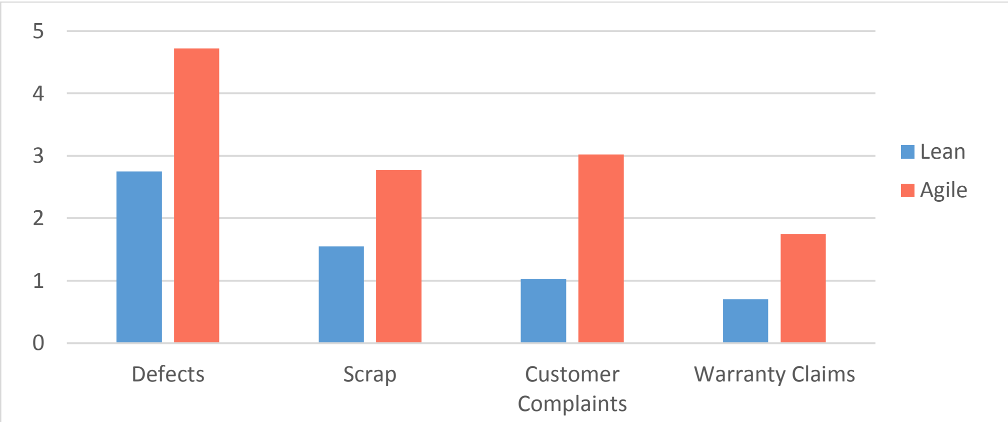
- **Defects:** Total orders which acquired defects where goods were not able to be transferred to the end customer or next stage of production (%).
- **Scrap Levels:** Total orders which acquired defects and were not able to be rectified order to meet customer expectations resulting in the disposal of the entire product (%).
- **Customer complaints:** Total orders which did not meet customer expectations and resulted in customers formally lodging a complaint (%).
- **Warranty claims:** Total orders which did not meet customer expectations and resulted in the organisation issuing replacement products at a discount/free charge (%).

The mean results between lean and agile manufacturing systems concerning each of the quality items are reported in Table 6.3.1 and Figure 6.3.1. All four quality sub-variables demonstrated superior mean levels of performance within lean firms, as opposed to agile firms. For instance, lean acquired a mean value of 2.75% of total products with defects, which was almost half the value of agile firms (4.72%). In terms of scrap levels and warranty claims, agile firms were also recorded as performing approximately half as well as lean firms as mean figures were 2.77% and 1.75% respectively. The greatest proportional difference in mean quality values were observed within the percentage of customer complaints. For instance, approximately 3% of total orders resulted in complaints from customers in agile systems, which was approximately three times greater than the percentage within lean systems (1.03%).

Table 6.3.1: Quality - Lean & Agile Mean Values

Quality	Lean (n=74)		Agile (n=66)	
	Mean	SD	mean	SD
Defects (%)	2.75	2.12	4.72	2.62
Scrap (%)	1.55	1.53	2.77	1.82
Customer Complaints (%)	1.03	1.02	3.02	2.92
Warranty Claims (%)	0.70	1.01	1.75	2.64

Figure 6.3.1: Quality - Lean & Agile Mean Values



Even though the mean differences in quality levels demonstrate clear disparities between each of the manufacturing concepts, T-Tests were also conducted. Table 6.3.2 reports the results of four independent T-Tests designed to determine if the mean differences between lean and agile production in each of the quality items were of significance. Unsurprisingly, all four variables used to assess quality levels reported significant differences between the two manufacturing concepts, as all P values were less than 0.01.

Table 6.3.2: Quality T-Tests

Quality	Sig. (2-tailed)
Defects	**.000**
Scrap Levels	**.000**
Customer Complaints	**.000**
Warranty Claims	**.000**

Next, Pearson correlations were conducted to determine whether or not each of the sub-variables were associated with one another, with results presented in Table 6.3.3

Table 6.3.3: Pearson Correlation Matrix of Quality Items

Quality	1	2	3	4
Defects (1)	**1**			
Scrap Levels (2)	.642**	**1**		
Customer Complaints (3)	.704**	.642**	**1**	
Warranty Claims (4)	457**	.704**	.754**	**1**

**. Correlation is significant at the 0.01 level (2-tailed)

All four quality sub-variables demonstrated significant relationships with one another and, more importantly, were significant at the 0.01 level. Even though the majority of combinations portrayed relatively large strengths, the greatest association was between customer complaints and warranty claims, with a Pearson correlation score of 0.754. This may be explained by the fact that if orders were not satisfactory to buyers, first, they would file a complaint with that firm. Second, in order to avoid negative reputational consequences and salvage the customer relationship, the organisation would then issue a warranty claim. Table 6.3.3 also demonstrated a strong association between defects and customer complaints with a Pearson correlation score of 0.704, which may be due to the fact that initial defects may not have been picked up by the manufacturer and only been reported once the customer had complained and raised it as an issue with the manufacturer in question. A large correlation (0.642) is also observed between scrap levels and defects, suggesting defects may not be salvageable and the products therefore scrapped.

Quality Regression Analysis

Once again, four independent multinomial regressions were conducted in order to determine if lean manufacturing firms acquired high levels of quality in comparison with agile firms. The dependability variables were categorised as low, medium and high, and Table 6.3.4 illustrates the parameters by which firms were deemed as achieving low, medium and high levels of performance. Table 6.3.5 illustrates the frequency of lean and agile firms deemed to be performing as low, medium and high in association with each respective quality variable.

Table 6.3.4: Quality Parameters: Low (1), Medium (2) & High (3)

Quality	**1 (Low)**	**2 (Medium)**	**3 (High)**
Defects	$x > 5$	$2.5 < x \leq 5$	$0 \leq x \leq 2.5$
Scrap Levels	$x > 2$	$1.0 < x \leq 2.0$	$0 \leq x \leq 1.0$
Customer Complaints	$x > 1.0$	$0 < x \leq 1.0$	$x = 0$
Warranty Claims	$x > 0.5$	$0 < x \leq 0.5$	$x = 0$
Average	1-1.64	1.65-2.29	2.3-3

Note: All quality sub-variables inversely coded. i.e. the smaller the value the greater the performance.

It is crucial to remember that the technique by which firms were categorised as low, medium and high has an inverse relationship with actual numerical percentages. In essence, the higher the percentage of defects, scrap levels, customer complaints and warranty claims, the lower the firm scored in terms of quality.

Table 6.3.5: Distinguishing Lean and Agile Based on Quality Parameters

	Quality	1 (Low)	2 (Medium)	3 (High)
Lean	Defects	5	31	38
	Scrap Levels	15	15	44
	Customer Complaints	21	37	16
	Warranty Claims	34	13	27
Agile	Defects	17	38	11
	Scrap Levels	32	24	10
	Customer Complaints	36	20	10
	Warranty Claims	35	11	21

Theoretically, although both lean and agile manufacturing concepts emphasise quality as being important, as more studies amplified higher quality within lean systems as opposed to agile systems (see Table 3.5.1). With this in mind agile firms were used as the baseline category. In essence, Table 6.3.6 illustrates the results for five independent multinomial regressions which were conducted in order to determine if lean firms were more likely to acquire higher levels of quality in comparison to agile firms.

Results from models 1 and model 2 within Table 6.3.6, which investigated defects and scrap levels respectively, both found the B coefficients to be positive for medium and high categories. However, the P values were found to be above the threshold for each of the medium categories and less than 0.05 for each the high categories. Taking this into account, the results suggest that lean firms (1) in comparison with agile firms (0) are more likely, but not significantly more likely, to acquire medium levels of defects and scrap levels, relative to low levels of defects and scrap levels respectively. However, lean firms (1) in comparison with agile firms (0) were found to be significantly more likely to acquire high levels of defects and scrap levels relative to low levels of defects and scrap levels. As there were significant differences between lean and agile firms, both hypotheses $\mathbf{H_{Qa}}$ and $\mathbf{H_{Qd}}$ were rejected.

Table 6.3.6: Multinomial Logistic Regression Results for Quality

Model 1) Defects	L/A	B	Sig	Exp (B)	Nagelkerke .171
Medium	L (1)	1.020	.070	2.774	
	A(0)	.	.	.	
High	L (1)	2.463	.000	11.745	
	A (0)	.	.	.	
Model 2) Scrap levels	L/A	B	Sig	Exp (B)	Nagelkerke .225
Medium	L (1)	.288	.526	1.333	
	A(0)	.	.	.	
High	L (1)	2.239	.000	9.387	
	A (0)	.	.	.	
Model 3) Customer complaints	L/A	B	Sig	Exp (B)	Nagelkerke .122
Medium	L (1)	1.164	.002	3.203	
	A(0)	.	.	.	
High	L (1)	2.031	.001	7.619	
	A (0)	.	.	.	
Model 4) Warranty Claims	L/A	B	Sig	Exp (B)	Nagelkerke .064
Medium	L (1)	1.678	.014	.187	
	A(0)	.	.	.	
High	L (1)	.463	.213	.630	
	A (0)	.	.	.	
Model 5) Overall Quality	L/A	B	Sig	Exp (B)	Nagelkerke .208
Medium	L (1)	.940	.020	.391	
	A(0)	.	.	.	
High	L (1)	2.291	.000	.101	
	A (0)	.	.	.	

Reference category is low and agile (0) is used as the baseline.

Results from model 3 (customer complaints) found the B coefficients to be positive for both medium (1.164) and high (2.031) categories, signifying that lean firms (1) when compared to agile firms (0) are more likely to acquire both medium and high levels of quality in terms of customer complaints relative to the low category. Furthermore, as each of these categories also acquired a P value less than 0.05, the previous assertion is of significance. Therefore, using the Exp (B) column, lean firms (1) when compared to agile firms (0) are significantly and (3.203-1=2.203) 220% and (7.619-1=6.619) 662% more likely to gain medium (less than 1% of customer complaints) and high levels (0% of customer complaints) of customer complaints relative to the low category. These high probabilities can be explained by examining the differences in frequency of firms within Table 6.3.5. For instance, 37 and 16 lean firms acquired medium and high levels of quality in terms of customer complaints respectively, which was considerably more than agile firms (22 and 4 firms). As there were significant differences hypothesis $\mathbf{H_{Qb}}$ was rejected.

Results from model 4, which investigated warranty claims, revealed it to be the only quality sub-variable which failed to differentiate lean and agile firms to the same degree as to the previous quality sub-variables. The B coefficients were found to be positive for both medium (1.678) and high (.463) categories, signifying that lean firms (1) when compared to agile firms (0) are more likely to acquire both medium and high levels of quality in terms of customer complaints relative to the low category. However, only the medium category acquired a P value below the threshold criteria. Therefore, using the Exp (B) column, lean firms (1) in comparison to agile firms (0) were (1-0.187=0.813) 81% and significantly more likely to acquire medium levels of warranty claims relative to the low category. However, although lean firms (1) in comparison with agile firms (0) were (1-0.630=0.37) 37% more likely to attain high levels of warranty claims relative to the low category, this was not of significance. For this reason, hypothesis $\mathbf{H_{QC}}$ was accepted.

In order to examine overall quality levels, this study calculated the mean categorical value concerning each of the sub-variables (refer to overall cost efficiency levels for detailed description into how this was achieved, also see section 4.6). Firms were distinguished as being low if acquiring a total quality performance value between 1 and 1.64; medium if acquiring a total quality performance value between 1.65 and 2.29; and high if acquiring a total quality performance value between 2.30 and 3.00 (see Table 6.3.4). Model 5 (Table

6.3.6) found the B coefficient to be positive for the medium (.940) and high (2.291) categories. Therefore, lean firms (1) when compared to agile firms (0) are (1-0.391=0.609) 61% and (1-0.101=0.899) 90% more likely to acquire medium and high levels of quality respectively, relative to the low category. As the P values were below the threshold criteria for each of these categories, significant differences were observed and $\mathbf{H_Q}$ was rejected.

Summary

Overall, results from each of the individual multinomial logistic regressions revealed that lean systems in comparison with agile systems were significantly more likely to acquire high quality levels in terms of defects, scrap levels and customer complaints. Warranty claims was the only quality sub-variable that did not demonstrate levels of significance between the two manufacturing concepts.

Table 6.3.7: Hypothesis Outcomes for Quality Measures

Hypothesis	Accept (A)/ Reject (R)
H_Q: Lean firms are likely to attain similar quality levels when compared with agile firms.	**R**
H_{Qa}: Lean firms are likely to attain similar defect levels when compared with agile firms.	**R**
H_{Qb}: Lean firms are likely to attain similar customer complaint levels when compared with agile firms.	**R**
H_{Qc}: Lean firms are likely to attain similar warranty claim levels when compared with agile firms.	**A**
H_{Qd}: Lean firms are likely to attain similar scrap levels when compared with agile firms.	**R**

6.4 Speed

When operationalising speed, and as well as seeking to obtain precise information corresponding to speed levels, this study not only measured the total order-lead time, but also looked into individual operations concerning manufacturing and delivery in their own right. Furthermore, this study incorporated the use of frequency of deliveries by which each organisation distributed orders. The ways in which each of these speed items were captured are outlined below:

- **Order-lead speed:** Average total elapsed period of time (days) between a customer making an order and receiving the order.
- **Frequency of delivery:** Average frequency of deliveries made within a month over a given period of time.
- **Delivery speed:** Average total elapsed time (days) spent on delivery alone.
- **Manufacturing speed:** Average total elapsed period of time (days) spent on manufacturing alone.

The mean values corresponding to each of the speed sub-variables are reported in Table 6.4.1, with analysis of these values signifying apparent differences between lean and agile manufacturing systems. For example, the mean order-lead duration within a lean firm was noted as 30 days, which is twice the value of an agile firm (15 days). In order to provide insight into why agile may require half the time in terms of total order-lead durations, it is important to analyse the additional three speed variables. For instance, observing the mean values in manufacturing speed and delivery speed, it is undoubtedly clear that agile systems also require less time within their operations. However, an important finding concerns the amount of time which seems to be unrecorded and is therefore arguably wasted. For instance, the total mean order-lead duration within an agile firm was 15 days, where 13 days are spent on manufacturing and 1 day is spent on delivering the product, which gives a combined account of 14 days, and only 1 day is unaccounted for. In contrast, the total mean order-lead time within a lean firm was recorded as 30 days, where 18 days are spent on manufacturing and 4 days spent on delivery, which gives a combined count of 22 days, with 8 days unaccounted for, raising the question of where those 8 days are being spent within lean manufacturing systems. In order to answer this question, it is necessary to examine the frequency of deliveries. On average, a lean organisation manages to ship 30 deliveries per calendar month; almost half the amount of deliveries in comparison with the average agile manufacturing organisation which manages 57 deliveries per month. With half the amount of deliveries being dispatched in comparison with agile firms, it can be proposed that within lean manufacturing systems, the 8 unaccounted days concerning the order-lead duration may in fact be spent wasted as a result of delivery limitations. Arguably however, lean systems may be largely efficient in terms of how they dispatch which revolves around the notion that dispatching orders at once, i.e. filling one distribution lorry to capacity, may indeed be efficient in terms of costs, but not so efficient in terms of speed.

Table 6.4.1: Average Speed Levels between Lean and Agile Manufacturing Systems

	Lean (n=74)		Agile (n=66)	
	Mean	SD	mean	SD
Order-Lead Speed (days)	30.0	11.32	15	8.68
Frequency of deliveries	30.0	15.84	57	28.00
Delivery Speed (days)	4.0	4.10	1.0	1.72
Manufacturing Speed (days)	18.0	16.00	13.0	8.64

In order to statistically validate the differences between the mean speed sub-variables and lean and agile firms, four independent T-Tests were conducted (see Table 6.4.2). Unsurprisingly all independent T–Tests illustrated significant differences between lean and agile manufacturing and each of the four speed performance measures at the .001 level.

Table 6.4.2: Speed Independent T-Tests

	Sig. (2-tailed)
Order-Lead Speed	**.000**
Frequency of deliveries	**.000**
Delivery Speed	**.000**
Manufacturing Speed	**.000**

Next, Pearson correlations were conducted to determine if each of the speed sub-variables were associated with one another, results are presented in Table 6.4.3. Importantly, a negative association between frequency of deliveries and each of the other three speed variables does not actually mean a negative correlation and can be explained with the following example. For instance, the less time a firm requires to manufacture or deliver a product, the more effective that firm is in terms of speed. Results from Table 6.4.3 suggest that a large significant and negative correlation is apparent between the frequency of deliveries and order-lead speed and manufacturing speed, both at the 0.01 level. This indicates that as the frequency of deliveries increases, the duration of both total order-lead speed and manufacturing speed decreases. Furthermore, results from this table indicated a significant (0.01 level) association between the total order-lead speed and manufacturing speed and delivery speed.

Table 6.4.3: Pearson Correlation Matrix of Speed Items

	(1)	(2)	(3)	(4)
Order-Lead Speed (1)	1			
Frequency of Deliveries (2)	-.679**	1		
Delivery Speed (3)	.324**	-.197	1	
Manufacturing Speed (4)	.643**	-.379**	.197	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Speed Regression Analysis

Four independent multinomial regressions were conducted in order to determine if agile firms acquired higher levels of speed in comparison with lean firms (see Table 6.4.6). The speed sub-variables were categorised as low, medium and high, and Table 6.4.4 illustrates the parameters by which firms were deemed as achieving low, medium or high levels of performance. Table 6.4.5 illustrates the frequency of lean and agile firms deemed to be performing as low, medium or high in association with each respective speed variable. As literature has identified speed to be more strongly associated with agile production, lean systems were used as the baseline for comparison. Therefore, all the results reported in Table 6.4.6 correspond to agile manufacturing systems in comparison with lean manufacturing systems relative to low speed levels.

Table 6.4.4: Speed Parameters: Low (1), Medium (2) & High (3)

Speed	1 (Low)	2 (Medium)	3 (High)
Order-lead speed	x >21	14< x ≤21	0≤ x ≤14
Frequency Deliveries	$0 < x \leq 20$	$20 < x \leq 40$	$x > 40$
Delivery speed	$x > 3$	$1 < x \leq 3$	$0 < x \leq 1$
Manufacturing speed	$x > 16$	$8 < x \leq 16$	$0 < x \leq 8$
Average	1-1.50	1.501-2.00	2.01-3

Note: With the exception of frequency of deliveries, all speed sub-variables inversely coded i.e. the smaller the value the greater the performance.

Table 6.4.5: Distinguishing Lean and Agile Based on Speed Parameters

	Speed	1 (Low)	2 (Medium)	3 (High)
Lean	Order-Lead Speed	50	16	10
	Frequency Deliveries	22	41	11
	Delivery Speed	13	20	33
	Manufacturing Speed	34	21	19
Agile	Order-Lead Speed	14	14	38
	Frequency Deliveries	8	15	43
	Delivery Speed	11	16	47
	Manufacturing Speed	25	22	19

Table 6.4.6: Multinomial Logistic Regression Results for Speed

Model 1 Order-lead speed	A/L	B	Sig	Exp (B)	Nagelkerke .469
Medium	A(1)	1.312	.007	3.714	
	L (0)	.	.	.	
High	A(1)	2.870	.000	17.643	
	L (0)	.	.	.	
Model 2 Frequency of deliveries	A/L	B	Sig	Exp (B)	Nagelkerke .364
Medium	A(1)	-.042	.935	.959	
	L (0)	.	.	.	
High	A(1)	2.576	.000	13.139	
	L (0)	.	.	.	
Model 3 Delivery speed	A/L	B	Sig	Exp (B)	Nagelkerke .132
Medium	A(1)	1.570	.001	4.808	
	L (0)	.	.	.	
High	A(1)	2.764	.000	15.865	
	L (0)	.	.	.	
Model 4 Manufacturing speed	A/L	B	Sig	Exp (B)	Nagelkerke .009
Medium	A(1)	.354	.380	1.425	
	L (0)	.	.	.	
High	A(1)	.307	.462	1.360	
	L (0)	.	.	.	
Model 5 Overall Speed	A/L	B	Sig	Exp (B)	Nagelkerke .262
Medium	A(1)	0.885	.042	2.423	
	L (0)	.	.	.	
High	A(1)	2.488	.000	12.042	
	L (0)	.	.	.	

Reference category is low and lean (0) is used as the baseline.

Results from model 1 and model 3 involve the investigation of order-lead speed and delivery speed respectively, both of which present similar results. The B coefficient in each of these models was found to be positive and significant for both medium and high categories, hence, agile firms (1) in comparison to lean firms (0) are significantly more likely to acquire high levels of performance concerning both total order-lead speed and delivery speed. In essence, these results suggest that agile firms (1) in comparison with lean (0) are significantly more likely to spend both 14-21 days (medium) and below 14 days (high) relative to spending more than 21 days (low) in terms of the total order-lead duration. Also, agile firms (1) in comparison with lean firms (0) are significantly more likely to spend between 1-3 days (medium) and below 1 day (high) relative to spending more than 3 days on delivery alone. Taking this into account, hypotheses $\mathbf{H_{Sa}}$ and $\mathbf{H_{Sc}}$ are both accepted.

Model 2, which investigated the frequency of deliveries, demonstrated mixed findings. For instance, the B coefficient within this model was negative (-.042) for the medium category and positive (2.576) for the high category. This implies that agile firms (1) when compared to lean firms (1) are less likely to possess medium levels of delivery frequency and more likely to acquire high levels of delivery frequency relative to the low category. However, the P value is only significant (.000) for the high category. Therefore, even though lean firms (1) in comparison with agile firms (0) are more likely to acquire medium levels of delivery frequency, this statement is not significant. This can also be supported using the examination of the Exp (B) column. For instance, agile firms (1) in comparison with lean firms (0) are only (1-0.959=.041) 4.1% less likely to acquire medium levels (dispatch above 20 but less than 40 orders per month) of performance relative to the low category (dispatch below 20 orders per month). However, agile firms (1) when compared to lean firms (0) are (13.139-1=12.13) 1213% more likely to acquire high performance levels (dispatch over 40 orders per month) relative to the low performance category (dispatch below 20 orders per month). For this reason, hypothesis $\mathbf{H_{Sc}}$ was accepted.

Model 4, which investigated manufacturing speed, was the only speed sub-variable which did not compliment the other speed items. For example, although the B coefficient concerning this regression was positive for both medium (.354) and high (.307) categories, the strength of these correlations was relatively weak. Furthermore, the P values for both medium and high categories were noted as .380 and .462 respectively, illustrating that neither category portrayed levels of significance. Therefore, using the Exp (B) column, although agile firms (1) when compared to lean firms (0) were (1.425-1= 0.425) 43% and (1-1.360= 0.36) 36% more likely to possess medium and high categories respectively relative to the low category, these were not of significance, leading to the rejection of hypothesis $\mathbf{H_{Sd}}$.

In order to examine overall speed levels, this study calculated the mean categorical value concerning each of the sub-variables (refer to overall cost efficiency levels for detailed description into how this was achieved, also see section 4.6). Firms were designated as low if acquiring a total speed performance value between 1 and 1.50; medium if acquiring a total speed performance value between 1.501 and 2.00; and high if acquiring a total speed performance value between 2.01 and 3.00 (see Table 6.4.4). The results for this regression are reported in Table 6.4.6 (model 5). The B coefficient was found to be positive for both medium (.885) and high (2.488) categories, and more importantly these were of significance. Therefore, using the Exp (B) column, agile firms when compared to lean firms are (1-2.423= 1.423) 142% and (12.042-1= 11.042) 1104% more likely to acquire medium and high levels of speed respectively, relative to the low category. As these findings clearly identified agile organisations to be more likely to outperform lean organisations, hypothesis $\mathbf{H_S}$ was accepted.

Summary

Overall, results from individual multinomial logistic regressions identified that agile firms in comparison with lean firms were significantly more likely to acquire high speed levels in terms of order-lead time, frequency of deliveries and delivery speed. Manufacturing speed was the only speed sub-variable that did not demonstrate levels of significance between the two manufacturing concepts.

Table 6.4.7: Hypothesis Outcomes for Speed Measures

Hypothesis	**Accept (A)/ Reject (R)**
H_S: Agile firms are more likely to attain higher speed levels when compared with lean firms.	**A**
H_{Sa}: Agile firms are more likely to attain higher order-lead time levels when compared with lean firms.	**A**
H_{Sb}: Agile firms are more likely to attain higher frequency of deliveries levels when compared with lean firms.	**A**
H_{Sc}: Agile firms are more likely to attain higher delivery speed levels when compared with lean firms.	**A**
H_{Sd}: Agile firms are more likely to attain higher manufacturing speed levels when compared with lean firms.	**R**

6.5 Conclusion

The aim of this chapter was to investigate statistical differences between each manufacturing concept in accordance with cost, dependability, quality and speed performance domains. As authors (Purvis *et al*., 2014) have continuously asserted that the key difference between the two manufacturing paradigms lies within the realm of flexibility, it was decided to keep this dimension of performance separate to the four performance dimensions named above. Table 6.5.1 provides a summary of the regression results obtained within this chapter. Each of the multinomial logistic regressions used low performance levels as the baseline for comparison, therefore Table 6.5.1 does not report on low performance levels. Light blue represents lean systems being more likely in comparison with agile systems, whereas dark blue represents lean systems significantly more likely in comparison with agile systems. On the contrary light pink represents agile systems being more likely in comparison with lean systems, and dark pink represents agile systems significantly more likely in comparison with lean systems.

Table 6.5.1: Cost, Dependability, Quality, Speed Summary

	Low	Medium	High
Revenue	-	A	L
Profit	-	L	L
Manufacturing Cost	-	L	L
Distribution Cost	-	L	L
Inventory Cost	-	A	A
Cost	-	L	L
Orders late	-	A	A
Wrong deliveries	-	L	L
Orders in stock	-	A	L
Lateness of orders	-	A	A
Dependability	-	A	A
Defects	-	L	L
Scrap Levels	-	L	L
Customer Complaints	-	L	L
Warranty Claims	-	L	L
Quality	-	L	L
Order-lead speed	-	A	A
Frequency of deliveries	-	L	A
Delivery speed	-	A	A
Manufacturing speed	-	A	A
Speed	-	A	A

Key: (Light Blue: Lean more likely; Dark Blue: Lean significantly more likely; Light Pink: Agile more likely; Dark Pink: Agile significantly more likely).

In summary, lean firms were identified as being significantly more effective in terms of costs and quality measures in comparison with agile systems. On the contrary, agile systems were recorded as being significantly more effective in terms of speed. Although, the overall measure of the dependability regression did portray agile systems as more likely to gain higher levels of efficiency in comparison with lean systems, this finding was not of significance.

Also, by conducting a final multinomial logistic within each of the four performance constructs allowed for the overall probabilities of each manufacturing domain to belong to either medium or high categories relative to the low categories to be calculated, and by using these probabilities, performance constructs can be ranked in terms of similarities or differences. For instance, in terms of each of the four performance constructs, findings revealed that speed was the largest differentiator between lean and agile systems. The second and third performance measures by which to differentiate lean and agile systems lie within cost and quality constructs respectively. As dependability failed to demonstrate significant differences between each manufacturing approach this was ranked as the last (fourth) performance measure. As multiple sources (Narasimhan *et al*., 2006; Purvis *et al*., 2014) have consistently advocated flexibility as a key performance measure separating lean and agile systems, the upcoming chapter will not just outline the flexibility trade-offs, but also determine if flexibility can outrank speed as the most significant performance construct by which to distinguish between the two manufacturing paradigms. In conclusion, findings from this chapter side with Skinner's (1969) theoretical declaration that no manufacturing strategy can compete on all performance measures, as trade-offs were apparent based on the analysis conducted.

CHAPTER 7 – ANALYSIS: LEAN & AGILE FLEXIBILITY TRADE-OFFS

The main objective of this chapter is to analyse multiple dimensions of flexibility and in turn complete answering RQ (b) *what are the trade-offs in performance between lean and agile manufacturing?* Although Chapter 6 did not reveal many differences in terms of dependability levels, clear disparities were evident in terms of cost, quality and speed performance constructs. Furthermore, the previous chapter revealed that of these four, speed was the most significant performance objective by which to distinguish lean and agile production concepts. Costs and quality were the second and third most important performance measures respectively, which could be assessed to disentangle the strengths between each of the manufacturing concepts. However, as mentioned throughout this thesis, as numerous studies (Naylor *et al*., 1999; Narasimhan *et al*., 2006, Purvis *et al*., 2014) have alleged flexibility as a crucial measure in which to distinguish the effects of lean and agile production, this dimension of performance was examined to a greater extent than the previous performance constructs. With this in mind the second objective for this chapter is to provide an answer concerning RQ (c): *Are flexibility trade-offs the most significant performance level by which to differentiate lean and agile firms?* Also, as flexibility, especially supply chain flexibility (SCF) is said to be within early stages of theoretical development (Bernardes and Hanna, 2009; Malhotra and Mackelprang, 2012), this was also explored in greater detail.

This chapter primarily comprises four sections. First, a statistical ratio analysis into the mean flexibility differences between each of the manufacturing approaches is provided. Second, regardless of lean or agile, the second section looks to investigate if each of the flexibility measures are positively or negatively related with one another. Third, this chapter illustrates the results for each of the multinomial logistic regressions when seeking to illustrate the likelihood of lean and agile manufacturing concepts acquiring different flexibility levels. In conjunction with the results obtained from the first three sections, the final section presents a flexibility framework by which to distinguish lean and agile systems.

7.1 Ratio Analysis

Nine levels of flexibility were investigated within the broader levels of EF and SCF, namely:

External Flexibility (EF) levels captured:

- **Volume Demand Flexibility:** Coefficient of variance in orders over a given time period.
- **Volume Cost Flexibility:** Mean total costs that are saved when doubling the output.
- **Product Mix Flexibility**: Number of unique products produced.
- **New Product Flexibility:** Duration of time (Days) required to design, configure and manufacture a new product.
- **Delivery Flexibility:** Mean delivery time that can be reduced when processing an order as urgent

Supply Chain Flexibility (SCF) levels captured:

- **Sourcing Flexibility:** Mean duration of time (Days) required to seek new suppliers.
- **Supplier base Flexibility:** Number of suppliers that are readily available.
- **Supplier Offering Flexibility:** Mean percentage change in output suppliers can accommodate.
- **Logistical Flexibility:** Total number of logistics organisations readily available when delivering products.

The review of the literature revealed that agile firms were expected to acquire higher flexibility levels when compared with lean firms; however, the motivation for this chapter is to not only examine if this statement is true, but to assess how much more flexible agile firms are in comparison with lean firms.

Mean flexibility levels between lean and agile firms are reported in Table 7.1.1, which also illustrates the results of a ratio analysis which looked to explore the proportional difference in mean flexibility levels between lean and agile systems. Taking lean manufacturing systems as the base (1), the flexibility ratios are shown in Table 7.1.1. Before analysing this table, it is important to be reminded that new product flexibility and sourcing flexibility were measured where time (t) was the unit of measurement and where time is expected to have an inverse relationship with flexibility levels, hence the greater the number the less flexible the firm. Sourcing flexibility was proportionally calculated as having the greatest difference in flexibility levels between lean and agile firms (1: 0.21), suggesting that the average lean firm may require over four times the duration of agile firms when sourcing new suppliers. Tachizawa and Thomsen (2007) asserted that as a mode of measuring SCF, sourcing flexibility can evaluate a firm's ability to redesign its current SC in order to meet the market demand. The remaining SCF measures captured in this study did not illustrate differences between lean and agile systems to the same extent as sourcing flexibility, however new product flexibility and mix flexibility were proportionally calculated as the second (1: 0.29) and third (1: 2.84) largest differences. The average agile firm was approximately three times more flexible in comparison with the average lean firm across these two dimensions. The average agile firm in comparison with the average lean was found to be almost threefold (1: 2.70) more cost effective when doubling the output in volume. Furthermore, the average agile firm was recorded as being just over twofold more flexible in terms of volume flexibility (1: 2.22) and just under twofold more flexible in terms of delivery flexibility (1: 1.91). In addition, the average agile firm had just under 50% more suppliers available to choose from. Lean and agile illustrated relatively even levels of logistic flexibility and supplier offering flexibility. Results from this table can imply that the average agile firm is likely to be approximately two and a half times more flexible in comparison with the average lean manufacturing firm.

In conclusion, results support existing theory as agile firms have significantly higher flexibility levels (Naylor *et al*., 1999; Narasimhan *et al*., 2006; Gunasekaran *et al.*, 2008; Hallgren and Olhager, 2009; Purvis *et al.,* 2014), particularly in terms of volume demand flexibility, mix flexibility, new product flexibility, delivery flexibility and sourcing flexibility. However, results do not support the argument that lean manufacturing firms attain high levels of product mix flexibility (Naylor *et al.*, 1999). Table 7.1.1 not only reports on the mean flexibility levels between lean and agile manufacturing systems, but also examines flexibility levels at different levels of the SC, which reveals that no matter whether lean or agile, flexibility levels increase lower down the SC.

Table 7.1.1: Mean Flexibility Levels between Lean and Agile Systems

		F_v cv	F_{vc} %	F_m number	F_n days	F_d days	F_s days	F_{sb} number	F_l days	F_o %
Lean										
N = 12	OEM	.223	3.7	69	45	2.5	24.8	19.6	2.6	8.9
N = 26	1st	.276	4.1	177	50	3.5	24.4	16.6	2.6	14.3
N = 17	2nd	.265	5.1	226	45	3.2	23.2	18.6	2.7	22.6
N = 14	3rd	.286	6.8	226	41	3.6	21.6	23.0	2.9	27.0
N = 6	4th & 5th	.317	6.2	295	39	4.2	20.0	26.2	3.0	29.8
N = 74	Mean	0.270	5.3	199	44	3.5	23.1	19.0	2.69	23.2
Agile										
N = 4	OEM	.572	9.0	470	15	5.9	5.3	25.5	2.8	11.3
N = 10	1st	.570	12.6	530	15	6.5	5.3	25.2	2.8	22.2
N = 15	2nd	.579	12.8	534	12	6.4	4.6	26.2	3.0	26.7
N = 19	3rd	.617	13.9	540	12	6.8	4.9	28.0	3.4	31.2
N= 18	4th & 5th	.670	14.6	571	10	7.2	3.5	32.1	3.8	34.3
N = 66	Mean	0.612	14.2	537	13	6.72	4.71	27.5	3.3	28.48
Mean Ratio	L: A	1 : 2.22	1 : 2.70	1: 2.84	1 : 0.29	1 : 1.91	1 : 0.21	1 : 1.45	1 : 1.22	1 : 1.22
Total										
N = 16	OEM	.367	6.1	169	37	4.4	19.9	21.2	2.6	9.5
N = 36	1st	.373	7.9	295	33	4.6	17.4	21.6	2.6	16.6
N = 32	2nd	.440	9.0	399	33	4.7	13.4	21.8	2.8	24.5
N = 33	3rd	.438	10.8	403	25	5.7	13.4	24.7	3.2	29.8
N= 23	4th & 5th	.542	11.1	472	18	5.7	9.0	26.2	3.6	33.2
N = 140	Mean	.431	9.6	359	29	5.0	14.4	23.0	3.0	23.4

Nine independent T-Tests were conducted in order to determine if there was a significant difference between the nine flexibility measures in association with lean and agile manufacturing systems (see Table 7.1.2). With the exception of logistical flexibility, which had a P value of 0.06, the P values for the remaining eight independent T-tests were less than 0.05, which supports the assertion (Naylor *et al*., 1999; Yusuf *et al.,* 2003; Narasimhan *et al*., 2006; Gunasekaran *et al*., 2008) that flexibility can distinguish lean and agile manufacturing systems. Even though the T-Test for logistic flexibility had a P value of 0.06, this was only slightly above the significance criteria, therefore a large difference may still be observed.

Table 7.1.2: Flexibility T-Tests

Flexibility Dimensions	Sig. (2-tailed)
F_v	.000
F_{vc}	.000
F_m	.000
F_n	.000
F_d	.000
F_s	.000
F_{sb}	.010
F_l	.040
F_o	.060

7.2 Inter-Flexibility Correlations

Before moving on to the findings from the regression, a Pearson correlation test was conducted in in order to determine if all nine flexibility measures were of significantly correlated with one another and the results are reported in Table 7.2.2. Before examining the results from Table 7.2.2, it is important to consider the operationalisation of flexibility in terms of range and mobility, which was discussed in the Methodology Chapter (section 4.5.3). Three groupings (volume, variety, delivery) were compiled within EF, where the range and mobility concerning delivery flexibility are captured within SCF and EF respectively. In terms of SCF, the main theme within lean and agile literature is supplier flexibility (Purvis *et al.*, 2014), with some advocating logistic flexibility, which can be argued as the range of delivery flexibility. In terms of supplier flexibility, supplier base flexibility was used as the range for this measure and both sourcing flexibility and supplier offering flexibility as the mobility of supplier flexibility. Table 4.5.6 in the Methodology highlighted the range and mobility of each of the constructs.

The correlations between the range and mobility concerning volume, variety, delivery, and supplier flexibility are highlighted in Table 7.2.2. The range and mobility concerning variety flexibility illustrated the highest level of correlation (-.731**) among the four paired combinations, however the actual strongest correlation (831**) between any two combinations was found between sourcing flexibility and new product flexibility. According to the literature, the ease with which an organisation can change SC partners is directly linked with supplier base (Gosain *et al*., 2004; Sánchez and Pérez, 2005), and the ability to change delivery dates is strongly linked with firms involving the use of multiple logistics organisations (Gosling *et al*., 2010). Even though the range and mobility concerning both supplier flexibility combinations (-.341**, -.452**) and delivery flexibility (.321**) portrayed significant levels of correlation, the strength of these two correlations was not as high as expected or as other flexibility correlations. As the range and mobility concerning volume, delivery and supplier flexibility did not reveal such large correlations as other paired combinations, this study did not incorporate them further when seeking to distinguish lean and agile systems. Results from Table 7.2.2 also show logistic flexibility and supplier base flexibility (.117), and supplier offering flexibility and logistic flexibility (.165) not to be correlated, as they were the only combinations which did not acquire levels of significance. In addition, logistic flexibility only illustrated levels of 0.05 significance with volume flexibility demand (.191*), product mix flexibility (.207*) and sourcing flexibility (-.187*). The remaining possible flexibility combinations demonstrated correlations which were of significance at the 0.01 level.

Individual flexibility correlations were also conducted within lean and agile systems separately. Due to the limited responses within each paradigm, the majority of flexibility correlations among lean and agile systems alone did not portray the same levels of significance as results in Table 7.2.2.

Table 7.2.2: Inter-Flexibility Pearson Correlation Coefficients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
F_v (1)	1								
F_{vc} (2)	-.452**	1							
F_m (3)	.697**	-.518**	1						
F_n (4)	-.678**	.525**	-.731**	1					
F_d (5)	.597**	-.382**	.554**	-.666**	1				
F_s (6)	-.668**	583**	-.730**	.831**	-.670**	1			
F_{sb} (7)	.310**	-.282**	.375**	-.375**	.304**	-.341**	1		
F_l (8)	.191*	-.243**	.207*	-.235**	.321**	-.187*	.117	1	
F_o (9)	.396**	-.518**	.511**	-.443**	.359**	-.452**	.286**	.165	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

7.3 Regression Analysis

Table 7.3.1 illustrates the parameters distinguishing firms as low, medium and high based upon flexibility variables. Table 7.3.2 further outlines the frequency of lean and agile firms deemed to be performing low, medium and high in association with each respective flexibility variable. Before moving on to the regression analysis is important to note that Schwab (2002) suggested that accurate logistic results would need to entail a minimum of 10 responses per group. However, due to the vast disparity in certain measures of flexibility, namely; volume flexibility demand; product mix flexibility; new product flexibility and sourcing flexibility it was not possible to distinguish three groups of performance (low, medium, high) and allocate an approximate number of 10 responses within certain groups. When it is not possible to allocate 10 responses within each categorical group, Schwab

(2002) has stated that unrealistic probabilities will be generated, which is the case for the four levels of flexibility in this case. With this in mind, it is expected that the multinomial logistic regressions results would have produced high/unrealistic categorical probabilities for each of the four flexibility levels addressed previously. Therefore, results from each of the multinomial regressions can be argued to be limited, which may explain why unrealistic Exp (B) values were obtained, but results can still be used to determine levels of significance.

Table 7.3.1: Flexibility Parameters: Low (1), Medium (2) & High (3)

Flexibility	1 (Low)	2 (Medium)	3 (High)
Volume Flexibility Demand	$0 < x \leq 0.25$	$0.25 < x \leq 0.50$	$x > 0.50$
Volume Flexibility Cost	$0 < x \leq 10$	$10 < x \leq 20$	$x > 20$
Mix Flexibility	$0 < x \leq 200$	$200 < x \leq 400$	$x > 400$
New Product Flexibility	$x > 28$	$27 < x \leq 14$	$x < 14$
Delivery Flexibility	$0 < x \leq 2$	$2 < x \leq 4$	$x > 4$
Sourcing Flexibility	$x > 15$	$14 < x \leq 7$	$x < 7$
Supplier Base Flexibility	$0 < x \leq 15$	$15 < x \leq 25$	$x > 25$
Logistic Flexibility	$0 < x \leq 2$	$2 < x \leq 4$	$x > 4$
Supplier Offering Flexibility	$0 < x \leq 20$	$20 < x \leq 30$	$x > 30$
Average Flexibility	1-1.49	1.50-1.99	2.0-3.0

Note: New product flexibility and sourcing flexibility inversely coded i.e. the smaller the value the greater the performance.

Table 7.3.2: Distinguishing Lean and Agile Based on Flexibility Parameters

	Flexibility	1 (Low)	2 (Medium)	3 (High)
Lean	Volume Flexibility Demand	30	41	3
	Volume Flexibility Cost	41	10	13
	Mix Flexibility	44	27	3
	New Product Flexibility	64	7	3
	Delivery Flexibility	14	51	9
	Sourcing Flexibility	60	12	2
	Supplier Base Flexibility	25	39	10
	Supplier Offering Flexibility	38	26	10
	Logistic Flexibility	12	43	19
Agile	Volume Flexibility Demand	3	14	49
	Volume Flexibility Cost	22	20	34
	Mix Flexibility	1	8	57
	New Product Flexibility	5	27	34
	Delivery Flexibility	11	17	38
	Sourcing Flexibility	5	16	45
	Supplier Base Flexibility	11	19	36
	Supplier Offering Flexibility	13	24	29
	Logistic Flexibility	10	25	31

Table 7.3.4 illustrates the results for nine independent multinomial regressions which were conducted in order to determine if agile firms were more likely to acquire higher levels of flexibility when compared with lean firms. Low flexibility levels were used as the reference category and lean firms were used as the baseline for comparison. In essence, results reported in Table 7.3.4 correspond to agile firms in comparison with lean systems relative to the reference (low) category. For instance, if the B coefficient was positive then agile systems in comparison with lean systems are more likely to be placed within the respective category, whereas if the B coefficient was negative then agile systems in comparison with lean systems are less likely to be placed within the respective category. Furthermore, if the P value is less than 0.05 then regressions can be deemed to be of significance.

Unsurprisingly, the four flexibility sub-variables (volume flexibility demand, product mix flexibility, new product flexibility, sourcing flexibility) which demonstrated the largest ratio differences (see Table 7.1.1) between lean and agile firms all obtained regression results which identified that agile firms (1) when compared to lean firms (0) were significantly more likely to acquire both medium and high levels of flexibility relative to the low category. It may be argued that these results are limited due to the number of responses within each category, however, there is no doubt that lean and agile manufacturing firms can be differentiated based upon each of these four flexibility levels. With this in mind, section 7.4 attempts to use each of these measures of flexibility to solely distinguish lean and agile systems. However, for the time being all four hypotheses referring to each of these flexibility measures, $\mathbf{H_{Fa}}$; $\mathbf{H_{Fc}}$; $\mathbf{H_{Fd}}$; and $\mathbf{H_{Fg}}$ can be accepted.

Table 7.3.4: Multinomial Logistic Regression Results for Flexibility

Model 1 Volume Flex Demand	L/A	B	Sig	Exp (B)	Nagelkerke .529
Medium	A (1)	1.228	.071	3.415	
	L (0)	.	.	.	
High	A (1)	5.096	.000	163.33	
	L (0)	.	.	.	
Model 2 Volume Flex Cost	L/A	B	Sig	Exp (B)	Nagelkerke .161
Medium	A (1)	-.071	.880	.932	
	L (0)	.	.	.	
High	A (1)	1.584	.000	4.874	
	L (0)	.	.	.	
Model 3 Mix Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .779
Medium	A (1)	2.568	.018	13.037	
	L (0)	.	.	.	
High	A (1)	6.729	.000	836	
	L (0)	.	.	.	
Model 4 New Prod Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .692
Medium	A (1)	3.899	.000	49.371	
	L (0)	.	.	.	
High	A (1)	4.977	.000	145.067	
	L (0)	.	.	.	
Model 5 Delivery Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .168
Medium	A (1)	-.639	.197	.528	
	L (0)	.	.	.	
High	A (1)	.934	.057	2.545	
	L (0)	.	.	.	
Model 6 Sourcing Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .698
Medium	A (1)	2.773	.000	16.00	
	L (0)	.	.	.	
High	A (1)	5.598	.000	270	
	L (0)	.	.	.	
Model 7 Supplier Base Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .189
Medium	A (1)	.061	.894	1.063	
	L (0)	.	.	.	
High	A (1)	1.966	.000	7.140	
	L (0)	.	.	.	
Model 8 Logistical Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .060
Medium	A (1)	-.360	.468	.698	
	L (0)	.	.	.	
High	A (1)	.672	.195	1.958	
	L (0)	.	.	.	
Model 9 Supplier Off Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .174
Medium	A (1)	.993	.020	2.698	
	L (0)	.	.	.	
High	A (1)	2.137	.000	8.477	
	L (0)	.	.	.	
Model 10 Overall Flexibility	L/A	B	Sig	Exp (B)	Nagelkerke .428
Medium	A (1)	1.534	.003	4.636	
	L (0)	.	.	.	
High	A (1)	2.923	.000	17.00	
	L (0)	.	.	.	

Reference category is low and lean (0) is the baseline.

Results from model 2 (volume cost flexibility) found the B coefficient to be negative (-.071) for the medium category and positive (1.585) for the high category. However, the P value was not of significance for the medium category, but was of significance for the high category. Therefore, agile firms (1) when compared with lean firms (0) were not significantly less likely to acquire medium levels of volume cost flexibility, but were significantly more likely to acquire high levels of volume cost flexibility relative to the low performance group. Therefore, hypothesis $\mathbf{H_{Fb}}$ was accepted.

Model 5, which examined delivery flexibility, revealed interesting findings. For instance, the B coefficient was found to be negative (-.639) for the medium category and positive (.934) for the high category and each of these categories acquired P values of .197 and .057 respectively. Therefore, agile firms (1) in comparison with lean firms (0) are (1-.528 = .472) 47.2% less likely to acquire medium levels of delivery flexibility relative to the low category, but (2.545-1 = 1.545) 155% more likely and almost significantly more likely to acquire high levels of delivery flexibility relative to low levels. As this model failed to produce results of significance, hypothesis $\mathbf{H_{Fe}}$ was rejected.

Model 8, which investigated logistical flexibility, also shared similarities with Model 5. For instance, the B coefficient was once again found to be negative (-.360) for the medium category and positive (.672) for the high category, acquiring P values of .468 and .195 respectively. Unlike model 5, the P value concerning the high category (.195) within Model 8 was far greater, therefore agile firms (1) when compared with lean firms (0) were not significantly more likely to acquire high levels of logistic flexibility. In conjunction with the Exp (B) column the it can be stated that agile firms (1) when compared with lean firms (0) are (1-.698= .302) 30.2% less likely to acquire medium levels of logistic flexibly relative to the low category, and (1.958-1= .958) 95.8% more likely to acquire high levels of logistic flexibility relative to the low category. However, as these findings were not of significance hypothesis $\mathbf{H_{Fi}}$ was rejected.

Model 7 and model 9, which investigated supplier base flexibility and supplier offering flexibility, illustrated similar results. For instance, both models acquired positive B coefficients for the high category with values of 1.966 and 2.137 respectively, with both of these models being of significance. With the use of the Exp (B) column, agile firms (1) in comparison with lean (0) were (7.140-1= 6.140) 614% and (8.477-1= 7.477) 748%, and significantly, more likely to acquire high levels of supplier base flexibility and supplier offering flexibility respectively relative to low levels of flexibility. Therefore, both hypotheses ($\mathbf{H_{Ff}}$ and $\mathbf{H_{Fh}}$) were accepted.

Similar to each of the four performance constructs in the previous chapter, in order to examine overall flexibility levels, this study calculated the mean categorical value concerning each of the sub-variables (refer to overall cost efficiency levels for detailed description into how this was achieved, also see section 4.6). Firms were categorised as low if acquiring a mean flexibility value between 1 and 1.49; medium if acquiring a mean flexibility value between 1.50 and 1.99; high if acquiring a mean flexibility value between 2.00 and 3.00. In essence, assigning a single value that corresponded approximately to a mean flexibility value allowed for the creation of parameters that could distinguish firms as being low, medium or high. Therefore, this allowed for an additional multinomial regression to investigate if there were significant differences between varying levels of overall flexibility and lean and agile manufacturing firms. The results for this regression are reported as model 10 in Table 7.3.4. Based on the parameters highlighted earlier, agile firms (1) when compared to lean firms (0) were (4.636-1=3.636) 363.6% and (17.0-1=16) 1600%, and significantly more likely of acquiring both medium and high mean flexibility levels respectively relative to low levels of flexibility. For this reason, hypothesis $\mathbf{H_F}$ was accepted. Also, results from this regression revealed that out of all the overall performance models conducted in the previous chapter, results from this model revealed the largest disparity between lean and agile firms. Therefore, flexibility can be acknowledged as the most crucial performance measure by which to distinguish between lean and agile firms.

Summary

In summary, with the exclusion of delivery flexibility and logistical flexibility, all the hypotheses were accepted as agile systems were significantly found to be superior to lean systems. In addition, volume flexibility demand, product mix flexibility, new product flexibility, sourcing flexibility revealed the greatest differences between lean and agile firms. With the exclusion of the four flexibility measures named previously, the remaining items, namely: volume flexibility cost; delivery flexibility; supplier base flexibility; logistic flexibility; and supplier offering flexibility, acquired less diverse results. Table 7.3.5 outlines all the hypotheses that were accepted or rejected based upon findings from the regression analysis.

Table 7.3.5: Hypothesis Outcomes for Flexibility Measures

Hypothesis	Accept (A)/ Reject (R)
H_F: Agile firms are more likely to attain higher flexibility levels when compared with lean firms.	A
H_{Fa}: Agile firms are more likely to attain higher volume flexibility demand levels when compared with lean firms.	A
H_{Fb}: Agile firms are more likely to attain higher volume flexibility cost levels when compared with lean firms.	A
H_{Fc}: Agile firms are more likely to attain higher product mix flexibility levels when compared with lean firms.	A
H_{Fd}: Agile firms are more likely to attain higher new product flexibility levels when compared with lean firms.	A
H_{Fe}: Agile firms are more likely to attain higher delivery speed flexibility levels when compared with lean firms.	R
H_{Ff}: Agile firms are more likely to attain higher supplier base flexibility levels when compared with lean firms.	A
H_{Fg}: Agile firms are more likely to attain higher sourcing flexibility levels when compared with lean firms.	A
H_{Fh}: Agile firms are more likely to attain higher supplier offering flexibility levels when compared with lean firms.	A
H_{Fi}: Agile firms are more likely to attain higher logistic flexibility levels when compared with lean firms.	R

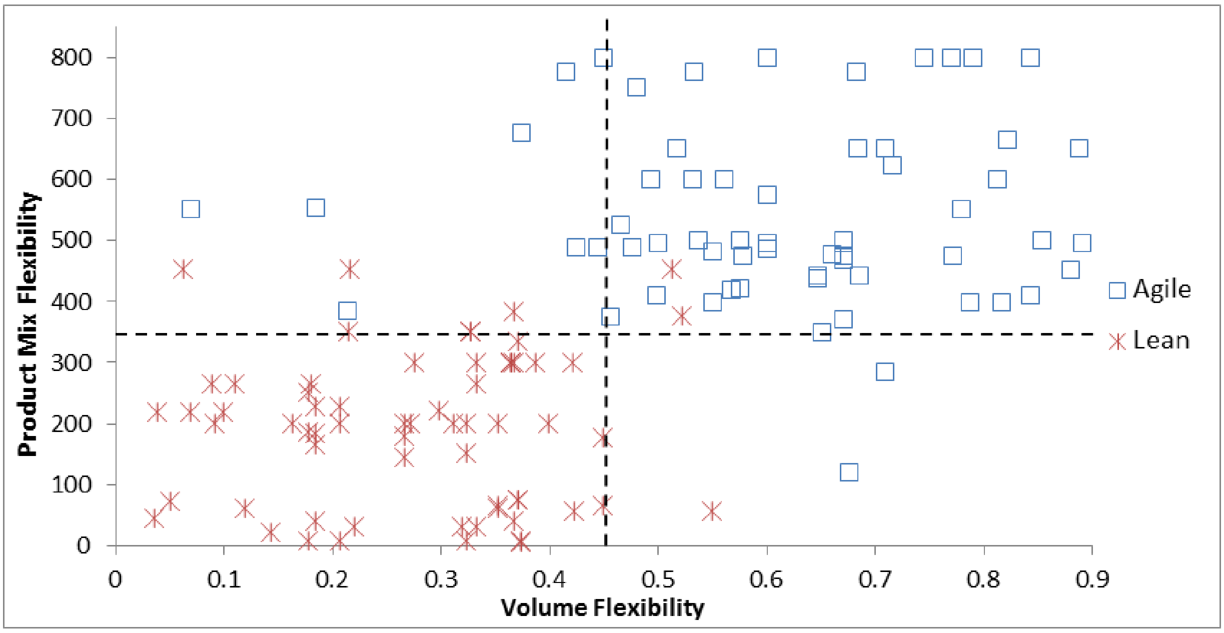
7.4 Developing a Revised Framework to Distinguish Lean and Agile Systems

In order to develop a similar framework to the one in which Naylor *et al.* (1999) distinguished lean and agile manufacturing systems, this study selected four flexibility variables (volume flexibility, product mix flexibility, new product flexibility, sourcing flexibility) which illustrated both the largest ratio differences between lean and agile and the strongest correlations amongst each other. Furthermore, these four measures of flexibility illustrated large disparities between lean and agile manufacturing systems and as such they could not be separated into three categories (low, medium, high) which produced realistic categorical probabilities within each of the multinomial logistic regressions.

Volume Flexibility & Mix Flexibility

The scatter graph in Figure 7.4.1 illustrates volume flexibility on the y-axis and mix flexibility on the x-axis. The majority of lean firms acquired a volume flexibility (CV) figure less than 0.45. The mean volume flexibility (CV) concerning lean manufacturing organisations was calculated as 0.270, which indicated that over the time period of 12 months, an assumption can be made that the uniformity of orders generally deviated to a small extent. In opposition, the volume flexibility (CV) concerning agile manufacturing organisations was relatively high, and the mean volume flexibility (CV) was calculated as 0.612. Therefore, the uniformity of demanded orders varied to a greater extent in comparison with lean manufacturers. In terms of product mix flexibility, it is apparent that lean manufacturers produce low levels of different products in comparison with agile manufacturers. A cut-off point, which distinguishes lean and agile most effectively suggests that lean firms generally produce no more than 350 unique products, whereas agile systems can produce up to a total of 800 different products. The mean number of different types of products produced was 190 and 539 for lean and agile manufacturing firms respectively. In conclusion, results upheld Naylor *et al.'s* (1999) statement that agile firms have high volume and mix flexibility levels, however contradicted the assumption that lean manufacturing systems can actually attain high levels of mix flexibility.

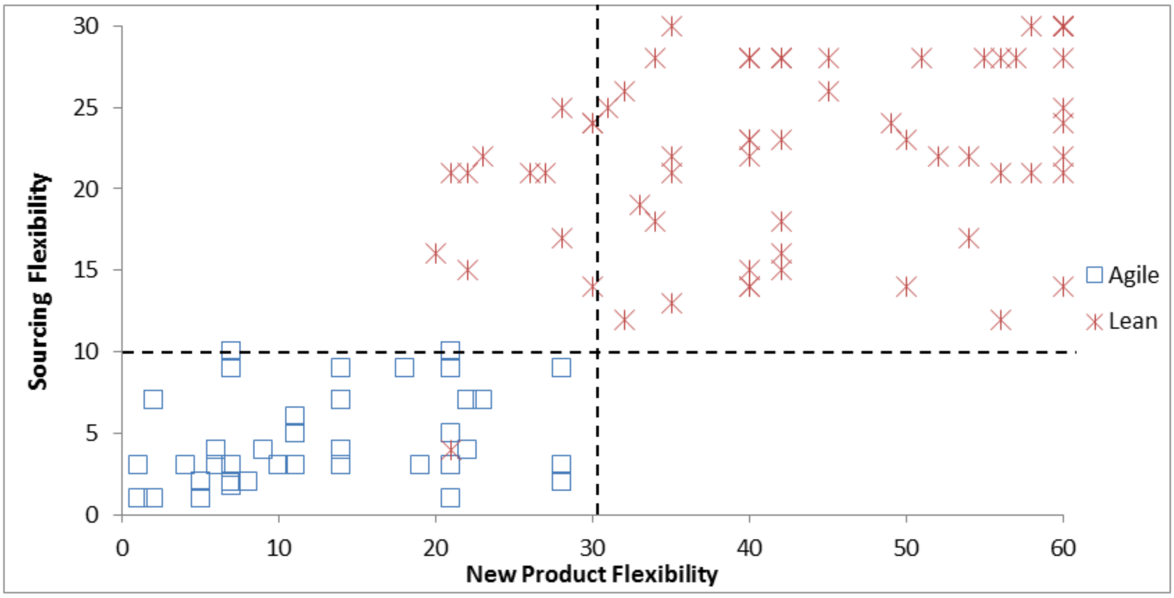
Figure 7.4.1: Comparing Volume Flexibility in Relation to Mix Flexibility



New Product Flexibility & Sourcing Flexibility

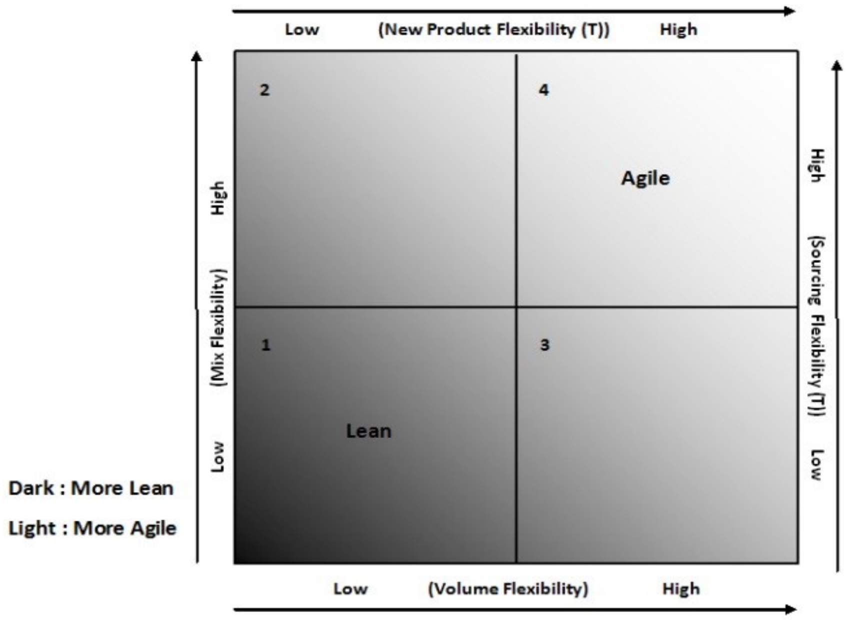
Figure 7.4.2 illustrates new product flexibility on the x-axis and sourcing flexibility on the y-axis. As flexibility is measured where response time is the unit measurement (Reichhart and Holweg, 2007), it would be expected that time has an inverse relationship with flexibility. Therefore, it would be expected for results would show flexible (agile) firms to be at the top right hand corner of this graph. A cut-off point, which distinguishes lean and agile to the greatest extent within Figure 7.2.4 is drawn between each flexibility measure. Agile firms ranged from taking between 1-30 days when introducing new products into their system, which is far less than the 30-60 taken by lean firms. Agile firms require 1-10 days when sourcing different suppliers, whereas lean firms generally required a range of between 10-30 days. The mean new product flexibility times within lean and agile systems were calculated as 44 days and 13 days respectively. Furthermore, the mean times required when sourcing new suppliers within lean and agile systems were calculated as 23 days and 5 days respectively. Results upheld Reichart and Holweg's (2007) assertion that speed and responsiveness can distinguish both concepts. In conclusion, a firm's ability to redesign its current SC in order to meet the market demand (Tachizawa and Thomsen, 2007) is not only directly linked with the ease at which a firm can introduce new products within its organisation (Beamon, 1999), but can be used as a key factor to add clarity to the confusion (Narasimhan *et al*., 2006) concerning the performance capabilities of lean and agile systems.

Figure 7.4.2: Comparing New Product Flexibility in Relation to Sourcing Flexibility



Naylor *et al.*, (1999) suggested that lean manufacturing systems can possess either low levels of volume flexibility and low levels of product mix flexibility, or low levels of volume flexibility and high levels of product mix flexibility. In contrast, agile manufacturing systems could possess high levels of both volume flexibility and product mix flexibility. Therefore, Naylor *et al.*, (1999) proposed the shading in their depiction of this phenomenon should not be evenly distributed diagonally (see Figure 3.5.1). However, results from this study (Figure 7.4.1) indicate that lean manufacturing firms generally do *not* acquire low levels of volume flexibility and high levels of product mix flexibility simultaneously, rather, this study found lean organisations to be acquiring low levels of both volume flexibility and product mix flexibility. These results contradict findings presented by Naylor *et al*., (1999) and received wisdom more generally, as findings from this study suggest that the shading should be dispersed evenly diagonally. By measuring a range of EF and SCF measures, this study found that volume flexibility, product mix flexibility, new product flexibility and sourcing flexibility portrayed the greatest difference over other flexibility levels when distinguishing lean and agile. In addition, these four flexibility levels also portrayed the strongest correlations amongst one another than the remaining flexibility combinations. With this in mind, this investigation set out to develop a more refined framework, following Naylor *et al.*'s (1999) (see Figure 3.5.1) attempt to distinguish lean and agile systems.

Figure 7.4.3: Volume Flexibility, New Product Flexibility, Product Mix Flexibility and Sourcing Flexibility Distinguishing Lean and Agile



Suitable cut-off points were selected which most effectively distinguished lean and agile systems. Firms located in quadrant 1 within Figure 7.4.3, attain low flexibility levels in each of the four dimensions, in contrast, firms located in quadrant 4 possess high flexibility levels in all four dimensions of flexibility. The set of parameters used in identifying and separating low (lean) and high (agile) flexible firms are outlined below:

Low (Lean) Flexible Firms:

- Volume flexibility: Coefficient of variance in demanded orders is below 0.45
- Product Mix Flexibility: Produce less than 350 unique products
- New Product Flexibility: The time required to introduce new products is greater than 30 days
- Sourcing Flexibility: The time required to source new suppliers is greater than 10 days

High (Agile) Flexible Firms:

- Volume flexibility: Coefficient of variance in demanded orders is greater than 0.45
- Product Mix Flexibility: Produce more than 350 unique products
- New Product Flexibility: The time required to introduce new products is less than 30 days
- Sourcing Flexibility: The time required to source new suppliers is less than 10 days

Table 7.4.1 highlights the reliability of using Figure 7.4.3 when distinguishing each manufacturing concept. Previously, using a 22 variable scorecard that measured certain practices associated with lean and agile manufacturing, 66 firms were identified as manufacturing using agility as their dominant concept, and 74 firms were manufacturing using lean manufacturing as their dominant concept. With regards to the parameters highlighted above, 66 out of the possible 74 lean firms can be placed in quadrant 1, whilst 56 out of the possible 66 agile firms can be placed in quadrant 4. These findings suggest that Figure 7.4.3 can be used as a viable tool when distinguishing lean and agile firms, as it was 89% and 88% reliable in accordance with the original scorecard respectively. Despite Figure 7.4.3 illustrating consistency when distinguishing lean and agile firms, it only accounts for four possible combinations out of the possible sixteen that can be made between each of the four flexibility measures. Lean firms that were not positioned in quadrant 1 attained a minimum of one high level of flexibility. Similarly, agile firms that were not positioned in quadrant 4 attained a minimum of one low level of flexibility. However as the majority of firms can be placed into these four combinations, it is plausible to suggest that the range of and the ability to accommodate change in production output (Gosling *et al.,* 2010), the time required between product mix changes (Beamon, 1999), the ease at which an organisation may change SC partners (Gosain *et al*., 2004; Sánchez and Pérez, 2005) and the ability to accommodate the production of new products (Gosling *et al.*, 2010) can be used to distinguish between lean and agile systems

Table 7.4.1: Testing the Reliability of Figure 7.4.3 when Distinguishing Lean and Agile Firms

Manufacturing Strategy	N (Number of Respondents)	Using Figure 7.4.3 to Distinguish Lean & Agile	Reliability of Using Figure 7.4.3
Lean	74	66 (Low (LLLL))	89%
Agile	66	56 (High (HHHH))	88%

7.5 Conclusion

This chapter explored the relationship between flexibility and lean and agile manufacturing systems, with the contention in the literature, that agile outperforms lean production in terms of EF and SCF, but lean production methods can also lead to high product mix flexibility. Overall, results from this chapter upheld findings from previous studies (Naylor *et al.*, 1999; Narasimhan *et al.*, 2006; Stevenson and Spring, 2007; Hallgren and Olhager, 2009; Purvis *et al*., 2014) which found flexibility to be a useful performance measures for distinguishing lean and agile manufacturing systems. The main findings from each of the predicted models are summarised in Table 7.5.1.

Table 7.5.1: Flexibility Regression Summary

External Flexibility	Low	Medium	High
Volume Flexibility Demand	-	A	A
Volume Cost Flexibility	-	A	A
Product Mix Flexibility	-	A	A
New Product Flexibility	-	A	A
Delivery Flexibility	-	L	A
Supply Chain Flexibility			
Sourcing Flexibility	-	A	A
Supplier Base Flexibility	-	A	A
Logistic Flexibility	-	L	A
Supplier Offering Flexibility	-	A	A
	-		

Key: (Light Blue: Lean more likely; Dark Blue: Lean significantly more likely; Light Pink: Agile more likely; Dark Pink: Agile significantly more likely).

Each of the multinomial logistic regressions used low performance levels as the baseline for comparison, therefore, the table does not report on low performance levels. Light blue represents lean systems being more likely in comparison with agile systems, whereas dark blue represents lean systems significantly more likely in comparison with agile systems. On the contrary, light pink represents agile systems being more likely in comparison with lean systems, and dark pink represents agile systems being significantly more likely in comparison with lean systems. Unsurprisingly no regression reported lean systems as significantly more likely to acquire either medium or high flexibility levels in comparison to agile systems. Even though agile systems were significantly found to be more likely to achieve high levels of flexibility within the majority of flexibility dimensions, in terms of delivery flexibility and logistic flexibility they were deemed as just likely and not of significance based upon the parameters used within this chapter. Interestingly, this study refutes Naylor *et al.'s* (1999) assertion that lean manufacturing systems can also attain high levels of mix flexibility, as based on the parameters set within this chapter lean systems generally did not attain high levels of mix flexibility. Furthermore, findings from this chapter also demonstrated that generally lean and agile levels of EF are far greater than the differences observed within SCF levels.

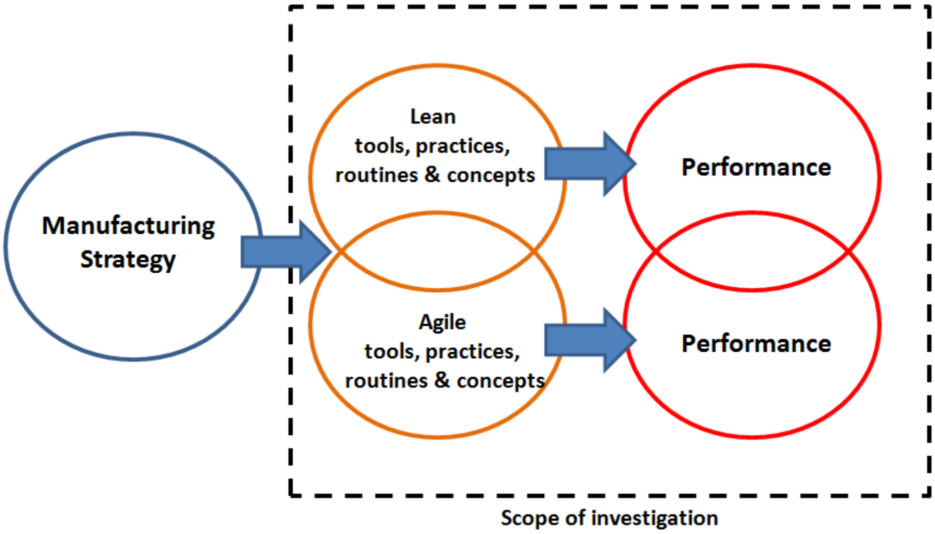
CHAPTER 8 - DISCUSSION

The main aim of this chapter is to discuss each of the research questions set. Initially, although briefly, this chapter reinforces the theoretical context upon which this investigation was based. Second, the discussion presents whether or not contextual factors bare a relationship with each of the manufacturing approaches. Next, this chapter discusses the performance trade-offs between each of the manufacturing paradigms in relation to existing views, as well as discussing which performance constructs are the most pivotal when seeking to distinguish between lean and agile production. Fourth, this chapter discusses findings from the contextual analysis, with an emphasis on supply chain positional tier, and the performance trade-offs in association with one another.

8.1 Theoretical Context

In summary, the theoretical underpinning of this thesis is based upon Skinner's (1969) claim that no manufacturing strategy, and in turn organisation, is able to compete on all levels of performance, with trade-offs inevitably present if they attempt to do so. With this in mind, firms acquire the relevant resources and capabilities in order to implement the necessary tools, practices, routines and concepts which are focussed to their performance priorities (see Figure 8.1.1). As well as drawing on the resource based view of the firm, this chapter incorporates a Resource Dependence Theory (RDT) perspective too; however, it is vital to stress that this investigation was not built upon RDT, rather it is used to speculate and rationalise why certain findings were evident within the ASC.

Figure 8.1.1: Theoretical Model



As previously mentioned, the problem presented in this investigation concerns the growing sense of confusion in relation to lean and agile paradigms (Narasimhan *et al*., 2006). The literature within the realms of lean manufacturing and agile production have, individually, urged that each of the paradigms can lead to both business and operational benefits. Therefore, what are the differences between effects of lean and agile production?

Chapter 3 (section 3.6 - Research Gap) established that there are only a handful of studies which have outlined the performance trade-offs between each of the approaches, and the studies which have looked into this matter have either presented contrary findings or measured a finite number of dimensions. Taking all of this into account, in order to prove some clarity into each of these issues, the following research question was presented, followed by 3 sub-questions.

RQ - What are the trade-offs between lean and agile manufacturing?

(a) What are the trade-offs in contextual factors between lean and agile manufacturing?

(b) What are the trade-offs in performance between lean and agile manufacturing?

(c) Are flexibility trade-offs the most significant performance level by which to differentiate lean and agile firms?

With these questions in mind, the following two sections focus on answering these questions based on the analysis of empirical data.

8.2 Contextual Factors Discussion

Before examining the trade-offs concerning lean and agile performance levels, the review of the literature revealed that contextual factors, also known as external factors, can play a role in determining the likelihood of firms being either lean or agile in nature. Hence, the following research question was set: *RQ (a) what are the trade-offs in contextual factors between lean and agile manufacturing?* With this in mind, Chapter 5 looked to investigate if there were individual relationships between the manufacturing strategy adopted and external factors, namely: firm age, manufacturing size, manufacturing classification, and positional tier within the ASC.

Shah and Ward (2003) have previously asserted that that older organisations are less likely to innovate their operational practices, as they be may be more resistant to change, and with this in mind, the first part of Chapter 5 looked to investigate if there was an association between firm age and manufacturing strategy employed (lean/agile). The notion of age playing a pivotal role has been supported by evolutionary economics, as this perspective states that older organisations have well-established routines and find it difficult accepting ‘newer’ practices (Nelson and Winter, 1982), even though they may be more beneficial for the firm. Although findings (see Table 5.2.2 and Table 5.2.3) tended to support the perspective that lean and agile firms were more likely to be ‘older’ and ‘younger’ in age respectively, these findings were not significant, hence the hypothesis was rejected. As these assertions were not of significance, results from this study side with Osterman’s (1994) finding that firm age does not play a pivotal role in practices employed by organisations, contrary to Shah and Ward’s (2003) findings.

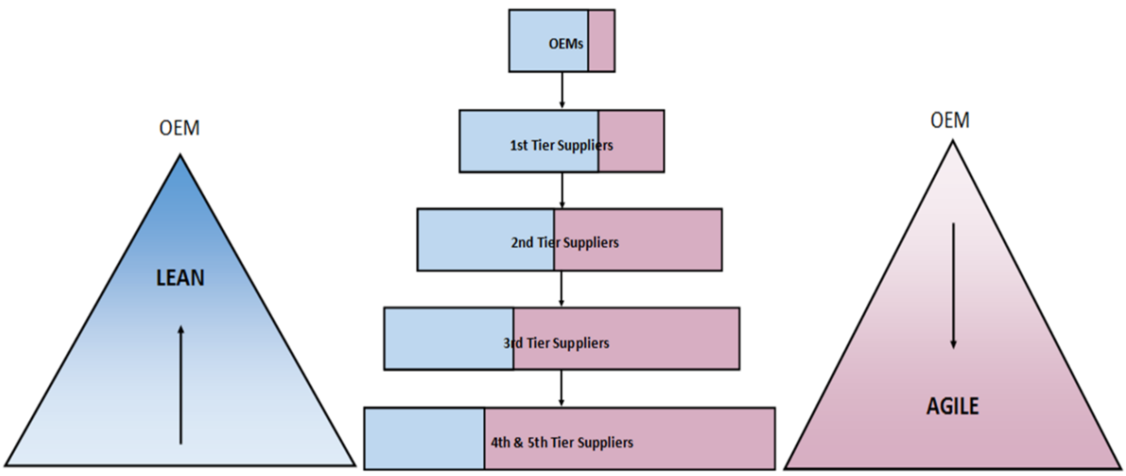
Next, as the automotive industry encompasses a range of firms from different sub-manufacturing industries, the second part of Chapter 5 looked to explore if there was a relationship between manufacturing classification and manufacturing strategy pursued. This test was theoretically grounded on the Fisher Model (Fisher, 1997). The notion here was that as the Fisher Model suggested firms producing innovative products were likely to be agile and firms producing functional products were likely to be lean, therefore firms operating within a highly innovative industry were conceptualised to be more likely to be agile, and firms operating in an industry with low levels of innovation were conceptualised to be more likely to be lean. It is important to recognise that the Fisher Model (1997) concens products, therefore, as findings were in the context of manufacturing industries, results do not necessarily support/reject the Fisher Model (1997). Findings suggested that even though there were clear disproportionalities in the number of lean and agile firms within selected sub-manufacturing categories, the majority of industries did not seem to portray such differences between the number of lean and agile firms. This could be explained by the fact that as this study only received 140 responses from 10 sub-manufacturing industries, it was not viable to conduct statistical regression analysis.

Nevertheless, overall there seemed to be a fairly consistent proportion of firms implementing each of the operational strategies, as 53% of organisations were identified as lean and 47% of firms were categorised as agile.

The third part of Chapter 5 involved determining if there was a relationship between firm size and the manufacturing concept employed. Once again, although findings tended to support the perspective that lean firms were more likely to be large and agile firms were more likely to be small. However, this was disputable as results were not of significance (see Table 5.3.2 & Table 5.3.3). Before disregarding the notion of lean is for large and agile is for small, it is important to note that the majority of organisations which participated in this study were SMEs, hence it could have been expected that the majority of firms should have been agile in nature, contrary to what was actually found, and in turn contradicting prior literature which states that larger firms are more likely to be lean (Narasimhan *et al*., 2006; Bonavia and Marin, 2006) and smaller firms more likely to be agile (Cohen and Klepper, 1992). However, as the majority of responses were from SMEs, this may have jeopardised the results and in turn explain why significant differences were not found.

The final and arguably most important findings from Chapter 5 extend the discussion (Reves *et al*., 2015; Sezen *et al*., 2012) concerning the positional tier to which individual firms belong to within the ASC. Findings (see Table 5.5.2 & Table 5.5.3) suggested that agile firms when compared with lean firms were 64%, and significantly, less likely to be positioned at the top (OEM & 1st tier) of the ASC relative to the middle (2nd tier) of ASC, and lean firms in comparison to agile firms were 179%, and significantly, more likely to be positioned at the top (OEM & 1st tier) of the ASC relative to the middle (2nd tier) of the ASC. Also, results revealed that agile firms in comparison to lean firms were 660%, and significantly, more likely to be positioned at the bottom (3rd, 4th & 5th tiers) of the ASC relative to the top (OEM & 1st tier) of the ASC, and lean firms in comparison to agile firms were 87%, and significantly, less likely to be positioned at the bottom (3rd, 4th & 5th tiers) of the ASC relative to the top (OEM & 1st tier) of the ASC. Figure 8.2.1, the Lean Agile Automotive Supply Chain (LAASC) Model, is therefore used to illustrate where lean and agile firms are positioned within the ASC. Triangles are used to represent the size of the ASC, for example, with a limited number of OEMs at the top and a vast number of 3rd, 4th and 5th tier suppliers at the base. The shading within each of the two triangles reflects the positioning of lean and agile firms within the ASC. For instance, the lean triangle suggests lean firms are located in the higher tiers of the ASC, and the agile triangle suggests that agile firms are located in the lower tiers of the ASC. In essence, there is an inverse relationship between each of the triangles.

Figure 8.2.1: The Lean Agile Automotive Supply Chain (LAASC) Model



Although findings concerning positional tier share similarities with recent lean studies (Marodin *et al.*, 2016; Tortorella *et al.*, 2017a), findings from this study are in direct contradiction to traditional thinking behind lean, agile and 'leagile' SCs. For instance, Mason-Jones *et al*. (2000) suggested that when operating within a 'leagile' SC, a decoupling point occurs where lean and agile activities meet. Firms within SCs were the unit of analysis. It is these organisations that provide the components and parts to construct the finished vehicle and which, together, form the value chain. In other words, the physical value chain is made up of firms carrying out production activities in order to create the final product. Given this, this study conceptualised the decoupling point as the point in the SC in which the majority of firms switch from predominantly employing TPRCs associated with lean production to TPRCs associated with agile production. In the analysis, this occurred at the third tier and beyond. 'Leagile' SC literature suggests that lean firms are located at the lower levels of a SC and operate upstream, enabling a level schedule in output. In contrast, agile firms are located at the top or higher levels of the respective 'leagile' SC, and operate downstream from the decoupling point, ensuring there is an agile response capable of delivering to an unpredictable marketplace. However, findings from this study suggest that when operating within a complex SC, lean firms were found to be operating downstream, whereas agile firms were found to be operating upstream.

Therefore, by taking the LAASC Model, as well as a RBV perspective, into account, it may be argued that firms implementing lean resources and capabilities (TPRCs), that compete on costs and efficiency levels, are more likely to be located at the top of the SC. In contrast, firms implementing agile resources and capabilities (TPRCs), who compete on flexibility and speed, are more likely to be located at the lower end of the SC. Although this directly contests Mason-Jones *et al*. (2000) as well as received wisdom, these varying competitive priorities within different tiers of the ASC are in line with assertions made by Doran (2004) and Boonsthonsatit and Jungthawan (2015). Furthermore, Marodin *et al*. (2016) and Tortorella *et al*. (2017a) also found firms to be leaner at the top tiers of an ASC and although their research did not look into the concept of agility, their findings did reveal firms positioned at the lower levels of the ASC to be less lean. In contrast, results contest findings by Tortorella *et al*. (2017b). However, as mentioned previously, Tortorella *et al*. (2017b) suggested their findings may have been an anomaly as the Brazilian ASC encompasses firms of oligopoly status lower down the ASC, which is why Panizzolo *et al.* (2012) suggested that SCs in developed and developing countries should be treated separately in this regard.

In summary, the main objective of Chapter 5 was to answer the following research question '*What are the trade-offs in contextual factors between lean and agile manufacturing*?'. In association with Contingency Theory, the research question is answered as contextual factors can play a part in differentiating between lean and agile organisations, especially the role of positional tier. However, results obtained in this study refuted some of the misconceptions concerning lean and agile production relative to contextual factors (Hines *et al*., 2004; Marodin *et al*., 2016; Tortorella *et al*., 2017a). For instance, although lean firms were expected to be larger and older in age when compared with agile firms, the results concerning these contextual factors were not of significance. Therefore, lean and agile firms could not be differentiated based upon firm size or firm age. Thus, findings side with Furlan *et al*. (2011) and Lucato *et al*. (2014). However, positional tier was an important and significant factor that could distinguish lean and agile organisations. Before developing the LAASC Model and the role of SC positional tier further, it is necessary to address the performance trade-offs between each of the manufacturing approaches, which are discussed within the following section.

8.3 Performance Trade-Offs

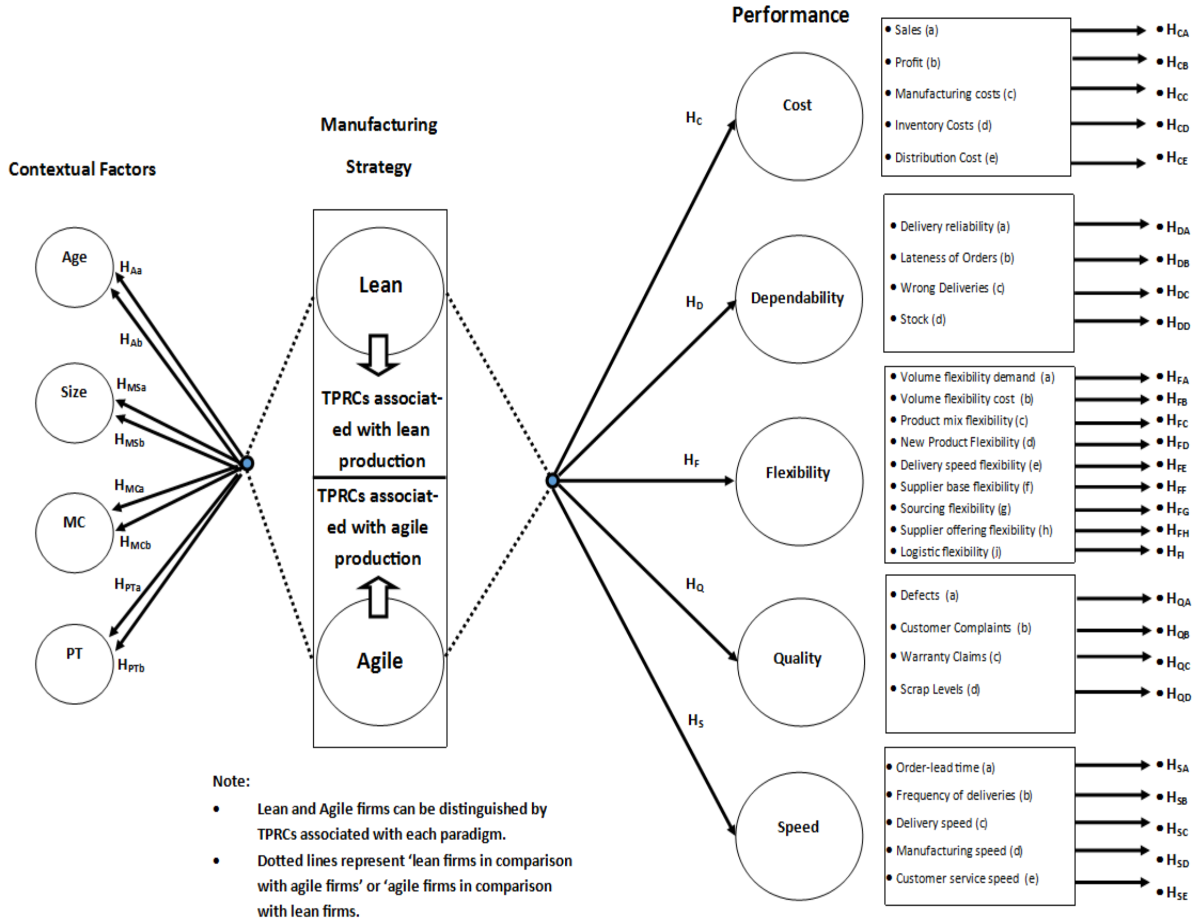
Results from Chapter 6 and Chapter 7 looked into the cost, dependability, flexibility, quality and speed performance trade-offs between lean and agile systems. In essence, the main aim of these respective chapters were to provide answers to the following two RQs:

(b) What are the trade-offs in performance between lean and agile manufacturing?

(c) Are flexibility trade-offs the most significant performance level by which to differentiate lean and agile firms?

In conjunction with the conceptual framework, a summary of the results from each of the performance measures are reported in Figure 8.3.1. It is crucial to remember that this investigation is primarily concerned with which manufacturing strategy, out of lean and agile, outperformed the other. With this in mind, each of the performance construct were categorised into low, medium and high, and multinomial logistic regressions were conducted where low performance was used as the reference category. Taking this into account, the table in Figure 8.3.1 does not report on low performance levels. In essence, with regards to the table in Figure 8.3.1, light blue represents lean firms when compared with agile firms as being more likely to be positioned within that performance group relative to the low performance group, whereas dark blue represents lean firms when compared with agile firms as being significantly more likely to be positioned within that performance group relative to the low performance group. On the contrary, light pink represents agile firms when compared with lean firms as being more likely to be positioned within that performance group relative to the low performance group, whereas dark pink represents agile firms when compared with lean firms as being significantly more likely to be positioned within that performance group relative to the low performance group.

Figure 8.3.1 Conceptual Framework Results



Cost		Low	Medium	High
a)	Revenue		A	L
b)	Profit	-	L	L
c)	Manufacturing Cost Efficiency	-	L	L
d)	Distribution Cost Efficiency	-	L	L
e)	Inventory Cost Efficiency	-	A	A
	H_C Overall Cost	-	L	L
Dependability				
a)	Delivery Reliability	-	A	A
b)	Lateness of Orders	-	A	A
c)	Wrong Deliveries	-	L	L
d)	Stock	-	A	L
	H_D Overall Dependability	-	A	A
Quality				
a)	Defects	-	L	L
b)	Scrap Levels	-	L	L
c)	Customer Complaints	-	L	L
d)	Warranty Claims	-	L	L
	H_Q Overall Quality	-	L	L
Speed				
a)	Order-lead speed	-	A	A
b)	Frequency of deliveries	-	L	A
c)	Delivery speed	-	A	A
d)	Manufacturing speed	-	A	A
	H_S Overall Speed	-	A	A
Flexibility				
a)	Volume Flexibility Cost	-	A	A
b)	Volume Flexibility demand	-	A	A
c)	Product Mix Flexibility	-	A	A
d)	New Product Flexibility	-	A	A
e)	Delivery Flexibility	-	L	A
f)	Supplier Base Flexibility	-	A	A
g)	Sourcing Flexibility	-	A	A
h)	Supplier Offering Flexibility	-	L	A
i)	Logistic Flexibility	-	A	A
	H_F Overall Flexibility	-	A	A

Note:

- Lean and Agile firms can be distinguished by TPRCs associated with each paradigm.
- Dotted lines represent 'lean firms in comparison with agile firms' or 'agile firms in comparison with lean firms.

Table 8.3.1: Pearson Correlations Matrix of Performance Constructs

Performance	Cost (1)	Dependability (2)	Flexibility (3)	Quality (4)	Speed (5)
(1)	1				
(2)	.079	1			
(3)	-.370**	-.037	1		
(4)	.399**	.092	-.395**	1	
(5)	-.229**	173*	461**	-.165	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Before discussing the differences in performance which were identified between lean and agile firms, it is important to acknowledge the trade-offs in performance variables, irrespective of lean and agile strategies. Table 8.3.1 illustrates a Pearson correlation between the mean categorised performance constructs, which were used in each of the five overall cost, dependability, flexibility, quality and speed regressions. Results go hand-in-hand with Skinner's (1969) assertion, as trade-offs are evidentially apparent. This table shows the combination of: costs and quality; and flexibility and speed to be positively and significantly correlated at the 0.01 level. However, costs are negatively and significantly correlated with flexibility and speed at the 0.01 level, while flexibility is negatively and significantly correlated with quality and costs. Dependability, was the only performance measure which did not reveal much in terms of trade-offs. This should not come as a surprise, as the trade-offs outlined in this table were the factors which distinguished lean and agile firms. The following section will discuss each of the lean and agile findings reported in Chapters 7 and 8.

Before discussing each of the performance dimensions that illustrated clear discrepancies between the two manufacturing concepts, it is important to discuss the similarities, as this may help to explain why there may be confusion within the literature. Dependability, which revolves around the factors which contribute towards an organisation providing a good/service as and when they are required or needed by customers (Slack *et al*., 2010), was the only performance dimension which failed to signify which manufacturing strategy was significantly superior to the other. The reasoning into why the final regression (see Table 6.2.6) looking into overall dependability levels did not reveal significant differences between each of the manufacturing paradigms stems from the mixed results acquired amongst the sub-dependability variables. For instance, results from Table 6.2.6 illustrated lean firms as being significantly more dependable in terms of wrong deliveries in comparison with agile systems, whereas agile systems were found as significantly being more dependable in terms of lateness of orders. Even though significant differences could not be found between the percentage of orders that were late and percentage of orders in stock, results did imply that agile systems were more likely to score higher in terms of not delivering orders late, and lean systems were more likely to score higher in terms of orders being readily available in stock. In an attempt to suggest why agile systems were significantly more likely to be dependable in terms of lateness of orders and more dependable in terms of orders being late, it is important to look at the results concerning distribution cost performance. For instance, results from Table 6.1.6 identified lean firms as significantly more cost effective in terms of distribution costs, hence they were spending less of distribution in comparison with agile firms. Therefore, agile firms were spending significantly more on distribution costs in comparison with lean firms, which may explain why agile firms were performing better in terms of orders being late. Also, results from Table 6.2.6 found that overall both medium and high levels of dependability were more likely to be ascribed with agile systems as opposed to lean systems, however this finding was not of significance.

As a whole, dependability was identified as the only performance domain which clear differences between each of the manufacturing concepts could not be distinguished. However, dependability results from this study still hold quantifiable relevance, as for instance when observing the reliability and dependability of lean and agile production, Hallgren and Olhager (2009) also observed similarities between each of the manufacturing approaches. Therefore, in terms of dependability, it may be argued that results from this thesis support Hallgren and Olhager's (2009) findings, but contradict findings presented by Cagliano *et al*. (2004) and Narasimhan *et al*. (2006), who both identified lean systems as being significantly more dependable in terms of reliability.

Investigations into the quality trade-offs between the manufacturing concepts have often reported mixed findings. For instance, Hallgren and Olhager (2009) found that lean initiatives were generating a greater impact on quality performance levels in comparison with agile initiatives, a view which was complemented by Agarwal *et al*. (2006), who also found that firms acting within a lean system acquired higher levels of quality supply chain weighted index performance in comparison with agile systems. However, this was contended by Yusuf and Adeleye (2002), who actually found little to no correlations between quality levels and agile systems. Although this was not supported by Narasimhan *et al*. (2006), as their investigation actually found that agile systems were slightly more associated with higher quality levels (design quality and conformance quality) in comparison with lean systems. Taking these mixed views into account, surprisingly, findings from Chapter 6 (see Table 6.3.6) revealed lean firms to be more associated with high quality performance levels concerning defects, scrap levels and customer complaints. In fact, results form Table 6.3.6 suggest that, in terms of probability, lean systems in comparison with agile organisations were up to 10 times, 9 times and 7 times more likely to acquire high levels of quality concerning defects, scrap levels and customer complaints respectively, relative to low quality levels. Warranty claims was the only sub-variable within the quality construct which did not illustrate a significant association with lean systems in comparison to agile systems. In an attempt to provide reasoning to why lean systems are superior in terms of quality in comparison with agile systems, it is necessary to acknowledge the strengths of agile systems. For example, the philosophy behind agile manufacturing lies within the realms of change, hence, the capability to change rapidly in face of ever changing demand conditions (Naylor *et al*., 1999). Therefore, if agile systems are constantly producing new products, or a mix of products, which requires them to continuously form a temporary network of suppliers (Browne and Zhang, 1999), is it unreasonable to assume that large internal and external variances are likely to experience more human/machine error in comparison with a lean system which exhibits small internal and external variances within the production process?

In summary, although studies (Sharifi and Zhang, 2001; Jin-Hai *et al*., 2003; Vazquez-Bustelo and Avella, 2007) have advocated that agile systems can acquire high levels of quality via the implementation of TQM, a management philosophy that urges continuous improvements, meeting customer requirements, employee involvement and competitive benchmarking. Results from this study suggest that although agile firms may implement TPRCs associated with quality control, they were significantly less likely to be obtaining as high levels of quality in comparison with lean firms. Overall, this study supports Agarwal *et al*.'s (2006) and Hallgren and Olhager's (2009) findings, as they too found higher levels of quality within lean systems, as opposed to agile systems.

In terms of cost performance, findings from Table 6.1.6 clearly illustrate lean systems as being far superior to agile systems as they were significantly more likely to acquire high profit levels, manufacturing cost efficiency levels, distribution cost efficiency levels and overall cost levels. However, results from the revenue regression suggested that although lean systems are generally significantly more likely to be more cost-effective in comparison with agile systems, this does not necessarily result in the generation of higher revenue, as no significant differences were identified between the three levels of revenue.

Multiple sources have attributed agile manufacturing with systems that produce highly profitable goods. For example, Bruce *et al.* (2004) and Agarwal *et al.* (2006) have suggested that lean systems universally have low profit margins, whereas agile systems have large profit margins. Furthermore, Clegg and Wan (2013) have previously outlined that firms operate within virtual enterprises in order to exploit specific opportunities within the market, where high levels of profitability is a key driving force. On the other hand, firms operating in 'less open' enterprises, i.e. the lean firms, acquire advantage and compete on economies of scale, therefore are less likely to be profitable as organisations operating within virtual enterprises. However, results from this study refute this view, as Table 6.1.6 identified lean firms as producing goods of significantly higher profit margins in comparison with agile systems. For instance, when lean firms were compared with agile firms, regression analysis revealed them to be approximately 3 times and 12 times more likely of acquiring profits of 5-10% and above 10% respectively, relative to acquiring profits below 5%. In order to understand why lean systems were acquiring higher profit margins in comparison with agile organisations it may be necessary to examine the additional cost items captured within this study. For instance, the majority of lean firms were observed to be spending a significantly lower proportion of total sales on manufacturing and distribution activities alone, hence, they are deemed more cost-effective than agile firms. With this in mind, it can be asserted that agile systems are generating lower profit margins in comparison comparison with lean systems as they are spending significantly more on manufacturing and distribution, which in turn is 'eating' into their profit margins. In fact, one may suggest that as lean firms were identified as significantly more likely to outperform agile firms in terms of defects, this may explain why agile firms were reported to spend a greater proportion of their total sales on manufacturing. Therefore, it can be argued that results from this chapter proposes a new way of theoretical thinking, as costs and quality were directly related, which has often been debated in the past. Furthermore, linking this with the literature on enterprise management, one could argue that firms operating in 'less open' enterprises, are more likely to be profitable in comparison with virtual enterprises, as efficiencies in economies of scale (delivery, quality) outweigh the financial profits of manufacturing within a dynamic market.

Results from Table 6.1.6 also provide an insightful finding concerning inventory cost efficiency levels. Notwithstanding lean being more cost-effective in terms of manufacturing and distribution activities, agile systems were in fact deemed significantly more cost-effective in terms of inventory costs. The reason why lean firms were not as cost-effective in terms of inventory can be explained by analysing the percentage of orders readily available in stock within the dependability performance domain (see Table 6.2.6). Although lean firms were not significantly more likely, they were found to be more likely to accumulate a greater percentage of orders in stock in comparison with agile firms. As agile manufacturing is synonymous with the production of goods that have shorter life-cycles (Mason-Jones *et al*., 2000; Bruce *et al*., 2004, Agarwal *et al*., 2006), whereas lean production is more associated with products of longer life-cycles, this may indeed help to explain why lean systems were identified as spending significantly more on costs associated with inventory. For instance, as lean systems are producing goods of longer life-cycles, they are most likely to generate additional stock in comparison with agile systems, who are producing goods of shorter life-cycles, which may explain why lean systems are observed as being less inventory cost-effective in comparison with agile systems.

In summary, literature within the broad realms of lean manufacturing has undoubtedly linked this paradigm with efficiency and cost control. Results from this thesis support existing views (Yusuf and Adeleye, 2002; Narasimhan *et al*., 2006; Gunasekaran *et al*., 2008; Agarwal *et al*., 2006) that lean systems are more cost-effective in comparison with agile systems, however, results from this study can also be used to show that lean systems are actually less cost-effective in terms of inventory costs in comparison with agile systems, but are more likely to generate higher profit margins. The notion here is that the lean organisations implement TPRCs (5S, production smoothing, line balancing, continuous improvement and cellular manufacturing) which allow them to acquire cost strengths within manufacturing and distribution activities. Acquiring cost strengths within these two activities ultimately outweighs the drawbacks of holding higher levels of stock, which is why these firms are generating greater levels of profit margin in comparison with agile organisations.

Agile manufacturing has been universally ascribed with responding quickly to sudden changes in the market environment (Naylor *et al*., 1999) via the implementation of TPRCs such as reconfiguration, rapid-prototyping, concurrent engineering and operating within a virtual enterprises. Taking this into account, it is no surprise that, in terms of speed, results uphold and support existing views within the literature. For instance, Table 6.4.6 clearly identified that the total time required to manufacture and deliver (order-lead) products, as well as delivery, were recorded as being significantly lower within agile firms, as opposed to lean firms. On the contrary, Hallgren and Olhager (2009) previously found that both lean and agile manufacturing to be associated with high levels of delivery speed, however, their results did show this to be slightly more associated within agile systems. Using parameters of greater than three days, greater than one day but less than three days, and less than or equal to one day, representing low, medium and high delivery speed levels respectively, results from this study found that agile firms, when compared with lean firms, were significantly more likely to acquire medium and high delivery speed performance levels relative to low levels. Contrary to popular belief, lean firms when compared with agile firms were more likely to acquire medium levels of frequency of deliveries per month. However, before proceeding with the notion that lean systems may indeed be more effective in terms of frequency of deliveries, results from Table 6.4.6 went on to illustrate that agile organisations were significantly more likely to acquire high levels of frequency of deliveries per month in comparison with lean firms, which is what was expected.

Manufacturing speed was the only sub-variable within the speed construct in Table 6.4.6 which could not significantly distinguish lean and agile firms. A closer examination of this table reveals that agile system were indeed more likely to achieve high levels of manufacturing speed in comparison with lean systems, but this observation was not of significance. With this in mind, if agile firms were not significantly manufacturing products at a faster speed in comparison with lean organisations, it raises the question of why agile systems are observed as requiring significantly less order-lead time.

In an attempt to answer this question, it is crucial to revisit delivery speed and frequency of deliveries within Table 6.4.6. Findings from this table identified agile organisations as significantly more likely to produce greater levels of frequency of deliveries, which in turn can explain why agile systems are requiring significantly less time in terms of delivery speed alone. Therefore, although lean and agile systems required a similar amount of time to manufacture a product, findings from this study suggest that agile systems were significantly more likely to spend more on delivery costs (see Table 6.1.6), hence, explaining why agile systems were not recorded as being cost-effective in term of distribution costs, but why they gain an advantage in terms of total order-lead time. This is in line with previous findings, as Narasimhan *et al*. (2006) also found agile firms to be far more effective than lean firms in terms of delivery speed.

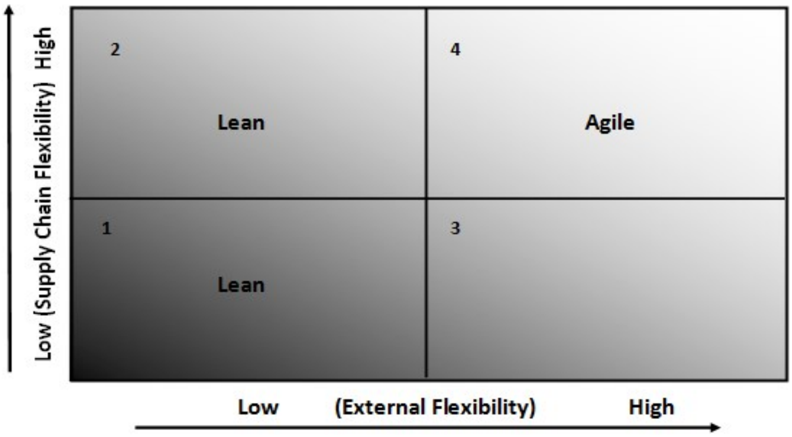
As flexibility has frequently been presented as a crucial measure by which to distinguish lean and agile systems (Purvis *et al.,* 2014), it was analysed in greater depth than the other performance constructs. Arguably, the regression results presented in Table 7.3.4 are rather limited, as it was not possible to categorise flexibility into three levels (low, medium, high) and acquire a minimum of 10 responses within each grouping. However, this difficulty complements received wisdom and goes hand-in-hand with the literature, as flexibility has been observed to demonstrate significant differences between each of the concepts (Narasimhan *et al*., 2006; Reichhart and Holweg, 2007; Gunasekaran *et al.,* 2008).

Furthermore, flexibility findings go hand-in-hand with the discussion surrounding enterprise management. For instance, Clegg and Wan (2013) asserted that there are three enterprise structures, and that the virtual enterprise structure is associated with the most agile form of enterprise. This was supported in the findings, as agile firms possessed a large supplier base (supplier base flexibility), and therefore required significantly less time when seeking new suppliers (sourcing flexibility) in comparison with lean firms. These findings imply that agile firms are more likely to be the firms that develop short-term collaborations with their suppliers. Flexibility findings concerning lean firms generally suggested that such organisations were operating under a vertically integrated enterprise structure. For instance, their respective pool of readily available suppliers was notably lower in comparison with agile firms, and therefore lean firms required more time when seeking new suppliers. This would suggest that lean firms develop longer-term relationships with their suppliers. Overall, lean and agile disparities seem to reflect those found within vertically integrated enterprises and virtual enterprises respectively (Binder and Clegg, 2007a, 2007b; Clegg and Wan, 2013). Importantly, this is not to say that lean firms did not demonstrate collaboration, rather, results implied that they experience lower levels of collaboration when compared with agile firms.

In fact, results from four flexibility variables, namely: volume flexibility demand, product mix flexibility, new product flexibility, and sourcing flexibility, were used to present a model that almost perfectly distinguished lean and agile manufacturing systems from one another (see Figure 7.4.3). For instance, 89% of all lean firms acquired the following: volume flexibility demand: coefficient of variance in demanded orders was below 0.45; product mix flexibility: less than 350 unique products produced; new product flexibility: the time required to introduce new products was greater than 30 days; sourcing flexibility: the time required to source new suppliers was greater than 10 days. On the other hand, 88% of all agile manufacturing systems acquired the following: volume flexibility demand: coefficient of variance in demanded orders was greater than 0.45; product mix flexibility: produce more than 350 unique products; new product flexibility: the time required to introduce new products is less than 30 days; sourcing flexibility: the time required to source new suppliers is less than 10 days. Using these respective cut-off points, and following Naylor *et al's*. (1999) model (see Figure 3.5.1), Chapter 7 went on to develop a revised model (Figure 7.4.3) which could be used as a viable tool to distinguish between the strategies. These findings were not surprising given that literature (Naylor *et al.,* 1999; Yusuf *et al*., 2003) has stated that for agile manufacturers, high flexibility levels may create large internal and external variances concerning factors such as volume, variety, delivery and supplier capabilities. By contrast, lean manufacturers aim to gain competitive advantage by becoming as efficient as possible which in turn reduces the internal and external variances of the same factors. Although Naylor *et al.,* (1999) previously suggested that lean manufacturing systems can acquire high levels of mix flexibility resulting in the capability to produce a large range of products, based on the parameters used within this study, findings from this investigation contend their assertion as lean firms were not observed to be generating high levels of mix flexibility.

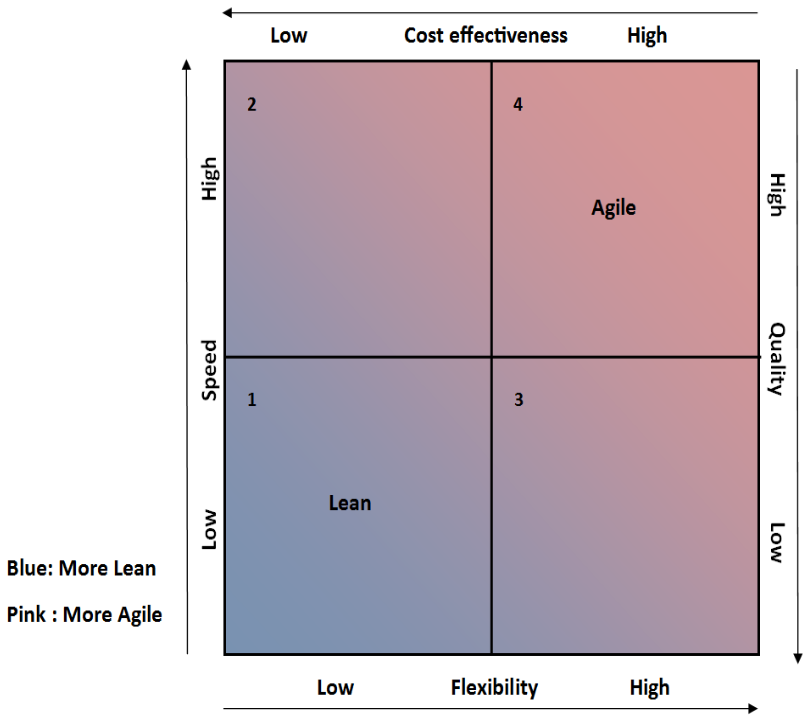
As mentioned in the literature review, current discussion surrounding flexibility has been more focussed on the SC context, as the literature (Pujawan, 2004; Sanchez and Perez; 2005; Swafford *et al*., 2006; Stevenson and Spring, 2007; Purvis *et al*., 2014) have advocated that examining individual firm flexibility levels is arguably too narrow. In line with this, organisations wishing to increase flexibility levels are now looking to examine their partners and linkages within their SCs, as this may affect performance levels within their individual firm (Swaminathan, 2001). Therefore, in order to grasp a rigorous understanding of flexibility, studies need to incorporate dimensions which include both traditional EF and SCF levels. Taking this into account, the final discussion point in terms of flexibility concerns extending the conversation (Bernardes and Hanna, 2009; Malhotra and Mackelprang, 2012) surrounding EF and SCF simultaneously. In terms of EF, findings from Chapter 7 illustrated agile systems as being far superior in comparison with lean, as mean proportional differences were up to fourfold more flexible. With the exception of sourcing flexibility, SCF variables failed to illustrate differences to the same extent as EF levels, as results from Table 7.1.1 illustrate that supplier base flexibility, logistic flexibility and supplier offering flexibility did not portray such large differences between lean and agile firms in comparison to volume flexibility, new product flexibility, product mix flexibility and delivery flexibility. As research into SCF is within early stages of development (Bernardes and Hanna, 2009; Purvis *et al.,* 2014), this study proposes that Figure 8.3.2 may act as a starting point when identifying lean and agile differences concerning both SCF and EF. Firstly, it is crucial to note this matrix is rather rectangular, which is to emphasise that there are large differences between lean and agile EF levels, but, relative to EF, there are smaller differences between lean and agile SCF levels. Figure 8.3.2 also proposes that lean firms can acquire either; low levels of EF and SCF levels or low levels of EF levels and high levels of SCF, whereas agile systems acquire high levels of both EF and SCF levels. With this in mind, it raises the question of why lean systems portray smaller SCF flexibility differences in comparison to EF. Section 8.4 will bridge the findings concerning positional tier and the performance trade-offs, and in turn attempt to answer to this question.

Figure 8.3.2: EF and SCF within Lean & Agile Systems



In summary, results from this thesis suggest that lean systems are significantly more likely to outperform agile systems in terms of costs and quality, while agile systems are significantly more likely to generate higher levels of speed and flexibility. This is depicted in Figure 8.3.3 - the LAPD (Lean Agile Performance Differences) Model. Importantly, dependability is not illustrated within Figure 8.3.3, as mixed findings within this construct illustrated that no significant differences were observed between each of the manufacturing concepts. In terms of proportionality, the likelihood of agile firms acquiring high levels of speed and flexibility strengths far exceeded the likelihood of lean systems acquiring high levels of costs and quality. Using the probabilities from each of the overall regressions conducted in Chapter 6 and Chapter 7, flexibility was observed as being the most critical performance levels which could disentangle lean and agile systems. Speed was identified as the second, and cost, quality and dependability were ranked as the third, fourth and fifth respectively as ways in which to differentiate between the systems.

Figure 8.3.3: The Lean Agile Performance Differences (LAPD) Model



8.4 Application of the LAASC & LAPD Model Together

Taking the LAASC Model and the LAPD Model into account, it may be argued that firms competing on costs and quality (lean) levels are more likely to be located at the top of the ASC. In contrast, firms competing on flexibility and speed (agile) measures are more likely to be located at the lower levels of the ASC.

In terms of generalisability, the LAASC Model may be applicable to SCs where the final good sold to the end customer is conformed of thousands of components. However, in terms of SCs producing simpler final goods which only require few components, the LAASC Model may not be applicable. Arguably, if agile firms at the lower end of the ASC are producing a great variety of components of relatively short life-cycles in comparison with lean firms (who are positioned at the higher end of the ASC), it leads to the question of why a greater variety of goods of short life-cycles are not apparent to the end customers.

This can be addressed using the following the example. If an OEM within the ASC is producing 15 different models of automobiles, as time passes they may refine the design of certain components and inevitably ask their suppliers to make adjustments according to their new specifications. When this occurs, agile suppliers will have to quickly adjust their products in line with the buyer's demands. Once this occurs, the end customer will still only see 15 different models of automobiles, even though thousands of components may have undergone slight modifications and improvements. However, although less apparent, lean firms were found to be operating at the lower levels of the ASC too. Considering an average automobile can require approximately 40,000 components, not all the components will actually need modifying when an OEM refines a particular model. For instance, the chassis, badge and headlight may remain the same, but there may be refinements in electrical components, plastic mouldings etc.

Although findings from this study refute Mason-Jones *et al.*'s (2000) 'received wisdom' concerning where lean and agile firms are positioned within 'leagile' SCs, findings from this study can be explained via some of the traditional ideas within SCM, more specifically the 'bullwhip effect'. Schmenner (2001) provided a historical overview concerning the bullwhip effect and advocated that this phenomenon is not new to SCM as Procter and Gamble had been addressing issues associated with the bullwhip effect since 1919. When applying the LAASC Model and LAPD model, firms that were experiencing high levels of flexibility, thus turbulence in operations, were found to operating upstream within ASCs in comparison with firms operating downstream ASCs, which is consistent with the bullwhip effect.

The bullwhip effect is a term that has developed in OM and SCM literature and was coined by Lee *et al.* (1997a, 1997b). The bullwhip effect refers to the scenario when suppliers have relatively large fluctuations in sales/orders in comparison with firms selling directly to the end customer. In essence, when firms operating downstream within SCs experience turbulence, the distortion in turbulence is more greatly amplified for firms operating upstream within SCs (Disney and Towill, 2003). Results from this thesis found that although OEMs and first-tiered suppliers experienced turbulence in volume flexibility in demand, firms that were operating upstream ASCs experienced significantly higher levels of turbulence in the same flexibility measures. Lee *et al*. (1997a, 1997b) suggested that there are five core reasons that may result in the bullwhip effect, namely: demand signalling processing; non-zero lead times; price variations; rationing and gaming; and order batching. Disney and Towill (2003) went on to suggest that demand signal processing and non-zero lead times are the causes for 'demand amplification', also known as the 'Forrester Effect'. The Forrester Effect was named after Jay Forrester (1961) who witnessed multiple issues within real-world SCs and illustrated these concerns via the use of Dynamo simulation.

Although the notion of the bullwhip effect within SCs has been around for decades, Disney and Towill (2003) stated that it is rather difficult to measure or quantify the impact of this effect on profitability levels within organisations. However, Metters (1997) utilised a linear programming approach and concluded that if the bullwhip effect was eliminated, then organisations operating upstream SCs could witness an increase in profitability levels of approximately 5%. Results from this thesis found that the mean profitability of lean firms (operating downstream ASCs), experiencing low levels of flexibility, acquired profit levels of 11.10%. The mean levels of profitability of agile firms, experiencing high levels of flexibility, who were predominantly found to be operating upstream ASCs acquired profit levels of 6.0%. Thus the profitability difference between lean firms, who experienced relatively low levels of variance in orders, and agile firms, who experienced relatively high levels of variance in orders, is calculated as being 5.10%, which is relatively consistent with Metters' (1997) findings. Furthermore, Stalk and Hout (1990) found that the costs associated with increasing and decreasing production levels, i.e. the capability to be manufacturing in a flexible manner, is seen to be extremely expensive. This was also found within this thesis, as agile firms, in comparison with lean firms, were found to be spending a significantly greater proportion of total costs on manufacturing related activities. This occurs when firms operating downstream SCs over-order products in response to real changes in market demand; however, this over-ordering is then seen to be over amplified upstream within the SC, inevitably creating wide fluctuations (Disney and Towill, 2003). This over amplification is costly, thus a form of waste, which may explain why firms operating in upstream ASCs were not considered to be as lean or efficient as firms operating in downstream ASCs.

Although the 'bullwhip effect' can explain why flexibility in demanded orders increases upstream in ASCs, there is little in the literature that provides an insight into why lean and agile firms were found to be competing, thus operating at different levels of the ASC. For instance, although the RBV provides the rationale behind the lean and agile performance trade-offs, it does not provide a reason for why the lean and agile production concepts were being implemented downstream and upstream within the ASC respectively. It is clear that the ASC is complex in nature, therefore, in order to provide a possible explanation for why lean and agile firms were found at different levels of the ASC, insights can be gained from the literature on Resource-Dependence Theory, and more specifically, power. The RDT has become one of the most useful theoretical stances within organizational theory and strategic management (Hillman *et al.*, 2009). Within RDT, the corporation is viewed as an open system, which depends on multiple contingencies within the external environment (Pfeffer and Salancik, 1978). In order to understand the behaviour within an organisation, the context of that behaviour must also be understood. The literature surrounding RDT has power at its heart (Touboulic *et al*., 2014), as an organisation's success within RDT can be traced down to power maximisation (Ulrich and Barney, 1984). In essence, one firm's ability to exercise power over another will play a part in being successful, where levels of dependency are crucial. Singh *et al*. (2011) stressed that RDT has only been scarcely explored and as such further development is needed. Also, Cox *et al.* (2001) has previously asserted that there are fundamental weaknesses concerning descriptive approaches to SCs within business management as authors tend not to examine the importance and complexity of power.

Figure 8.4.1 highlights the power and leverage position that can exist between buyers and suppliers according to Cox *et al.* (2001). Figure 8.4.1 presents four general buyer and supplier positions concerning power, namely: buyer dominance; interdependence; independence and supplier dominance. During times of buyer dominance (>) buyers will generally be able to achieve all they desire operationally and commercially at the expense of their suppliers (Cox *et al.,* 2004).

Figure 8.4.1 - The Power Matrix: Attributes of Buyer and Supplier Power

Attributes to Buyer Power Relative to Supplier

	LOW	HIGH
HIGH	**BUYER DOMINANCE (>)** Few buyers/many suppliers Buyer has high % share of total market for supplier Supplier is highly dependent on buyer for revenue with few alternatives Supplier's switching costs are high Buyer's switching costs are low Buyer's account is attractive to supplier Supplier's offering is a standardized commodity Buyer's search costs are low Supplier has no information asymmetry advantages over buyer	**INTERDEPENDENCE (=)** Few buyers/few suppliers Buyer has relatively high % share of total market for supplier Supplier is highly dependent on buyer for revenue with few alternatives Suppliers switching costs are high Buyers switching costs are high Buyers account is attractive to supplier Supplier s offering is relatively unique Buyers search costs are relatively high Supplier has moderate information asymmetry advantages over buyer
LOW	**INDEPENDENCE (0)** Many buyers/many suppliers Buyer has relatively low % share of total market for supplier Supplier has little dependence on buyer for revenue and has many alternatives Supplier's switching costs are low Buyer's switching costs are low Buyer's account is not particularly attractive to supplier Supplier's offering is a standardized commodity Buyer's search costs are relatively low Supplier has very limited information asymmetry advantages over buyer	**SUPPLIER DOMINANCE (<)** Many buyers/few suppliers Buyer has low % share of total market for supplier Supplier has no dependence on buyer for revenue and has many alternatives Supplier's switching costs are low Buyer's switching costs are high Buyer's account is not particularly attractive to supplier Supplier's offering is relatively unique Buyer's search costs are very high Supplier has substantial information asymmetry advantages over buyer

Attributes to Supplier Power Relative to Buyer

Source: Adapted from Cox *et al*. (2001, p. 14).

In relation to the LAASC Model, it was found that lean firms tended to be generally operating downstream within the ASC. Therefore, as there are few buyers and many suppliers, agile firms, who are the suppliers to lean buyers, are in a position of high buyer dependency. Given this, when OEMs or first-tiered suppliers (lean organisations) require changes, as they are in a positon of buyer dominance, they can acquire the flexible (and less efficient) benefits operationally at the expense of their suppliers.

Schleper *et al*. (2017) suggested that the concept of supplier exploitation has been rarely investigated from an ethical perspective. Buying firms, such as OEMs, are generally held more accountable for costs and quality related issues within their direct SC network, which is why these firms ensure that their direct suppliers are also implementing practices (TPRCs) that are seen to be efficient (Meinlschmidt *et al*., 2017). This may explain why OEMs and their direct suppliers (first-tier) were found to be lean. In fact, a large allocation of social and quality concerns is actually placed on the suppliers who are operating further upstream within the ASC (Meinlschmidt *et al*., 2017). This may explain why firms operating upstream within the investigated ASCs were predominantly implementing TPRCs associated with speed and flexibility, as they may see flexibility as the only way they can manoeuvre themselves into a position of some power superiority (Hingley, 2005) and competitive advantage.

According to RDT, the way firms cope with environmental uncertainty and mitigate any SC risk, depends upon whether they are external (buffering) or internal (bridging) within a current exchange relationship (Mishra *et al.*, 2016). Buffering has been defined as "*the regulation and/or insulation of organizational processes, functions, entities, or individuals from the effects of environmental uncertainty or scarcity*" (Mishra *et al.*, 2016, p.184). Buffering is a common mitigation strategy as firms are able to protect their respective SCs against any disruptions by holding sufficient inventory, that acts as a 'shock absorber' (Bode *et al*., 2011). Fundamentally, a buffering strategy is a form of safeguarding that a company implements in order to lessen exposure in the event of supply disturbances, and although it helps firms to protect themselves from SC disruptions, at times it may be counterintuitive to process improvement strategies, such as lean. Results from this thesis suggested that although lean firms were efficient, they were holding a larger amount of inventory in comparison with agile firms. Although OEMs and first-tier (lean) suppliers were found to be more lean and thus more efficient than agile firms, they were also found to be holding higher levels of inventory in comparison with (agile) firms operating upstream in the ASC. This may imply that such firms were employing buffering as a defensive mechanism.

In opposition to buffering, 'bridging' looks to protects a firm from risk or disruption by forging strong linkages with the exchange partners (Mishra *et al.,* 2016). Such a strategy involves managing resource dependencies by increasing an organisation's influence over its partner. This has been asserted to be internal of existing relationships (Bode *et al*., 2011). Furthermore, Mishra *et al.* (2016, p.185) asserted that "*bridging actions are attempts to manage uncertainty through engaging in 'boundary spanning' and 'boundary shifting' actions with an exchange partner*". Arguably, findings concerning agile firms operating in the ASC are in line with the literature surrounding bridging. For instance, as agile firms were more likely to be positioned upstream within ASCs, one may argue that the only way agile firms are able to increase their respective buyers dependence on themselves is by acquiring high levels of flexibility; a competence that lean firms find difficult to acquire internally. Therefore, it is can be reiterated that agile firms may employ flexibility as a means of manoeuvring themselves into a position of some power superiority, albeit at the expense of cost performance.

This may explain why firms operating downstream within the investigated ASCs are seen to be implementing the resources (TPRCs) affiliated with efficiency and quality levels (lean), whereas firms operating upstream within the ASC were found to be implementing resources (TPRCs) that were more geared towards adaptability and flexibility levels, which came at the expense of cost efficiency and production quality (agile). Crute *et al*. (2003) also asserted that firms will find it extremely difficult to implement lean systems when in a position of low negotiation power. In line with this this, Cox (2004) suggested that lean may only work when the buyer has a dominance over their suppliers, and these suppliers would have no choice but to pass value to the buyer. These assertions go hand-in-hand with the proposition of the LAASC Model.

In fact, power may be at the heart of why lean and agile firms choose to compete on their respective competitive priorities. At the end of section 8.3, the following question was presented: *why are lean systems portraying smaller SCF differences in comparison with EF differences?* In an attempt to answer this question, the LAASC Model suggests that lean (rigid) systems are primarily located at the higher end of the ASC, whereas agile (flexible) systems are primarily located at the lower end of the ASC. Therefore, it is viable to assume that organisations who supply to lean firms are more likely to be agile, hence, explaining why the SCF disparity between lean and agile firms were not as large as the differences in EF levels. As mentioned previously, SCF revolves around the ability to reconfigure a SC, therefore if lean firms are more likely to be OEMs or 1st tier suppliers, they may possess more power when making alterations to the SC in comparison with agile firms who are primarily located at the lower end of the SC. In terms of thinking theoretically, if a firm is positioned at the higher end of a SC, where goods are 'more of a finished product' and is commonly known to assemble goods requiring the purchase of multiple components from alternative suppliers, this may inhibit their ability to change rapidly in terms of EF. Results indicate that lean firms are constrained by EF levels, but when experiencing change in customer taste or requirements, it can be argued that lean firms, who are positioned at the higher end of the SC, need to possess a certain degree of SCF in order to accommodate such change. In addition, if lean firms are producing a 'more finished' product, whereby a range of products are purchased from lower-tier suppliers, in the face of change they may simply request that their suppliers to make changes to the component products. With this in mind, it can be argued that firms positioned at the higher end of the SC don not have to be agile, instead it is their suppliers who have to possess strong capabilities for change.

This goes hand-in-hand with Mehri's (2006) and Kamata's (1984) findings where both authors looked to explore the drawbacks concerning the way Toyota (lean production) conducts its operations, as both authors suggested that Toyota rarely innovate, and more importantly the majority of innovative (flexibility) ideas and products within Toyota actually acquired via the purchase of SMEs, who would have been operating at the lower levels of the ASC. Typically, firms operating within Western automotive industries have been identified as operating under contractual models (Binder et al., 2008). These models have been identified with adversarial relationships that aim at maximising ones own power position (Binder *et al*., 2008). Crucially, the importance of power has often been excluded from studies that have investigated business-to-business relationships (Hingley, 2005). Thus, if ASCs are to move forward and continue to innovate without putting too much cost pressures on firms upstream in the ASC, further research that understands that there are not only complexity issues, but power issues too, is required.

This phenomenon is not only occurring in the automotive industry, but the smartphone industry too. For instance, Apple's success with the iPhone smartphone may be down to this. It is no secret that Apple do not produce much of their final product, and rather act as an 'assembler' as opposed to manufacturer. For instance, just the displays and Touch ID sensor are produced by multiple firms (Japan Display, Xintec, Sharp, LG, Samsung etc.) (Minasians, 2016). As Apple releases a new version of the iPhone every year, one may suspect Apple to possess relatively high levels of flexibility. However, it is important to stress that it is not Apple which is actually adjusting and adapting to consumer tastes, but in fact are passing this pressure to their suppliers. Arguably, one may even suggest that performance strengths associated with automotive OEMs discovered in this study are in direct association with Apple, who are also competing on producing goods of high quality and high profit margins.

8.5 Conclusion

The main aim of this chapter was to discuss each of the research questions set. Although much was not found with the notion of contextual factors impacting the choice of whether firms were lean or agile, an important discovery was found with regards to positional tier. With this in mind this chapter outlined a LAASC Model, which may be generalisable to complex SCs. In terms of the performance trade-offs, results complemented Skinner's (1969) declaration, as lean firms acquired strengths within cost and quality levels, whereas agile firms were stronger in terms of flexibility and speed. Next, the LAASC Model was used in conjunction with the performance trade-offs in order to understand why firms are competing on varying performance objectives. The LAASC Model refutes existing SC literature concerning the 'leagile' decoupling point, as lean firms (high: cost & quality, low: flexibility & speed) were predominantly found to be operating downstream in ASCs and the majority of agile firms (high: flexibility & speed, low: cost & quality) were observed to be operating upstream ASCs. As this finding is in direct contradiction with decoupling SC literature, this section invoked Resource Dependence Theory (RDT) involving a power perspective to better understand why this phenomenon may be occurring. Using RDT, this section asserts that as lean firms are primarily located at the top tiers of the ASC, lean firms do not have to compete on EF as they are in a power position of buyer dominance, which inevitably leads them to acquire high levels of cost and quality, as well as reasonable levels of SCF. In contrast, as agile firms operate upstream ASCs they are not in positions of power and compete on all forms of flexibility in order to remain competitive. As the current literature regarding lean, agile and flexibility, especially SCF, is relatively underdeveloped, this study makes a major contribution to the field by providing practical, applicable and empirical evidence concerning lean and agile systems.

CHAPTER 9 - CONCLUSION

This chapter concludes this investigation by providing a summary of the research findings as well as listing the theoretical and methodological contributions. By adopting a positivist stance, in comparison with previous lean-agile debated studies, this study attempted to *more* objectively and rigorously explore the effects and trade-offs between lean and agile manufacturing paradigms relative to five performance dimensions, namely: cost; dependability; flexibility; quality; and speed. The automotive industry within the West Midlands provided the context of this study, with survey data collected from 140 organisations. Grounded on Contingency theory, this study also looked to determine if positional tier, as well as other contextual factors, influenced whether firms were more likely to be pursuing a lean or agile strategy. Lean and agile firms were determined by which bundled set of tools, processes, routines and concepts (TPRCs), affiliated with each of the production concepts, was adopted to a greater extent within each firm. The main aim of this study was to dispel the ambiguity between the domains of lean and agile manufacturing. This chapter is divided into three sections. First, the theoretical and methodological contributions as well as managerial implications, are presented. Second, the limitations and generalisability of this study, followed by suggestions for future research, are discussed. Finally, this chapter outlines the implications of this investigation for the field of production and operations management (OM).

9.1 Contributions

Findings from this study not only have theoretical and methodological implications for OM and supply chain management, but also practical managerial implications which can be used to inform day-to-day firm operations. As will be discussed, not only does this research empirically broaden the understanding of the effects of lean and agile systems with regard to performance levels, but it also extends the literature concerning lean and agile concepts in relation with supply chain management. In doing so, several contributions are made.

9.1.1 Theoretical Contributions

As mentioned previously, in order to provide some clarity to the lean-agile debate the main research questions was presented as '*What are the trade-offs between lean and agile manufacturing?*' As the main aim of this thesis was to dispel some of the ambiguity concerning the lean-agile debate, this thesis developed three sub research questions as follows:

RQ (a) What are the trade-offs in contextual factors between lean and agile manufacturing?

RQ (b) What are the trade-offs in performance between lean and agile manufacturing?

RQ (c) Are flexibility trade-offs the most significant performance measures to differentiate lean and agile firms?

Although perspectives from evolutionary economics were used when answering RQa, CT was the main over-arching theory applied. Importantly, when answering RQa this study found supply chain positional tier to be significantly related with the choice of firms to pursue lean or agile, thus the Lean Agile Automotive Supply Chain (LAASC) Model was presented. The LAASC Model illustrates where the lean, agile and inevitably performance strengths are located within an ASC. The LAASC model proposes that lean firms are significantly more likely to be operating as the top levels of the ASC. As this finding directly contradicts literature concerning the 'leagile' supply chain, this thesis speculated, via the use of a power perspective, as to why this may have been found. In summary answering RQa contributed towards clarifying the general misunderstandings related to the contingent nature of lean and agile production (Hines *et al.,* 2004; Tortorella *et al.* 2017a). Results from this thesis have theoretical implications. For instance, the idea that lean can be implemented as 'best practice' within all companies is refuted, as contingent variables, such as positional tier, can be an influential and significant factor. Although Marodin *et al*. (2016) found that lean production was not only being implemented in large-volume and low-variety companies, such as OEMs and first-tier suppliers, results from this study did not convey the same argument. For instance, firms positioned lower down the ASC were generally found to be implementing TPRCs associated with flexibility (agile) as opposed to efficiency (lean). Firm size and firm age did not portray levels of significance; however, they did illustrate signs of bearing a relationship between lean and agile production.

When answering RQb, the main theoretical contribution of this study is the empirical validation of Skinner's (1969) assertion that manufacturing strategies, and in turn organisations, compete on various measures of performance. More specifically, results from this thesis suggested that lean and agile firms do not compete on the same measures of performance. In turn, this study sides with the notion of the 'trade-off law' as opposed to the 'law of cumulative capabilities' (Schmenner and Swink, 1998). As mentioned in Chapter 2, in order to explain why trade-offs were apparent, and by adopting a RBV perspective, it is necessary to turn to what was happening inside the organisation, hence the mode in which lean and agile firms were distinguished. For instance, as lean and agile firms were categorised based upon the degree to which certain tools, practices, routines and concepts (TPRCs), also referred to as resources, were being implemented to a greater extent, this may explain why differences in performance (capabilities) levels were found. A summary concerning the performance trade-offs is outlined next.

In terms of trade-offs, lean production was affiliated with higher cost efficiency levels in comparison with agile manufacturing, which supports previous findings (Yusuf and Adeleye, 2002; Narasimhan *et al*., 2006; Gunasekaran *et al*., 2008; Agarwal *et al*., 2006) but refutes the assertion that agile systems are operating with high profit margins (Bruce *et al*., 2004). With the exclusion of inventory cost efficiency, findings were largely supportive of the literature (Yusuf and Adeleye, 2002; Narasimhan *et al*., 2006; Gunasekaran *et al*., 2008; Agarwal *et al*., 2006) which asserts, in terms of costs, lean production as superior to agile manufacturing. In an attempt to theoretically understand why lean firms are less cost effective in terms of inventory costs, this thesis proposes that organisations producing goods of shorter life-cycles (agile) are more likely to be inventory cost effective, as they are less likely to accumulate stock in comparison with organisations producing goods of longer life-cycles (lean).

High levels of quality were found to be significantly associated with lean production, which contends the theoretical thinking of quality being equally as important within both lean and agile systems (Mason-Jones *et al.,* 2000). Previous findings (Yusuf and Adeleye, 2002; Agarwal *et al*., 2006; Hallgren and Olhager, 2009) have also advocated this phenomenon, however Narasimhan *et al*.'s (2006) study does not. However, as findings from this study side with the majority of investigations which have sought to explore the differences between lean and agile production, perhaps quality should be embedded within OM as a factor with which to distinguish lean and agile firms too.

In terms of speed, results from this thesis supports existing views (Yusuf and Adeleye, 2002; Hallgren and Olhager, 2009) as high levels of speed were significantly associated with agile systems. Although this research did identify similar manufacturing speed times between lean and agile firms, as lean organisations were significantly spending less on distribution, this may have been the underlying factor why their total order-lead time was far slower than agile organisations.

Dependability was the only performance measure which overall failed to distinguish one manufacturing strategy as favourable to the other. This was down to this performance construct containing mixed findings amongst its sub-variables. Although Cagliano *et al.* *(*2004) and Narasimhan *et al*. (2006) found high dependability levels to be largely related with lean practices, this study does side with Hallgren and Olhager's (2009) study, who also found no significant differences in reliability and dependability between the two approaches.

In terms of flexibility, results from this thesis support previous assertions that high flexibility levels can be used to distinguish lean and agile systems. More specifically, the flexibility disparities between lean and agile firms were far greater than the other four performance measures, thus, findings empirically validate RQc. However, results revealed lean systems do not obtain high levels of mix flexibility, which contradicts Naylor *et al.'s* (1999) mode of distinguishing between lean and agile systems. A framework incorporating four flexibility measures, namely: volume flexibility; product mix flexibility; new product flexibility; and sourcing flexibility, was developed as a means of almost perfectly distinguishing lean and agile firms. As the current literature regarding flexibility, especially SCF, is relatively underdeveloped, this study also contributes to the limited discussion concerning the trade-offs between lean and agile systems in terms of EF and SCF.

9.1.2 Methodological Contributions

A significant methodological contribution of this study concerns the innovative technique by which firms were distinguished as being lean or agile. A scorecard was developed based on existing literature, which measured the degree to which firms were either implementing lean, agile or hybrid practices. Depending on which collection of practices scored the highest firms were distinguished as lean, agile or hybrid. Even though this scorecard was used to distinguish between lean and agile organisations within the automotive industry, researchers may also use it when distinguishing organisations from other manufacturing industries.

The second methodological contribution involves the sampling technique employed within this study. Recognising the fact that the ASC consists of firms from a diverse range of industries rather than just the manufacture of motor vehicles, and considering the fact that each industry had varying number of firms operating within the automotive industry, this study incorporated the use of both cluster sampling and proportional random sampling. Taking this into account, the results from this investigation may be more 'true' and generalizable to other supply chain's outside of the automotive sector.

Acknowledging that authors have previously stressed the difficulty involved in measuring flexibility levels (Sethi and Sethi, 1990), as well as other performance dimensions, one of the greatest contributions of this study concerns the rigour employed when assessing and measuring a range of cost, dependability, flexibility, quality and speed levels without using Likert-scale questions. Previous studies that have looked into similar relationship testing between manufacturing strategy (lean or agile) and performance trade-offs have either used case studies (Mason-Jones *et al*., 2000; Towill and Christopher, 2002) or Likert scale based questions (Cagliano *et al*., (2004; Agarawal *et al*., 2006; Narasimhan *et al.,* 2006; Hallgren and Olhager, 2009). It is crucial to note that all performance variables were captured in numerical form, which may be argued to be 'less' discursive as opposed to using Likert scale based surveys. As the mode in which data was collected consisted of numerical values, if this study was repeated again, findings would be the same, hence the validity and reliability of this study can be deemed to be relatively high. This was one of the only, if not only, research investigation which captures numerical data first and then categorises performance variables as low, medium and high levels of performance, hence this research arguably holds greater methodological rigour than previous studies. However, this is not to say that Likert-Scale questions were not used within this study, but these type of questions were not included when measuring levels of performance.

9.1.3 Managerial Implications

Firstly, as there is a confusion between lean and agile paradigms (Narasimhan *et al*., 2006), the scorecard used to distinguish lean and agile systems can be used by operational managers as a reference point in order to determine whether their respective firm is leaner or more agile. Second, the results presented in this study suggest that neither lean nor agile manufacturing systems can compete on all performance levels. With this in mind, managers within the industry may use the results obtained within this investigation in order to help them achieve their performance objectives. For instance, if firms are striving to be more cost and quality effective they may implement or develop the TPRCs that were identified as lean. On the contrary, if a firm is looking to improve their flexibility and speed levels they can develop the TPRCs that were noted as being agile. Third, specifically for managers operating within the Midlands automotive industry, results revealed that in general, firms positioned at the lower levels of the ASC were prioritising speed and flexibility objectives, whereas firms positioned at high levels of the ASC were more focussed on costs and quality. Therefore, if firms are operating at the lower levels of the ASC and prioritising costs objectives, but not necessarily winning orders, arguably they made need to re-think their performance objectives in order to compete with local rivals.

9.2 Limitations

Although this investigation acquired responses from 140 organisations, statistical analysis involved comparing one manufacturing paradigm to the other. Therefore, categorising firms into three performance groups (low, medium, high), with only 66 and 74 observations can be acknowledged as being limited. Acquiring more responses may not have resulted in firms being perfectly separable within certain levels of flexibility. However, the statistical tests applied were robust enough to draw generalisable conclusions.

This study examined performance levels via a cross-sectional survey corresponding to the 2014 annual year which arguably, which only provides a glimpse into what is occurring. Longitudinal research would have enabled more robust conclusions to be drawn, but unfortunately it was not a suitable design for this study due to the time commitment involved.

This investigation did not explore whether the extent of lean or agile is impacting different levels of performance. The scorecard developed in this study was used to distinguish between lean and agile systems based on the degree to which they are implementing lean or agile concepts, for example, firms which were identified as lean, may not necessarily reflect 100% commitment to lean, but actually are implementing 'more' lean practices in comparison with agile practices. Nevertheless, the fundamental aim of this thesis was to provide clarity into the differences between each of the approaches, therefore, the degree to which firms were implementing each concept was not explored further.

Finally, it is important to acknowledge that this study only investigated firms operating within the production process of ASCs. Therefore, although ASCs were found to be operating under 'leagile' SC processes, and that lean and agile firms were significantly more likely to be found downstream and upstream within ASCs, the distribution process of automotive vehicles was not included. Therefore, this is a limitation concerning this study. For instance, if the distribution of vehicles was expanded further downstream the ASC to include dealerships, agile methods may have been discovered. However, this was beyond the scope of this investigation as this thesis was primarily interested in the production process within ASCs.

9.3 Generalisability

Even though this study investigated the automotive industry, as thousands of components are required for the production of an automotive vehicle it is important to stress that many firms were identified by SIC code as operating in other manufacturing industries (see section 5.4). It could therefore be proposed that the performance trade-off findings are generalizable to firms operating within different industries, transcending the automotive industry. Also, it would be limiting to suggest that the LAASC Model is not generalizable to complex SCs. The argument here is that an OEM producing goods formed of thousands of components may struggle to be agile in nature, and in the face of change would simply ask their suppliers to make changes to design specifications that are required. Therefore, in the case of complex SCs where the final product is conformed of many components, then the LAASC Model may be generalizable, as the OEM, will unlikely be able to introduce new products of relative short life-cycles at great speed; and if they did require changes, then they would pass this constraint to their suppliers (see section 8.4).

9.4 Suggestion for Future Research

Even though this investigation involved the use of a range of performance constructs, future studies may develop these constructs to include a greater number of items relating to each of the five performance categories which may lead to further assertions and generalisations concerning the trade-offs between each of the manufacturing approaches.

A primary aim of this study was to develop the discussion surrounding flexibility, particularly supply chain flexibility due to the scarcity in related literature. With this in mind, although results from this study indicated agile systems as being far superior in comparison with lean systems, a closer examination of EF and SCF, revealed that overall the proportional differences between lean and agile systems concerning EF, far exceeded the differences in SCF levels. As this study has contributed to the role of flexibility and performance in lean and agile systems, future studies may build on this by measuring a range of flexibility levels, especially EF and SCF levels, as this would further the development concerning the trade-offs between lean and agile systems.

It would be interesting for future studies to replicate this investigation in a different ASC with a larger population in order to determine if the LAASC Model is generalizable to all ASCs or if the findings from this study are region specific. It would also be beneficial to recreate this investigation in the context of a different industrial supply chain, particularly a complex SC, where the final product is consisting of thousands of products. If findings support the theory presented in the LAASC Model, the literature could be developed to further contend traditional views regarding 'leagile' SCs and the decoupling point.

Although this thesis presented the LAASC Model illustrating where lean and agile methods were applied with ASCs, the focus of this study was on the lean-agile debate within the production process of ASCs. Therefore, it is important for future studies to expand on the findings presented in this thesis by exploring if lean or agile methods are applied within the distribution process and service process within ASCs.

9.5 Implications for Production and Operations Management

Research within the field of production and OM have undoubtedly looked into the TPRCs affiliated with both lean and agile production, and even though there are a vast number of studies investigating the performance effects of lean and agile manufacturing systems in their own right (see Table 3.3.1 for lean production & Table 3.41 for agile production), the literature has also revealed relationships with business and operational performance. Prior research within the field of production and OM have generally failed to illustrate the performance trade-offs as there is a scarcity in studies which look to explore both concepts within a singular study, magnifying the need for this study. Furthermore, the scarce studies which have explored the trade-offs between each of the concepts have been observed to reveal contradicting findings or assess a finite number of performance dimensions (see 3.5.1 Table), especially flexibility, which is a deficiency identified by multiple authors. Considering the confusion cited between lean and agile manufacturing, a greater effort within the realms of production and OM should be dedicated to determining the empirical trade-offs between each of the manufacturing concepts, as this may dispel the ambiguity and confusion between each of the production strategies.

This study significantly contributes to the field of OM by integrating theory and capturing raw empirical data to determine both the performance strengths and weaknesses of lean and agile production. It is important to stress that as far as the author is aware, there are no studies which seek to explore the cost, dependability, quality, speed and multiple measures of flexibility trade-offs, between lean and agile production within a singular study. The theoretical underpinning upon which the thesis is set upon revolves around Skinner's (1969) assertion that no manufacturing strategy, and in turn organisation, can compete on all levels of performance; instead trade-offs are present. This foundation was based upon the idea that although lean and agile strategies are similar in certain respects, they are ultimately distinct and cultivate different performance objectives. Therefore, incorporating the use of RBV, although lean and agile organisations may acquire similar resources and capabilities (TPRCs), in turn these organisations will also acquire different resources and capabilities (TPRCs), which are geared to their performance objectives.

Findings from this study identified that, in terms costs and quality, lean manufacturing was superior to agile systems. On the contrary, in terms of flexibility and speed, agile production was illustrated as being superior to lean systems. These results upheld previous received wisdom concerning lean and agile systems (Naylor *et al*., 1999; Yusuf and Adeleye, 2002; Agarwal *et al*., 2006; Narasimhan *et al*., 2006; Gunasekaran *et al*., 2008; Purvis *et al*., 2014), but contend the notion that cost and quality ultimately are performance trade-offs that are inversely related. Irrespective of lean and agile production, the greatest trade-off in two performance constructs consisted of flexibility and quality, which has been previously proposed by Mapes (1997) and Schroeder *et al.* (1996). In addition, this study found that, as a performance construct as a whole, dependability was the only performance domain which illustrated relatively similar performance levels between each of the concepts, where no strategy could be identified as superior or weaker when compared to the other.

Furthermore, in terms of contextual factors, namely: firm size; firm age and manufacturing classification, results from this study did not reveal to be significantly more or less affiliated with either of the manufacturing strategies. This implies that large firms are not constrained to just being lean, and on the contrary, agile organisations are not constrained to being small. The most noteworthy finding concerning contextual factors, revolves around the positional tier to which lean and agile organisations belong to within a complicated supply chain. For instance, lean firms, who were identified as being more cost and quality effective, were significantly identified as belonging to the top tiers of the ASC. In contrast, agile firms, who were identified as being more flexible and speed effective were significantly more likely to belong to the lower tiers of the ASC. As this phenomenon was in direct contradiction with 'leagile' SC literature, by adopting a RDT theoretical lens, and more specifically power, this study speculates regarding the reasons for this findings and suggests that a new way of thinking may be required (see section 8.4).

9.6 Conclusion

The theoretical and conceptual framework used within this thesis was based upon Skinner's (1969) declaration that no manufacturing strategy, and in turn organisation, can compete on all levels of performance. In order to address the occurrence of performance trade-offs, this study took a RBV stance, in that firms would prioritise their performance objectives and acquire the relevant resources and capabilities (TPRCs) which would gear them towards their goals. With this in mind, this investigation conceptualised and distinguished lean and agile systems via a RBV approach, where a review of the literature revealed 15 TPRCs (Elimination of Waste; Continuous Improvement; 5S; Zero Defects; Production Smoothing; Line Balancing; Value Stream Mapping; Total Productive Maintenance; Cellular Manufacturing; Just-in-Time; Kanban; Multifunctional Teams/Machines; Total Quality Management; Employee Empowerment; and Setup Reduction (SMED)) with lean production and 13 TPRCs (Just-in-Time; Kanban; Multifunctional Teams/Machines; Total Quality Management; Employee Empowerment; Setup Reduction (SMED); Virtual Enterprise; Core Competence Management; Knowledge Driven Enterprise; Reconfiguration; Rapid Prototyping; Concurrent Engineering; and IT Driven Enterprise) with agile production.

Empirical data was collected in the West Midlands automotive manufacturing industry. Given that the automotive industry is hailed as the birthplace of lean production and due to the clear differences in contextual factors (firm size, firm age, manufacturing classification, positional tier) (Marodin *et al*. 2016) it was deemed an important industry to investigate. Furthermore, the automotive industry has been faced with flexibility issues, which needed addressing. With this in mind, the automotive industry was deemed the most suitable one in which to investigate the performance trade-offs between lean and agile systems.

A general conclusion, based on the results developed from the scorecard, is that lean and agile systems can be differentiated without using the term ‘hybrid. For instance, based on the collection of TPRCs ascribed with lean, agile and ‘hybrid’, every organisation was identified as implementing either lean or agile practices to a greater extent in comparison with ‘hybrid’. Importantly, this is not to say that firms are implementing lean or agile concepts fully, rather they are implementing one of the strategies to a greater extent.

With regards to the findings, two main conclusions can be drawn:

1) In terms of the main performance trade-offs associated with each of the manufacturing paradigms, results upheld Skinner’s (1969) assertion that no manufacturing strategy, and therefore organisation, can compete on all levels of performance. Lean systems were observed as being superior to agile systems in terms of costs and quality levels, but in contrast, agile organisations were deemed far superior to lean systems in terms of flexibility and speed. Findings concerning costs, speed and flexibility go hand-in-hand with previous assertions but previous authors have advocated high quality levels with both lean and agile systems, which the findings of this research contend. Interestingly, in terms of dependability levels, both lean and agile systems failed to illustrate superiority, suggesting both strategies acquire similar dependability levels. In essence, with the exclusion of TPRCs associated with both manufacturing paradigms (Just-in-Time, Kanban, Multifunctional Teams/Machines, Total Quality Management, Employee Empowerment, SMED), results from this study imply that organisations implementing the following practices: Elimination of Waste; Continuous Improvement; 5S; Zero Defects; Production Smoothing; Line Balancing; Value Stream

Mapping; Total Productive Maintenance; and Cellular Manufacturing, are significantly more likely to acquire cost and quality strengths. On the other hand, manufacturing firms implementing the following practices: Virtual Enterprise; Core Competence Management; Knowledge Driven Enterprise; Reconfiguration; Rapid Prototyping; Concurrent Engineering; and IT Driven Enterprise, are significantly more likely to gain flexibility and speed advantages.

2) The second conclusion concerns the positional tier to which lean and agile systems belong within the ASC. Using the results from this study, a LAASC (Lean Agile Automotive Supply Chain) Model was presented which identified lean systems to be significantly more likely to be positioned at the top levels of the ASC, whereas agile organisations were significantly more likely to be allocated at the lower levels of the SC. Taking this, as well as the performance trade-offs into account, this study concluded after having speculated with regard to RDT theory, that organisations at the higher levels of the ASC do not have to compete on flexibility and speed performance levels due to their power position of buyer dominance. Furthermore, as firms at the higher levels of the automotive supply chain, generally ‘assemble’ products as opposed to ‘manufacture’, in the face of change in market conditions, they do not need to acquire high levels of speed or flexibility, as this constraint would be passed on to their suppliers who are operating at the lower levels of the ASC. Using this philosophy of power in accordance with the LAASC Model, this study also widened the discussion into why the differences between each of the paradigms were greater concerning EF levels in comparison with SCF levels.

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APPENDIX A – TOOLS, PRACTICES, ROUTINES & CONCEPTS (TPRCs)

a) Eliminations of Waste

The elimination of waste concerns the removal of all non-value adding activities and can be achieved in seven ways:

Table AA1: Description of Seven Wastes

Waste	Description
1) Overproduction	This occurs when manufacturing operations continue to produce goods when there is no demand. This results in an excess of products, products being made too early and an increased inventory.
2) Waiting	Waiting is often know as queuing and occurs for a limited amount of time when there is no activity occurring in a downstream process because previous activities are not delivered on time.
3) Transport	This refers to the unnecessary movement of materials, for example, the movement of certain work in progress goods from one operation to another.
4) Over Processing	Poor management often leads to over processing such as rework, reprocessing and over production due to excess inventory.
5) Inventory	The total inventory that is not directly required to fulfil customer orders. This includes raw materials, work-in-progress goods and finished goods. The presence of extra inventory is likely to lead to over processing.
6) Motion	Unnecessary or too much movement of machines and workers required to perform the task. This can down to inefficient layouts, defects and overproduction.
7) Defects	This occurs when finished goods are not up to specification for the customer's order, which causes customer dissatisfaction.

Source: Womack and Jones (1996).

b) Continuous Improvement

Originating from the Japanese word 'kaizen', this concept refers to seeking perfection via gradual and orderly continuous improvements (Womack & Jones, 1996). The 5S model is one of the most useful tools regarding continuous improvements and can be used as a preliminary tool against waste reduction. This tool consists Seiri, Seiton, Seiso, Seiketsu and Shitsuke which mean to sort, straighten, sweep (clean), systemise and standardise respectively.

c) 5S

The 5S tool is used to unearth potential strengths and capabilities.

Table AA2: Description of the 5S Tool

5S	Application
Seiri (Sort)	Transfer items that are not being used on a regular basis away from the items that are being used on a regular basis. Removal of needless items will help materials flow more smoothly whilst enabling workers to move more at ease.
Seiton (Straighten)	The removal of items from certain areas that have no use within those respective areas. The arrangement of items to certain areas will ensure tools, jigs and resources more accessible and easier to use.
Seiso (Sweep)	Cleaning the workplace so that it is ready for the next shift. The workplace should be cleaned on a daily basis and goods are put back to their right places.
Seiketsu (Systemise)	This refers to maintaining a high standard of housekeeping and workplace arrangement. Employees will be assigned areas of responsibility which will help to maintain a high standard of housekeeping.
Shitsuke (Standardise)	This refers to the management of training employees in order to follow housekeeping rules. The organisations management team should reward individuals who follow these rules and guide the individuals who do not.

Source: Feld (2000); Sweeny (2003).

d) Zero Defects (Poka-yoke)

Zero defects ensures products are fault-free throughout the production process which is arguably only achieved by continually improving the manufacturing process. Zero defects aims to detect errors before the finished good is produced. Poka-yoke is an autonomous defect control system which can be used to enact the zero defect principle, and can be placed on every machine inspecting all parts are working in order to strive for zero defects.

e) Production Smoothing

Production smoothing (Heijunka) strives to adjust an organisation's management style so that it holds a greater degree of process control and aims maintain daily production at a constant a level as possible (Womack *et al*., 1990). For this to be achieved, the production schedule has to be smooth in order to produce the required quantity of products, whilst also utilizing labour efficiently. If firms are unable to operate smoothly the production level will not be constant which eventually leads to waste, e.g. work-in-process goods.

f) Line Balancing

Line balancing refers to the implementation of tasks at workstations consisting of equal quantities (Son *et al*., 2001; Slack *et al.,* 2010) and is primarily eliminate wasted time. It ensures every workstation produces the right quantity of goods at the right time, before work is sent to the next workstation without stoppages, thus ensuring that all workstations are synchronised and guaranteeing smooth operations.

g) Value Stream Mapping (VSM)

The two main aims of VSM are to identify all forms of waste within the value chain and implement the necessary steps to eliminate all forms of waste. VSM can be implemented using three steps:

1) Select a particular product or product group as the target for development.
2) Highlight and map all the steps within production process.
3) Identify a new map depicting how the system should be without inefficiencies.

h) Total Production Maintenance (TPM)

TPM consists of three components: preventive maintenance, corrective maintenance and maintenance prevention. Preventive maintenance specifies that there has to be regular and planned (rather than random) maintenance checks which help prevent sudden breakdowns and improve the throughput of individual machines. Corrective maintenance specifies decision making in terms of fixing old machines or buying new machines i.e. if a machine is deemed unreliable it would be viable to buy a new machine even if it costs more than fixing the old machine, as it will last longer with a greater uptime. Maintenance prevention concerns purchasing equipment e.g. if a machine prevails to be difficult to maintain then such maintenance may occur less frequently, resulting in a loss.

i) Cellular Manufacturing

Cellular manufacturing is the organisation of the process for a particular product or similar products into a group (cell), which includes all the necessary machines, equipment and operators. It is applied within an organisation to increase the variety of products produced with the least amount of waste possible. A typical cell will consist of equipment and workstations staffed by workers with the right skills arranged in such a way that maintains a smooth flow of materials and components throughout the process.

j) Just-in-Time (JIT)

JIT attempts to eradicate sources of waste (i.e. work-in-process goods, defects and large waiting times) by producing the right product at the right time and place (Womack and Jones, 1996). The flow of material can be classified into two categorical systems: push (traditional) and pull (JIT). JIT can be broken down into three categories: production, purchasing and distribution.

k) Kanban

A Kanban is an information system used to coordinate the implementation of JIT (Monden, 1998; Abdulmalek & Rajgopal, 2007), by controlling the quantity of different parts needed at varying stages of the production process. Withdrawal kanban and production kanban are common forms which determine the quantity to be pulled from the previous step and produced for the next stage (Monden, 1998). Supplier Kanban is used between suppliers and manufacturers operating under JIT conditions.

l) Multifunctional Teams & Multifunctional Machines

Multifunctional teams and machines refers to the ability of employees and machines to conduct more than just one particular task, which facilitates task rotation and flexibility when seeking to accommodate any changes in production, however as the number of tasks increases, workers and machines require a greater degree of training and inspection respectively (Dankbaar, 1997).

m) Total Quality Maintenance (TQM)

TQM is holistic approach to quality management emphasising the role of all parts and people within an organisation in influencing and improving quality (Slack *et al.,* 2010). TQM is a philosophy that urges continuous improvements, meeting customer requirements, employee involvement and competitive benchmarking. Arguably, TQM is a management philosophy on its own, however based upon the assertions of multiple studies (Abdulmalek and Rajgopal, 2007; Shah & Ward, 2007; Taj & Morosan, 2011) this study also included TPM as a TPRC associated with lean production.

n) Employee Empowerment & Quality Circles

Yan *et al.* (2011, p.252) define employee empowerment as "*the human element of lean manufacturing such as formal training programs, problem solving groups, self-directed work teams and autonomous problem solving*". Although it is closely linked with autonomy, the concepts are different as autonomy refers to giving the employees the ability to change the way they conduct their duties, whilst empowerment means giving the employees the authority to make changes to the job itself (Slack *et al.,* 2010). Lean promotes the use of empowerment via the use quality circles, small group meetings where employees are given the chance to put forward recommendations regarding improvements in the production process.

o) Setup Reduction (SMED)

Single minute exchange of dies (SMED) is a set of techniques that reduces machine changeover times. SMEDs are implemented to reduce the set up time between machines internally and externally. Internal activities can only be carried out when machines are not running and external activities can be carried out when machines are running, so SMED involves transferring activities from internal to external (Feld, 2000). By reducing the setup time firms reduce the need for die-change specialists and are able to hold less inventory.

p) Virtual Enterprise

Virtual enterprise concerns the formation of a temporary network of alliances with other organisations to make a specific product for a specific period of time, which is quickly dissolved once orders are fulfilled (Sharp *et al.,* 1999) (see section 2.3.2 for more detail).

q) Core Competence Management

According to Jin-Hai *et al*., (2003) suggested that possessing a set of resources and skills within a firm is no longer sufficient, instead organisations need to concentrate on their individual competencies and identify any missing ones which can be acquired via alliances. Cooperation with competitors is thus of significant value, with agile production proposing competition and cooperation are compatible (Yusuf *et al*., 1999) (see section 2.3.2 for more detail).

r) Knowledge-driven Enterprise

A knowledge-driven enterprise involves employee empowerment and multifunctional skills. Organisations who wish to be agile must place an emphasis on the development of well-trained employees in possession of the right skills, knowledge, expertise and power. In essence, agile firms have to recognise and push the notion that 'knowledge is power' so that employees have the ability to make key decisions at great speed (see section 2.3.2 for more detail).

s) Reconfiguration

Firms wishing to operate under agile conditions must possess the capabilities to diversify, reconfigure and re-align. Firms must develop and follow a strategic plan that launches new products in relatively succession. as launching a single product without the strategic planning of follow-ups can be counter-productive (Yusuf *et al.,* 1999) (see section 2.3.2 for more detail).

t) Rapid Prototyping

Agile systems must be able to rapidly reconfigure their systems to capitalize on immediate market opportunities, therefore agile systems need to acquire the right resources in terms of production and design. Prototyping concerns the initial design of the final product, and though it may not be the same as the end good, it has enough features to allow for testing of certain aspects (e.g. visual, physical, functional). Rapid prototyping goes hand-in-hand with IT packages such as CAD.

u) Concurrent Engineering

Also known as simultaneous engineering, concurrent engineering is a method of designing and developing products, in which the different stages run simultaneously, as opposed to consecutively. Concurrent engineering therefore refers to conducting product development steps in parallel rather than sequentially.

v) IT Driven Enterprise

Sharp *et al.* (1999) has suggested that an IT driven enterprise it is a key enabler of concurrent engineering given that it can provide automation within the organisation (Burges, 1996; Yusuf, 1996; Sharp *et al*., 1999). Tools within an IT driven enterprise include the likes of email, computer-aided design (CAD), computer-aided manufacturing (CAM), manufacturing resource planning (MRP), distribution resource planning (DRP), and electronic commerce (EC) which enable firms to be faster and more efficient when making modifications to orders, as IT systems connect them with both suppliers and customers.

APPENDIX B – LEAN & AGILE TPRCS CORRELATIONS

Table AB1: Pearson Correlation of Lean TPRCs

	Elimination of Waste (1)	Continuous Improvement (2)	Zero Defect (3)	Production Smoothing (4)	Line Balancing (5)	Vale Stream Mapping (6)	Total Productive Maintenance (7)	5S (8)	Cell Man (9)
(1)	1								
(2)	.028	1							
(3)	.101	.661**	1						
(4)	.051	.319**	.372**	1					
(5)	145	.195*	.218*	.496**	1				
(6)	.109	.304**	.423**	.507**	.443**	1			
(7)	.113	.351**	.422**	.479**	.397**	.581**	1		
(8)	-.089	.412**	.404**	.296**	.124	.327**	.615**	1	
(9)	.189	.435	.301*	.509**	.332	.221*	.421**	.385	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table AB2: Pearson Correlation of Agile TPRCs

	Virtual Enterprise (1)	Concurrent Engineering (2)	IT Driven Enterprise (3)	Rapid Prototyping (4)	Capability for Reconfiguration (5)	Core Competence Management (6)	Knowledge Driven Enterprise (7)
(1)	1						
(2)	.626**	1					
(3)	.525**	.542**	1				
(4)	.647**	.623**	.588**	1			
(5)	.705**	.653**	.622**	.647**	1		
(6)	.569**	.572**	.703**	.601**	.697**	1	
(7)	.656**	.624**	.636**	.591**	.679**	.760**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX C – PARTICIPANT INFORMATION SHEET & CONSENT FORM

Participant Information Sheet

LEAN VERSUS AGILE MANUFACTURING

Background to the study

I am a PhD doctoral researcher at the Birmingham Business School, University of Birmingham, and my research is focusing on automotive firms within the West midlands implementing lean, agile or hybrid manufacturing concepts in relation to performance measures. The main aim of this study will be to explore which manufacturing concept is having a greater impact on performance measures, whilst also distinguishing the two concepts further. This research will also seek to investigate the degree of lean or agile manufacturing concepts applied within organizations in order to increase the validity of the results collected.

The information that will be collected for this research will account of organization performance figures concerning cost, dependability, quality, speed and flexibility. Organizations will be divided between lean, agile and hybrid manufacturing which will allow the researcher to make comparisons by analyzing the trade-offs between each manufacturing concepts. The survey will also be used to determine the degree individual firms are implementing each concept, whilst also providing grounds for the researcher to measure the ability of firms to be flexible.

The surveys sent out will take place between September (2014)-March (2015) and the study should be completed by December 2015. This research is fully funded by the Midlands Excellence Organisational Improvement Programme (MidEx) which aims to generate a sustained positive benefit to the performance of organisations across the Midlands region through collaboration with private, public and third sector organisations.

Confidentiality

Surveys will be stored in a secure location which will be password protected and only the researcher and his main supervisor will have access. People's names and job titles will not be included in reports. Organisations will be name coded and not be identifiable through any answers made. Participants and organisations will be offered a copy of their survey transcript and provided with the opportunity to take out or amend any part of it that they do not wish reported in the findings. Participants should also be aware that the researcher has a legal obligation to disclose information relating to unethical or criminal behaviour.

We hope you will be able to help with this important area of research. If you agree to take part please complete the consent form. You are able to withdraw from this study without giving a reason until March 2015.

How will the results be used?

1. PhD thesis
2. Academic research papers
3. A summary report to be circulated to all interested participating organizations

Please indicate on the consent form if you would like to receive a report containing the summary of the results and I must kindly ask if can you return the survey by post (see above for address) or by email

Please get in touch if you would like any further information:

Amir Qamar Contact Number: Email Address:
Dr Mark Hall (Supervisor) Email Address:

Consent form

Issue	**Respondent's initial**
I have read the information presented in the participant information letter about this study.	
I have had the opportunity to ask any questions related to this study, and received satisfactory answers to my questions, and any additional details I wanted.	
I am also aware that excerpts from the survey may be used in publications to come from this research. Organisations and any data used in this research will be kept anonymous.	
I understand that relevant sections of the data collected during the study may be looked at by the researcher's main supervisor and give permission for them to have access to my responses.	
I understand that if I withdraw from this study I will lose the rights to receive a report illustrating the key findings from this study.	

With full knowledge of all foregoing, I agree to participate in this study and am aware I am able to withdraw from this study without giving a reason up until March 2015.

I agree to being contacted again by the researcher for a report illustrating the key findings from this study and if my responses give rise to interesting findings.

☐ no
☐ yes

if yes, my preferred method of being contacted is:
☐ telephone …………………………………………………..
☐ email ………………………………………………………..
☐ other ………………………………………………………..

Organisation Name:			
Participant(s) Name:		Consent taken by	
Participant(s) Job Title:			
Participant(s) Signature:		Signature	
Date		Date	

I must kindly ask if you can you return the survey and consent form by post (see above for address) or by email

APPENDIX D – SURVEY

Survey

LEAN VERSUS AGILE MANUFACTURING

Section A: Background Information (Questions 1 – 9)

Question 1)

What type of product is manufactured in your organisation?
(Please **only** tick one **box** accordingly)

a)	Manufacture of leather and related products	☐
b)	Manufacture of wood and of products of wood and cork, except furniture;	☐
c)	Manufacture of coke and refined petroleum products	☐
d)	Manufacture of chemicals and chemical products	☐
e)	Manufacture of rubber and plastic products	☐
f)	Manufacture of other non-metallic mineral products	☐
g)	Manufacture of basic metals	☐
h)	Manufacture of fabricated metal products, except machinery and equipment	☐
i)	Manufacture of electrical equipment	☐
j)	Manufacture of machinery and equipment	☐
k)	Manufacture of motor vehicles, trailers and semi-trailers	☐
l)	Manufacture of other transport equipment	☐
m)	Manufacture of furniture	☐
n)	Manufacture of computer, electronic and optical products	☐
o)	Other manufacturing	☐

If other please can you provide a description…………………………………………………………………………….

……….

……….

Question 2)

How many workers are employed within your organisations?
(Please **only** tick **one** box accordingly)

a)	0 - 50	☐
b)	51 - 250	☐
c)	250+	☐

(Turn Over)

Question 3)

How long has your organisation been operating?

(Please **only** tick one **box** accordingly)

a) Fewer than or equal to ten years	☐
b) More than ten years but fewer than or equal to 20 years	☐
c) More than 20 years	☐

Question 4)

What percentage of total products produced by your organisation is for the automotive industry?

(Please **only** tick **one** box accordingly)

a) 0%	☐
b) 1% – 10%	☐
c) 11% - 20%	☐
d) 21% - 30%	☐
e) 31% - 40%	☐
f) 41% - 50%	☐
g) 51% - 60%	☐
h) 61% - 70%	☐
i) 71% - 80%	☐
j) 81% - 90%	☐
k) 91% - 100%	☐

If you have ticked box A please move on to question 9.

Question 5)

What type of automotive component is your organisation predominantly producing?
(Please **only** tick **one** box accordingly)

a) Vehicle	☐
b) Body/Main Part	☐
c) Electrical/Electronics	☐
d) Interior	☐
e) Powertrain and Chassis	☐
f) Miscellaneous Auto Parts	☐
g) Other	☐

If **other** please can you provide a description…………………………………………………………………..

……

……

(Turn Over)

Question 6)

What other types of automotive components does your organisation produce?
(Please **tick** as **many** boxes applicable)

a) Vehicle	☐
b) Body/Main Part	☐
c) Electrical/Electronics	☐
d) Interior	☐
e) Powertrain and Chassis	☐
f) Miscellaneous Auto Parts	☐
g) Other	☐

If **other** please can you provide a description…………………………………………………………………………..

………

Question 7)

What tier would you class your organisation belonging to within the automotive supply chain?
(Please **only** tick **one** box accordingly)

a) OEM	☐
b) 1st Tier	☐
c) 2nd Tier	☐
d) 3rd Tier	☐
e) 4th Tier	☐
f) Other	☐

If **other** please can you provide a description…………………………………………………………………………..

………

Question 8)

What tier does your organisation predominantly supply to within the automotive supply chain?
(Please **only** tick **one** box accordingly)

a) OEM	☐
b) 1st Tier	☐
c) 2nd Tier	☐
d) 3rd Tier	☐
e) 4th Tier	☐
f) Other	☐

If **other** please can you provide a description…………………………………………………………………………..

………

(Turn Over)

Question 9)

What automotive OEM supply chains does your firm operate within?

(Please **only** tick **one** box accordingly)

a) Jaguar Land Rover	☐
b) Mini	☐
c) Nissan	☐
d) Other	☐

If **other** please can you provide a description…………………………………………………………………..

……

Section B: Manufacturing Operations (Questions 10 – 12)

Question 10)

Manufacturing organisations use a variety of concepts in order to meet performance objectives, please can you state which manufacturing concept your organisation is **pursuing** to a **greater** extent?

Lean Manufacturing: Lean manufacturing involves never ending efforts to eliminate or reduce waste (improve efficiency) concerning design, manufacturing, distribution, and customer service.

Agile Manufacturing: Agile manufacturing is a term applied to an organization that has created processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality.

(Please **only** tick **one** box accordingly)

a) Lean manufacturing	☐
b) Agile manufacturing	☐
c) Hybrid Manufacturing	☐

If **other** please can you provide a description…………………………………………………………

……

……

……

(Turn Over)

Question 11)

There are a number of production tools, practices, routines and concepts (TPRCs) associated with manufacturing; please can you indicate the extent to which each technique and practice is adopted within your organisation during the last financial year?

(See glossary for description of each manufacturing business practice labelled from a-v)
If there are any other TPRCs you would like to include please fill them in from lines aa–ee. If you have filled in other practices and techniques in lines aa–ee please can you provide a description of what they entail in the lines below the table.

(Please **only** tick **one** box corresponding to each row)

	1 None	2 Low Levels	3 Moderate Levels	4 Reasonably High Levels	5 High Levels
a) Elimination of waste					
b) Continuous improvement					
c) 5S					
d) Zero Defect					
e) Production Smoothing					
f) Line Balancing					
g) Value Stream Mapping					
h) Total Productive Maintenance					
i) Cellular Manufacturing					
j) Just-in-Time					
k) Kanban					
l) Multifunctional Teams/Machines					
m) Total Quality Management					
n) Employee Empowerment					
o) Setup Reduction (SMED)					
p) Virtual Enterprise					
q) Core Competence Management					
r) Knowledge Driven Enterprise					
s) Reconfiguration					
t) Rapid Prototyping					
u) Concurrent Engineering					
v) IT Driven Enterprise					
aa)					
bb)					
cc)					
dd)					
ee)					

……

……

……

(Turn Over)

Question 12)

In terms of the business strategy employed within your organisation please rank and fill in the performance objectives in association to importance.

Please **only** fill in **one** performance objective in association to each rank.
(**note**. 1 being the most important and 5 being the least important)

For Example:

Performance Objectives	Importance (Rank)
a) Cost	1 Cost
b) Dependability	2 Quality
c) Flexibility	3 Speed
d) Speed	4 Flexibility
e) Quality	5 Dependability

Performance Objectives	Importance (Rank)
a) Cost	1
b) Dependability	2
c) Flexibility	3
d) Speed	4
e) Quality	5

(Turn Over)

PLEASE NOTE ALL INFORMATION IS STRICTLY CONFIDENTIAL

Section C: Performance (Questions 13 – 17)

Question 13)

Cost Performance

i) What were the……..in your organisation during the last financial year?

(Please fill in **all** sections accordingly)

a) Total Costs (£)	
b) Sales (£)	
c) Profits (£)	
d) Inventory Costs (£)	
e) Manufacturing Costs (£)	
f) Distribution Costs (£)	

Question 14)

Dependability Performance

i) In terms of total output what……in your organisation during the last financial year?

(Please fill in **all** sections accordingly)

a) Percentage of orders were late (%)	
b) Percentage of orders were delivered to the wrong address (%)	
c) Percentage of products were already in stock (%)	
d) Was the average lateness of orders (hours/days/weeks)	
e) Was the Average schedule adherence (hours/days/weeks)	

Question 15)
Quality Performance

i) In terms of total output what was the average……in your organisation during the last financial year?

(Please fill in **all** sections accordingly)

a) Percentage of defects (%)	
b) Percentage of scrap levels (%)	
c) Time between failures (hours/days/weeks)	

(Turn Over)

Question 15 Continued)

ii) In terms of orders what was the average……in your organisation during the last financial year?

Please fill in **all** sections accordingly)

d) Percentage of customer complaints (%)	
e) Percentage of warranty claims (%)	

Question 16)

Speed Performance

i) What was the average……..in your organisation during the last financial year?

(Please fill in **all** sections accordingly)

a) Order-lead time (hours/days/weeks)	
b) Frequency of deliveries per month	

i) What percentage of order-lead **(Q15a)** time was spent on the……..in your organisation during the last financial year?

c) Delivery time (%)	
d) Manufacturing time (%)	

Question 17)

Flexibility Performance

i) What were the……..in your organisation during the last financial year?

(Please fill in **all** sections accordingly)

a) Lowest quantity/volume/units of goods produced in a month	
b) Highest quantity/volume/units of goods produced in a month	
c) Total quantity/volume/units of goods produced	
d) Total number of different types of products produced	
e) Average time duration when introducing new products (design to production)(hours/days/weeks)	
f) Average time spent seeking new suppliers (hours/days/weeks)	
g) Total number of different suppliers used	
h) Percentage of suppliers used from the previous financial year (%)	
i) Total number of customers	
j) Percentage of customers used from the previous financial year (%)	
k) Total number of distributors	
l) Percentage of distributors used from the previous financial year (%)	

(Turn Over)

Question 17 Continued)

ii) When orders were processed at short notice and high priority during the last financial year, what was the average total amount of time that was **solely** reduced on **delivery**?

iii) If your organisation were to **double** its production volume during the next financial year, what would be the **percentage** increase in **total costs**?

Thank you for completing the survey!
(End of survey)

If you have any additional comments you would like to make regarding this survey please outline below:

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