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An Integrated Framework to Assess 'Leanness' Performance in Distribution Centres

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An Integrated Framework to Assess 'Leanness' Performance in Distribution Centres

By

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This thesis is submitted to Dublin Institute of Technology as the fulfilment of the requirement for the award of the degree of

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Supervisor

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Declaration Page

I certify that this thesis which I now submit for examination for the award of Doctor of Philosophy (PhD), is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

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ABSTRACT

The theory behind lean philosophy is to create more value with less. Effective lean management enables organisations to exceed customer expectations while reducing costs. Despite the fact that numerous practices and approaches are used in the process of implementing lean philosophy and reducing waste within supply chain systems, little effort has been directed into assessing the leanness level of distribution and its impact on overall performance. Given the vital role of distribution units within supply chains, this research aims to develop a comprehensive lean assessment framework that integrates a selected set of statistical, analytical, and mathematical techniques in order to assess the 'leanness' level in the distribution business.

Due to the limited number of published articles in the area of lean distribution, there are no clear definitions of the underlying factors and practices. Therefore, the primary phase of the proposed framework addresses the identification of lean distribution dimensional structure and practices.

The other two phases of the framework discuss the development of a structured model for lean distribution and address the process to find a quantitative lean index for benchmarking lean implementation in distribution centres. Integrating the three phases provides the decision makers with an indicator of performance, subject to applying various lean practices.

Incorporating the findings of a survey that sent to 700 distribution businesses in Ireland along with value stream mapping, modelling, simulation, and data envelopment analysis, has given the framework strength in the assessment of leanness.

Research outcomes show that lean distribution consists of five key dimensions; workforce management, item replenishment, customers, transportation, and process quality. Lean practices associated with these dimensions are mainly focused on enhancing the communication channels with customers, simplifying the distribution networks structure, people participating in problem solving and a continuous improvement process, and increasing the reliability and efficiency of the distribution operations.

The final output of the framework is two key leanness indices; one is set to measure the tactical leanness level, while the second index represents the leanness at the operational level. Both indices can effectively be used in evaluating the lean implementation process and conducting a benchmarking process based on the leanness level.

List of Acronyms

CBS	Class-Based Storing
CITC	Corrected Item Total Correlation
CFA	Confirmatory Factor Analysis
CPI	Process Capability Indices
DC	Distribution Centre
DEA	Data Envelopment Analysis
DMU	Decision Making Units
DRP	Distribution Resource Planning
EFA	Exploratory Factor Analysis
ERP	Enterprise Resource Planning
HRM	Human Resource Management
JIT	Just in Time
KPI	Key Performance Indicator
MSE	Measurement System Analysis
OEE	Overall Equipment Effectiveness
OM	Operations Management
PCA	Principle Component Analysis
SBM Model	Slack Based Model
SEM	Structure Equation Modelling
SKUs	Stock Keeping Units
TPS	Toyota Production System
TPM	Total Preventive Maintenance
TQM	Total Quality Management
VSM	Value Stream Mapping
WIP	Work in Process
WMS	Warehouse Management System

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Chapter 1: INTRODUCTION

1.1 Overview

The level of competition between enterprises is intensifying at an ever-increasing rate. Managers realise that competition is no longer enterprise versus enterprise, but is rather a case of supply chain network versus supply chain network (Li et al., 2005). In addition, the current economic crisis has brought significant disturbances to the business world. Companies worldwide have no choice other than to apply cost reduction strategies to their supply chains and operations in order to sustain profits. Finding the lowest-cost sources and manufacturing locations has forced supply chains to be extended through long distances across the globe. Despite issues of location constraints, time zones, and other difficulties, supply chains are required to ensure a high service level to their customers under the pressure of reducing costs and inventory.

Total Quality Management, Six Sigma, Lean Management, Process Re-engineering, and many other management strategies were introduced as improvement strategies for many business applications. Most of these strategies had as their core the issue of eliminating sources of waste and non-value added activities in order to achieve business goals and meet customer needs. Lean management originated in the Toyota production system, and proved its capabilities in reducing sources of wastes and inefficiency in manufacturing processes as well as throughout the entire supply chain (e.g. logistics, suppliers, procurement, and consumption) (Taylor, 2006; Lammin,1996).

1.2 Research Motive

Distribution is a critical component of the foundation that maintains the efficiency, flexibility, and reliability of any supply chain. Supply chains with the resolve and skill to provide a high-quality distribution service, and which do so efficiently, prosper and grow. The Distribution Centre (DC) often performs more than one function in supply chain networks including make-bulk/break-bulk consolidation centre, cross docking centre, product fulfilment centre and depot for return goods (Higginson and Bookbinder, 2005). In addition, it acts as a depot for trucks where drivers switch vehicles to avoid violating workforce constraints (i.e. transhipment facility) (Ross and Droge, 2002). It also offers customer support by scheduling services such as product installation or offering space for retail sales to end-consumers (i.e. factory-outlet store) (Berman, 1996).

Furthermore, DCs play an instrumental role in leveraging supply chain performance in terms of time, quality and cost (Yang *et al.*, 2010). A survey in Europe estimated that DC accounts for 24% of logistics cost, while the inventory within them represents 13% (European Logistics Association/AT Kearney, 2004). As regards customer service, distribution is normally the node in the supply chain where customer orders are assembled and despatched (Baker, 2004). The failure of providing high customer service at the distribution level has significant negative impacts on supply chain performance in terms of sales and profits (Kiff, 2000). DCs are also considered crucial elements in the debate of supply chain resilience, which has been of increasing interest in recent years, particularly as global sourcing have increased supply chain risk. This is due to the role that DC as a buffer against supply chain risk and uncertainty (Christopher and Peck, 2004). Despite the importance of the distribution performance on the entire supply chain network, it is still considered a neglected area in the supply chain literature (Higginson and Bookbinder, 2005).

DCs face many challenges in an environment characterised by increasing globalisation, competitiveness and consolidation. Increasing globalisation tends to lead to longer supply lead time as well as high level of variations and uncertainties in all supply chain activities (Waters, 2003). Expanding sales channels with the existence of online merchants and other direct ship channels also contributes in increasing order rates, reducing quantities per order and changing the mix of outbound transportation that complicate distribution functions even more. The quest to offer high level of service to customers while keeping a worthwhile profit margin under these challenges urged DC managers to think of new approaches to manage and improve their activities. Many management fads and planning methods were proposed for improving distribution performance such as supplier partnerships, customer segmentation, mass-customisation distribution (MCD), agile distribution centres, warehouse management systems (WMS), and distribution resource planning (DRP). While these strategies may improve distribution performance, they provide only a part of the solution being focused on individual distribution dimensions.

Lean philosophy is defined as a multidimensional approach that effectively eliminates or at least mitigates system waste. It utilises a collection of practices that simultaneously tackle the sources of inefficiency from different system areas. Lean is described as the reason behind the significant competitive advantage of the Japanese car manufacturers (Ignizio, 2009). Extending lean philosophy beyond manufacturing and into distribution provides the supply chain with more efficiency and responsiveness to customer demands, and they therefore become more competitive (Reichhart and Holweg, 2007).

Despite this, lean as an industry standard is not clearly defined with specific regard to the distribution industry. This caused a level of ambiguity regarding what constructs contribute to or detracts from the level of leanness. Without specifying the underlying factors and practices of the lean distribution, it would be impossible to extend the benefits of lean thinking into the distribution industry. Moreover, to date the most of lean assessment models are based on subjective methods of assessment which ultimately create numerous difficulties in determining a consistent approach to assess the leanness of distribution companies or benchmark their performances (Ray *et al.*, 2006). The idea being that in order to successfully implement lean thinking there is a need to track the level of improvement or benchmark the results using a quantitative leanness index. Without quantifying the level of leanness, the failure rate of lean implementation process is extraordinarily high.

1.3 Research Question

Academics and practitioners alike agree that lean philosophy is a driver to better systems performance, and consequently to a higher competitive advantage for companies. However, informal interviews with supply chain managers pointed to the shortage of developing lean distribution frameworks that support and assess the implementation process.

Hence, the key question of this research is:

Can a Lean Distribution Framework be developed to assess the leanness level in the distribution industry?

To answer this question, two main objectives have been set:

Objective 1

Identify lean distribution underlying factors and their corresponding practices

To advance the theory and empirical work in lean distribution area, the concept and the structure of lean distribution paradigm has to be clarified. While the lean production paradigm has been well researched, lean distribution has received far less attention in the literature. Several authors have indicated that lean distribution is a broad and multi-dimensional concept, and involves several diverse aspects of an organization. However, little research addresses how can a distribution center achieve lean? Answering this question is necessary towards improving distribution performance. It is also important to identify lean distribution before commencing the lean assessment phase since the lack of clarity of lean distribution concept and its structure can negatively influence the assessment results. Hence, the first study objective aims to analytically explore the antecedents of lean distribution and identify the critical factors and their correspondent practices that determine and influence lean distribution paradigm (i.e. lean distribution measurement and structured model).

Objective 2

Develop a quantitative and synthesised lean distribution assessment models to assess the overall leanness level and set a lean benchmark.

‘*If you can’t measure it, you can’t improve it...*’ *(Sir William Thomson, 1907)*: this hundred year old truth has sparked many research efforts in the current decade, with researchers and managers alike realizing the importance of the numerical assessment of a system’s leanness level. Research on assessing leanness over the last decade has focused on creating lean indices for manufacturing systems, but no reports addressing techniques to assess leanness in the distribution industry were found.

Due to the many factors that affect lean distribution, developing a standard measure that integrates the leanness levels of these factors into one scalar becomes important. This scalar – leanness index – can be used to indicate company's current leanness state, evaluate the effectiveness of the proposed lean initiatives as well as benchmark for the lean performance. Owing to the fact that an individual lean metrics cannot represent the overall leanness level in the distribution industry, an integrated lean assessment model is required in order to synthesize a group of lean metrics into one leanness scale – objective 2.

1.4 Research Background

1.4.1 Lean in Distribution Environment

Distribution is one of the most important supply chain functions, being the key interface between company sources (i.e. suppliers or manufacturers) and end-consumers. The unpredictable variations in customer demand increase the pressure on the distribution activities and negatively impacts on their performance. Pushing investments in more advanced distribution technologies and equipments is not enough to achieve flexible distribution performance. In contrast, it sometimes reduces the level of system flexibility due to the complexity they add on to the business processes (Higginson and Bookbinder, 2005). Moreover, the high cost of applying such technologies is considered a drawback, especially for the small and medium sized distribution companies. According to distribution managers, distribution forecasting plans were suggested as a solution to resolve customer demand variation by planning further into the future with a higher level of accuracy. However, the changes in consumers and industrial markets became too fast for forecasting to sufficiently optimize and execute accurate distribution plans. Forecast-based plans have reached their limit in dealing with current economic challenges and ongoing severe market competition (Rodrigues *et al.*, 2008).

In the last decade, lean distribution was presented as an efficient alternative to the traditional forecast plans, with it being focused on creating a responsive distribution environment against the fluctuation in customer demands (Manrodt *et al.*, 2008). It aims to increase systems responsiveness and reduce the total cost by simplifying distribution operations and targeting the sources of waste and non-value added activities. In contrast to forecast-based plans, lean practices are highly flexible to market variations through various levers, including minimizing the cycle time, reducing lot sizes, isolating sources of variation and increasing operations reliability (Zylstra, 2006). These levers are linked to all distribution dimensions (e.g. customer service, item replenishment, supplier, transportation, buffers, and quality) and activities.

1.4.2 Lean Assessment for Distribution Industry

Some companies have adopted specific lean elements (i.e. practices and tools), while others have employed the whole spectrum of lean elements. It is essential in the lean transformation process to gauge their current and desired leanness level in order to clearly guide lean implementation process. Because leanness is not a measurable value in its own right, the leanness index is usually generated based on the system parameters (i.e. independent variables) that contribute to the leanness level (i.e. dependent variable).

Lean assessment models usually performed through different methodologies, including surveys, benchmarking, graphical representations, and analytical models. Each model deals with specific kinds of lean practices and metrics. For instance, a lean assessment survey focuses on the subjective lean practices and metrics and then scores results presenting the difference between the current system state and the ideal state that is predefined in the survey. The generated leanness score can only be used to evaluate the compliance between the system and the lean indicators, as opposed to a quantitative index representing the real leanness level.

On the other hand, lean metrics, value stream mapping, and benchmarking are all used to quantitatively assess system's leanness. Lean metrics are the performance indicators that track the effectiveness of the lean implementation or continuous improvements processes (Nightingale and Mize *et al.*, 2002). Value stream mapping evaluates the leanness state by providing a graphical presentation for the value stream and visualising the waste and non value-added activities (Rother and Shock 1999). Finally, benchmarking quantitatively assess the leanness by comparing a system's leanness state against the benchmark in the sector (Knuf, 2000).

1.5 Dissertation Layout

The dissertation layout is organised based on the sequence of the research questions and objectives. It starts with an extensive literature review of the areas of lean thinking, distribution centres management, and lean assessment. This is followed by a discussion of the methodologies, approaches and tools that are employed to achieve research objectives. Upon completion of the review, the framework structure is described and finally real distribution case studies are presented. Figure 1-1 shows graphically the thesis layout.

Chapter 2: Literature Review

This chapter is divided into two key parts; the first aims to review the fundamental principles of lean distribution, while the second tracks the research records in the lean assessment area. It begins with a generic discussion about lean philosophy and its important role in enhancing manufacturing and supply chain performance. After that, distribution system elements are discussed illustrating the roles that distribution centres play in supply chain, distribution operations and distribution performance metrics. A review of the previously studied lean distribution frameworks, practices and lean assessment techniques then takes place.

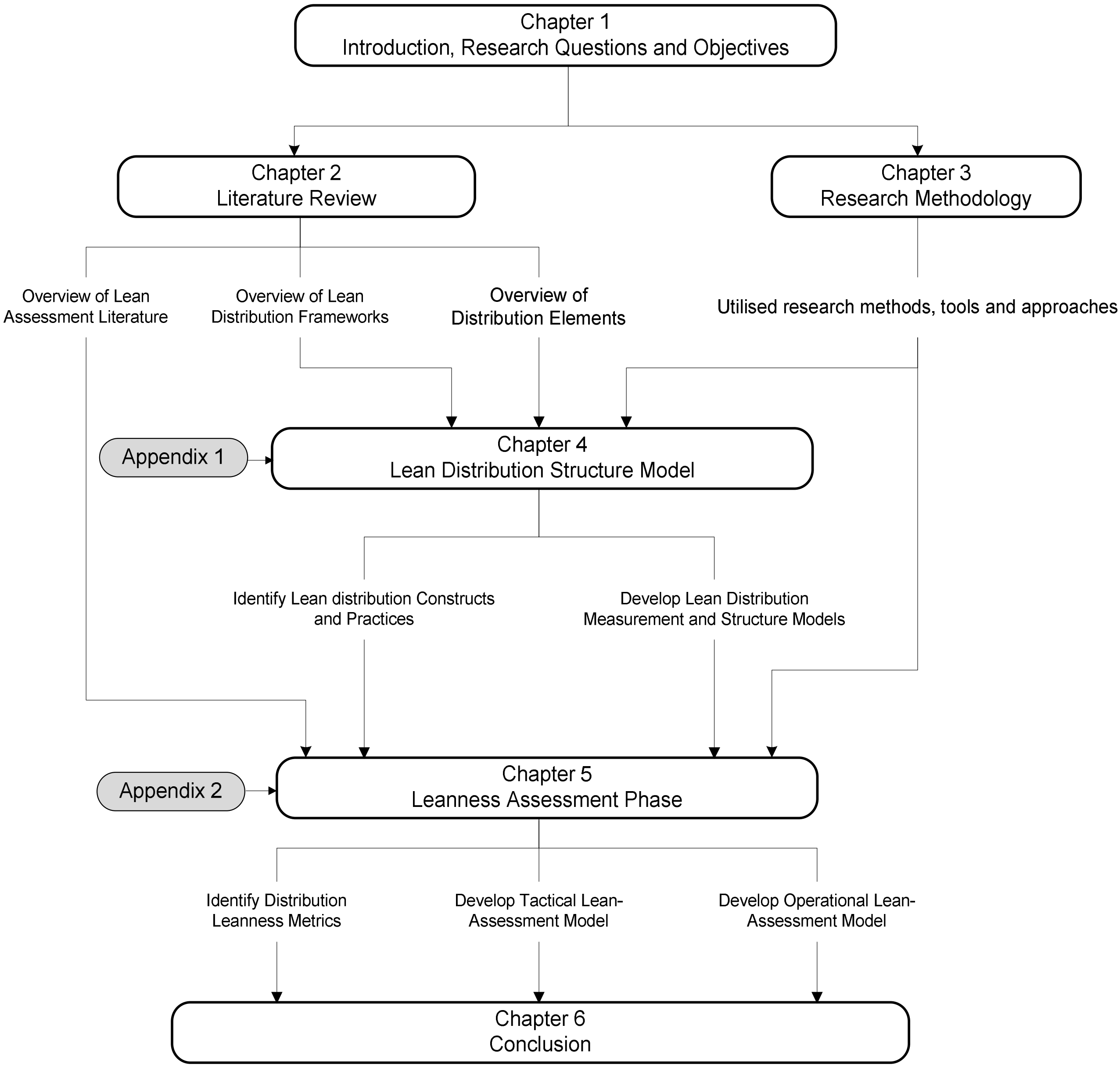


Figure 1-1 Research layout flow chart (Source: Author).

Chapter 3: Research Methodology

An explanation and justification of the research methodologies employed for carrying out the study is presented in this chapter. Research philosophies, design, approaches, and strategies are briefly discussed including quantitative and qualitative research methods. This chapter will also highlight the data collection methods used during the different phases of the research.

Chapter 4: Lean Distribution Framework: Identification and Development Phase

Chapter 4 explains the structure of the proposed framework. It elaborates the two key phases of the framework (i.e. the identification and development phases). For the identification phase, it provides an overview regarding the lean distribution concept based on the relationship between its generated constructs. Exploratory and confirmatory analyses are then applied to identify a lean distribution measurement model. Finally, a structure equation model is developed to find the correlation between the lean distribution variable and the identified constructs.

Chapter 5: Lean Assessment Phase

The chapter shows the third phase of the developed framework – lean distribution assessment. It starts by identifying the performance metrics that represent the distribution leanness level. The selected metrics are divided into tactical and operational metrics based on the nature of the evaluated dimensions and practices. Principle component analysis is applied on five distribution companies in order to generate their tactical leanness index. At the same time, VSM, modelling and simulation, and DEA – SBM – are integrated to calculate the operational leanness index. The generated leanness indices will be used to explore the improvement opportunities in the studied companies and assess the influence of the lean initiatives on company's leanness level.

Chapter 6: Conclusion

Finally, a discussion of the study outcomes and recommendations for future research will be presented.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

Organisations can no longer effectively compete in isolation of their supply chain entities (Lummus and Vokurka, 1999). Various definitions of a supply chain network were provided in the past years. It was defined as the network of entities (e.g. suppliers, carriers, manufacturing sites, distribution centres, retailers and customers) through which material flows (Lummus and Alber, 1997). Hur *et al.* (2004) presented the supply chain as a collection of three sequential-linked value-creating networks including supply network, conversion network and distribution network. Each network consists of different, multiple, organisational units and functions. Supply chains were divided into three categories according to the entities relationship complexity levels; direct supply chain, extended supply chain and ultimate supply chain (Mentzer *et al.* 2001).

In order to reduce costs, improve products, shorten lead time and enhance competitiveness for the entire chain, supply chain entities and units have to be efficiently managed (Mentzer *et al.* 2001). The term supply chain management (SCM) has been used to explain the planning and control of materials and information flows as well as the logistics activities across the entire supply chain network (Cooper *et al.* 1997). The SCM concept was also employed to describe strategic inter-organisational issues, discuss the relationship a company develop with its suppliers and address the purchasing and supply perspectives (Chen and Paulraj, 2004). A number of fields such as purchasing and supply, logistics and transportation, strategic and operations management and management information system were addressed in the SCM context (McIvor, 2000; Heng *et al.*, 2005). Distribution Centres (DC) continue to play a key role in modern supply chain networks (Frazelle, 2002b). Owing to this fact, various improvement initiatives and strategies have been addressed towards achieving more efficient distribution performance (Hertz *et al.*, 2001, Gebennini *et al.*, 2009, Mason and Lalwani, 2008). Most of these attempts offered solutions to a number of the distribution problems yet can be viewed as partial improvement efforts in a distribution environment.

The lean paradigm is a configuration of practices and tools which eliminate system waste by isolating sources of variability and non-value added activities (Shah and Ward, 2007). It is designed from the interaction of its constituent elements and applied as a whole instead of one element at a time. While the research efforts of lean manufacturing began to grow in the 1950s and were extended to suppliers operations in the 1970 (Ohno, 1988), lean distribution started to attract academic attention in 1980s (Fisher *et al.*, 1994). Its connection to superior performance and its ability to provide competitive advantage gained it a significant attention among academics and practitioners (Jones *et al.*, 1997, Kiff, 2000, Reichhart and Holweg, 2007). In the last decade, in particular lean distribution has become an integral part of most industries.

2.2 Lean Paradigm

Lean thinking attempts to achieve streamlined and waste-free operations by attacking all negative aspects of resource consumption (Christopher, 2004). Toyota introduced lean philosophy by developing a hybrid production system merging Ford's mass production techniques with a small batch production policies creating Toyota Production System (TPS) (Fujimoto, 1999, Ohno, 1988). Lean production has continuously evolved

(Holweg and Pil, 2004) and included a set of practices including just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM) and human resource management (HRM) (Shah and Ward, 2003). While the majority of the lean articles focused on the production applications, the notion was also stretched to include other supply chain activities (e.g. procurement, supply, logistics and consumption) (Jones, *et al.*, 1979; Wilson and Ray, 2009; Womack and Jones, 2995). Lean became a more generic supply chain philosophy by introducing various lean practices such as just-in-time inventory and closer supplier-customer relationship (Hammer, 2004, Christensen, 1996). For service industry, lean management was used to efficiently identify and eliminate waste in internal service operations and to positively impact on customer satisfaction levels (Piercy and Rich, 2009, Maleyeff, 2006).

2.2.1 Lean Manufacturing & Design

The Toyota Production System has evolved in western countries and has been branded initially as JIT production and subsequently as lean production (Womack *et al.*, 1996). Examining the historical evolution of lean production is important to identify the different perspectives that are embedded in the concept. Figure 2-1 shows the history of lean production starting from 1927 – Ford Production System – until the 2000s. Lean production is described from two perspectives; (i) a philosophical point of view focusing on guiding principles and concepts (Spear and Bowen, 1999, Womack *et al.*, 1996) and (ii) a practical perspective which includes management practices, tools or techniques. Table 2-1 illustrates a list of authors – arranged based on chronological order – that focused on different practices and techniques of lean manufacturing showing the multi-dimensional nature of the lean concept.

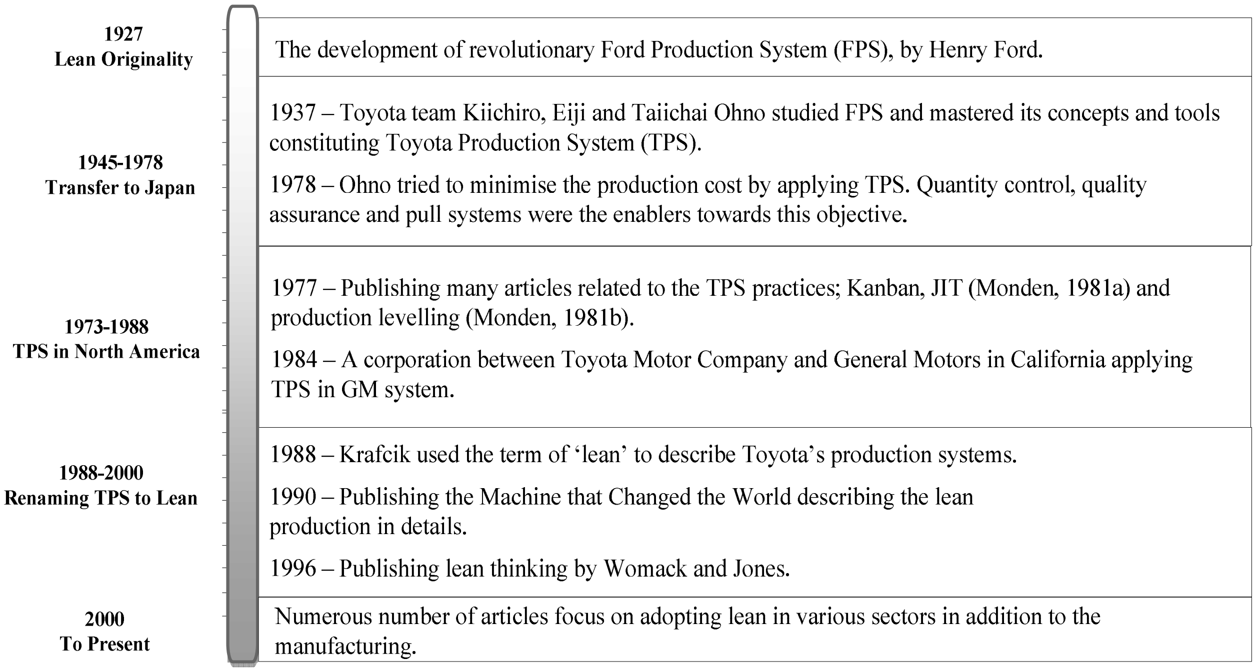


Figure 2-1 Critical phases of lean production evolution (Source: Shah and Ward, 2007).

There are many descriptions of lean production and its underlying components including Cellular Manufacturing (Chan *et al.*, 1993), Cycle Time Reduction (Sakakibara *et al.*, 1997), JIT (White *et al.*, 1999), TPM (Flynn *et al.*, 1999) and TQM (Koufteros *et al.*, 1998). To apply JIT, for instance Kanban, (one of the main four concepts of TPS) a pull of the materials from upstream stations, is key to manage product flow (Ohno, 1988). JIT was described as one of the key approaches of lean production. It was applied in different strategies including production smoothing, customer focus and set up time reduction (Hall, 1987, McLachlin, 1997, Sugimori *et al.*, 1977). The same concept was applied in other components of lean production such as total quality management and total preventive maintenance approach (Mehta and Shah, 2005).

Table 2-1 Lean manufacturing principles and constructs (Source: Author).

Constructs / Authors	Standardisation & Documentation	People	Quality Control	Communication	Workplace Organisation (5S)	Lot Sizing	Material Flow (Kanban)	Continuous Improvement (Kaizen)	Customers	Process Mapping	Pull System (JIT)	Cultural Characteristics	Level production	Cellular Manufac -turing
(Worley and Doolen, 2006)		X		X			X		X	X	X			X
(Treville and Antonakis, 2006)	X	X	X	X	X		X				X	X		
(Chapman, 2005)					X									
(Rooney and Rooney, 2005)	X				X	X	X	X			X		X	X
(Quinn, 2005)							X		X	X	X			
(Ballé, 2005)								X				X		
(Mehta and Shah, 2005)	X	X			X		X					X		
(Liker, 2004)	X	X	X	X	X	X	X	X						
(Kojima and Kaplinsky, 2004)		X	X				X	X			X	X		
(Hancock and Zayko, 1998)		X	X	X									X	
(Womack *et al.*, 1996)	X	X	X	X	X	X	X	X						
(Womack *et al.*, 1991)		X	X			X	X	X						
(Shingo *et al.*, 1989)	X		X	X		X	X	X						
(Ohno, 1988)	X	X	X	X		X	X	X						

In some cases, lean manufacturing was integrated with lean design in order to enable rapid and efficient respond to the customer needs from new and improved products. Lean design aims to improve the quality of product design, reduce development time and reduce manufacturing cost (Swink, 1998). Four main practices of lean design were stated in the literature including concurrent engineering, design of manufacturability, value analysis and standardisation (Jayaram *et al.*, 2008). The four practices were based on the integration between the design and manufacturing activities. They contributed in increasing the design quality and applicability by identifying manufacturing capabilities and constraints early on the design phase.

2.2.2 Lean Supply Chain

In a market where the competition between enterprises has become a matter not only of productivity but also of the overall supply chain (Li *et al.*, 2005), applying lean manufacturing in integration with other supply chain elements became essential. Without an efficient, reliable supply chain, it is hard to fully benefit from lean manufacturing. It does not matter how fast the product can be manufactured if it gets stuck in the logistics chain (Daugherty and Pittman, 1995). This was realised by the manufacturers themselves as Toyota's president, Fuijo Cho, announced at Detroit Motor Show in 2000 that it was the right time to apply Toyota's JIT production concepts into distribution and marketing operations (Andrews, 2000). In line with Mr. Cho, researchers reported that a lean supply chain is a unifying conceptual framework, which includes upstream, internal and downstream sides of the supply chain (Jayaram *et al.*, 2008). It focuses on providing high customer service level by creating smooth flow of information and a quick response to demand fluctuation.

A special interest in applying the principle of lean supply has been developed in the lean supply chain literature in particular automotive industry since a large part of a cars manufactured value is provided by component suppliers (Lamming, 1996). The author also reported that there is an opportunity to apply same concept in the design phase of the new software development. To enhance long-term competitiveness for supply chains, it is important to establish effective suppliers partnership and collaboration in order to develop capabilities of JIT production and delivery (Helper, 1991).

Lean was also applied in the procurement process by aiming to reduce supply chain inventories, improve cost savings and production efficiencies (Wilson and Roy, 2009). The principles of lean procurement generally imply small lot sizes, purchasing from few suppliers who have to deliver the items in the exact quantities and at specific times. Unlike traditional procurement systems where price is the dominant factor, suppliers in lean procurement are evaluated and selected based on a combination of factors such as; quality, reliability, culture, behaviour and delivery performance (Ellram, 1995). The principles of lean production reached out to streamline the consuming process also (Womack and Jones, 2005). Lean consuming was concerned with the consumption process not only as an isolated moment of decision about purchasing a specific product, but also as a continual process that includes many initiatives to solve consumer problems (Orman, 2007). It contains different practices including: (i) solve customer's problem by ensuring the reliability of the services involved, (ii) provide exactly what customer's need and when it needed and (iii) continually aggregating and creating solutions to reduce customer's time and efforts.

In addition to lean supply, procurement and consumption, lean was also employed to improve supply chain logistics performance (Fuller *et al.*, 1993, Hill, 1993). It became critical for new companies in the move from manufacturing age to information age competition and link is the improvement into logistics practices for cost reduction (Kaplan and Norton, 1996). According to Jones *et al.* (1997), Toyota presented a typical implementation of lean logistics with a significant enhancement in its ordering and delivering performance. Microsoft Ireland has also applied lean principles for its logistics functions and achieved savings of €3m and a significant drop for its backorders in one year of lean operations (Fynes and Ennis, 1994). In an agri-food supply chain, a number of lean logistics practices that were applied include (Taylor, 2006):

- As few transport links as possible should be created between production processes,
- Very little inventory level should exist in the right amount, in the right place and be held for the right reason,
- Shortest possible lead time from the order placing to the delivery should be experienced,
- As little information processing as possible with high accuracy and no "demand noise" in the information flow, and
- All the above principles should be applied with the least possible or even zero cost.

In conclusion, the implementation of "Lean Principles" has enabled manufacturing firms across the globe to be more customer-focused, flexible and profitable. Tasked with reducing waste and non-value added activities into supply chain, various authors have attempted to identify the key Lean Principles that can be applied to the supply chain networks. In addition, they determined how these principles should be adopted to build adaptive, flexible and collaborative supply chain. Various publications have addressed the application of lean in supply, procurement, retailing, logistics and consumption in supply chains literature, however very little authors have reported lean distribution. The following sections aim to explore the main determinants of lean distribution through an extensive literature review on distribution elements and management practices. Before that, an overview on distribution roles, operations and performance indicators are presented in order to provide an understanding for the distribution function natures.

2.3 Distribution Industry Analysis

2.3.1 Distribution Centres Role in the Supply Chain Context

While warehouses only provide storage places for the raw materials and finished products after the manufacturing process (Maltz and DeHoratius, 2004, Rouwenhorst *et al.*, 2000), distribution centres supply more services for customers including customer orders fulfilments, products configurations, packaging, shipping and others (Langevin and Riopel, 2005). Dawe (1995) stated that warehouses are mainly used to store a large number of similar products, but distribution centres hold minimum inventories, and of predominantly high-demand items. Emphasising this fact, Coyle *et al.* (2003) defined the distribution centres as post-production warehouses for finished goods which are held for distribution. The term distribution warehouse was used by Frazelle (2002a) as the facility that accumulates and consolidates products from various points of manufacturing for combined shipment to common customers. Distribution centres are considered the first line of defence against customer demand fluctuation. They pursue the optimal control of stock levels as well as the agile performance concerning customer demand changes. Achieving effective item and information flow from a supply chain's upstream (i.e. supply side) to its downstream (i.e. end customers) is a key factor for a successful distribution performance. Distribution centres often perform more than one role in a supply chain aiming to deliver the best customer value (Ross and Droge, 2002). A summary of these roles was reported in Langevin and Riopel (2005):

- ***Make/break-bulk consolidations centre*:** This is a traditional distribution function where large incoming loads are disaggregated for mixing products in specific assortments (i.e. customer orders) as well as consolidating outbound shipments to gain transport economics (Baker, 2007).
- ***Cross-dock centre*:** This is a customer-focused strategy aiming to reduce order cycle time by directly fulfilling the items from suppliers and manufacturers and moving them as quickly as possible – 48 hours maximum – for merging with other items delivered to the same destination (Apte and Viswanathan, 2000, Chopra, 2003).
- ***Transhipments facility***: This is a carrier-focused strategy where the distribution facility can be used as a place for changing transportation modes or vehicle types (Daganzo, 2005). It provides the flexibility to cope with route constraints and customer's delivery requirements (Beuthe *et al.*, 2001).
- ***Assembly facility****:* This is about postponing item configuration, packaging and labelling, with the activities to be carried out in the distribution centres in order to improve product localisation – the ability to configure an item in a given market area to better reflect the characteristics of that market (Simchi-Levi *et al.*, 2003).
- ***Product-fulfilment centres***: In this role, distribution centres connect directly to the end customers to deliver the orders (Ackerman and Brewer, 2001).
- ***Returned good depots****:* Receiving returned products and getting them back into the forward distribution process at minimum cost and cycle time (i.e. reverse distribution) (Srivastava and Srivastava, 2006).

2.3.2 Distribution Operations

Value is the pivotal target that lean tries to achieve in any application domain. Because storing is the only function of warehouses, Bancroft (1993) stated that they do nothing to add value to the end customers. Distribution centres, on the other hand, provide important value-added to firms' customers by moving finished products and items from source (e.g. supplier or manufacturer) to end consumer. It is necessary to create customer value in a way that optimal cost/benefits trade-off is achieved and company profit is maximised (Christopher, 1992). Innovative distribution solutions such as cross-docking, postponement and merge-in-transit were suggested to increase customers value and decrease the distribution cost (i.e. reducing total inventory level and transportation cost) (Stalk and Hout, 1990).

In order to efficiently deliver customer value, distribution centres require reliable and efficient operations. Distribution operations were categorised into seven different groups regarding to their purposes. These groups were identified based on an extensive literature review for the distribution operations management area as illustrated in Table 2-2. While inbound activities focus on receiving, unloading and storing items, outbound operations concentrate more on managing customer orders and include various operations such as picking, assembling, loading and then delivering to customers (Smith, 2007). More efficient loading and unloading operations could be achieved by employing truck docking operations (Zhou and Li, 2005). A survey covering 349 UK distribution centres revealed that a new set of activities (e.g. reverse flow and prior to despatch) were taking place in the distribution environment (Baker, 2004). The author reported that 71% of the surveyed companies undertook some 'prior to despatch' operations such as labelling, pricing and tagging goods, while 42% have operated 'reverse flow activities like disassembly, refurbishment and repairing. A new set of operations such as product packaging, assembly and products configuration are necessary to be performed if the distribution centre used as an assembly facility (Maltz and DeHoratius, 2004).

Table 2-2 Distribution operations and activities (Source: Author).

Categories	Distribution Activities	Description	Authors
Inbound Activities	Inbound Planning	Pre-planning of inbound shipments and booking slots for storage.	(Smith, 2007);(Higginson and Bookbinder, 2005); (Zhou and Li, 2005)
	Tipping	Unloading containers	(Smith, 2007); (Zhou and Li, 2005); (Huertas *et al.*, 2007)
	Put-away	The physical act of placing items into their final location in the storage area.	(Smith, 2007); (Higginson and Bookbinder, 2005);(Petersen and Aase, 2004); (Rouwenhorst *et al.*, 2000); (Pfohl *et al.*, 1992); (Bancroft, 1993); (Huertas *et al.*, 2007)
Outbound Activities	Picking & Assembly	The physical act of picking and retrieving items from their storage	(Smith, 2007); (Higginson and Bookbinder, 2005); (Petersen and Aase, 2004); (Tompkins, 2003); (Rouwenhorst *et al.*, 2000); (Pfohl *et al.*, 1992); (Bancroft, 1993); (Zhou and Li, 2005); (Huertas *et al.*, 2007);
	Shipping	Delivering ordered items to the end-consumers	(Higginson and Bookbinder, 2005); (Rouwenhorst *et al.*, 2000); (Pfohl *et al.*, 1992)
	Loading	Loading outbound trailers, or customer vehicles.	(Smith, 2007); (Zhou and Li, 2005); (Huertas *et al.*, 2007)
	Outbound Planning	Processing orders to be picked (i.e. printing labels, assigning personnel to pick and assemble the goods and booking transport)	(Smith, 2007)
Truck Docking	Truck Registration	Records truck identifications and related information	(Zhou and Li, 2005)
	Trucks unloading	Unload the incoming items from the trucks	
Prior to Despatch	Labelling, Pricing & Tagging Goods	label and tag items information such as numbers, prices and other instructions	(Baker, 2004); (Maltz and DeHoratius, 2004)
Reverse Flow Activities	Disassembly	Disassemble returned products and store the semi-finished items	Baker (2004)
	Refurbishment	Send returned products to the manufacturing site for refurbishment	
	Repair& Modification	Send returned products to the manufacturing site for fixing	
	Loss Claim Support	Preparing and issuing the information and documents of loss items and replacement	
Postponement	Final Packaging	Items packing according to customer requirements or products specification	(Mason and Lalwani, 2008); (Baker, 2004); (Maltz and DeHoratius, 2004), (Rouwenhorst *et al.*, 2000); (Pfohl *et al.*, 1992)
	Products Configuration	Configure finished products according to customer requirements and specifications using semi-finished items	
Other Activities	Break Bulk	Taking large deliveries and breaking them into smaller quantities	(Mason and Lalwani, 2008)
	Products Inspection	Quality inspection for incoming products	
	Managing vendor inventories	Allocating and managing he inventory at the vendor site	

2.3.3 Distribution Performance Metrics

Although performance metrics for logistics and supply chains were extensively addressed in the literature (Ballou *et al.*, 2004, Keebler, 2001), few of them discussed the measuring of distribution performance explicitly. The three parts of logistics effectiveness – customer satisfaction, cost and capital tied up – are used as performance indicators in different cases. The Warehousing Education and Research Council (WERC) reported a wider range of 50 distribution performance indicators categorised into five key groups; customers, operational, financial, capacity/quality and employee through a survey on 613 distribution companies (WERC, 2010). Table 2.3 shows the top 10 most popular metrics according to WERC.

Table 2-3 The top 10 most popular DC metrics (Source: WERC, 2010).

Metric Category	DC Metric	Definition	Calculation
Customer	On Time Shipments	The percentage of orders shipped at the planned time	Number of on-time ships/ total number of orders shipped
Quality	Order Picking Accuracy	The number of errors that may be caught prior to shipment (e.g. during packages)	Orders picked correctly/Total order picked
	Inventory Count Accuracy	Measures the accuracy of the physical inventory compared to the reported inventory	The sum of the absolute variance in units or dollars/The sum of total inventory in units or dollars
Capacity	Average Warehouse Capacity	The average amount of warehouse capacity used over a specific amount of time	Average capacity used/Average capacity available
	Peak Warehouse Capacity	The amount of warehouse capacity used during designated peak seasons	Peak capacity used/Capacity available
Employee	Annual Workforce Turnover	The rate at which permanent employees are replaced	Number of new employee at the beginning of the period/Total number of employee
Outbound Operations	On-Time Ready to Ship	The percentage of orders ready at the planned time to meet customer requirement	Number of orders ready to shipment on time/Number of total orders shipped
	Fill Rate	The percentage of orders filled according to customer request	Number of orders filled to customer request/Total number of orders filled
Inbound Operations	Dock-to-Stock Cycle Time	The time required to put-away goods	Total cycle time of all supplier receipts/ total number of supplier receipt
Finance	Distribution Cost as a Percent of Sale	The cost to run distribution relative to total sales	Total distribution cost/Total sales

Additional metrics for storing and picking operations including shipping accuracy (percentage of SKUs shipped without errors), warehouse damage percentage

(percentage of dollar-value of damage per dollar-value of items shipped), volume and mix flexibility, storage capacity, response time, and order fulfilment quality was suggested by (Rouwenhorst *et al.*, 2000). Total distribution cost (e.g. transportation, inventory, operational and distribution expenses) and distribution throughput rate were considered to gauge the distribution systems efficiency and cost-effectiveness (Christopher, 1992). Decreasing individual elements of distribution cost on the expenses of others often result in high total distribution cost. The objective should be to achieve minimum total distribution cost rather than any one cost element (Ballou, 1987).

2.4 Lean Distribution Concept

Distribution systems have only recently gained attention in the lean context. The definition of lean distribution was inherited from the general philosophy of Lean – *lean thinking can be summarised as maximising the relative value delivered by reducing the waste and thus operational cost* (Womack *et al.*, 1996, Jones *et al.*, 1997, Hines *et al.*, 2004). Some authors defined lean distribution from the perspective of waste and cost reduction (Kiff, 2000) while others extended the definition to the customer service issue (Reichhart and Holweg, 2007). Lean distribution is viewed as a configuration of interacted practices, tools and tightly related and mutually dependent factors and management practices that cover all distribution constructs, see Figure 2-2 . Viewing lean distribution through a configuration lens provides a clear vision of its multiple facets together and supports the understanding of the relationships between lean distribution elements (Lamming, 1993).

Few attempts to characterise lean distribution are reported in the literature, for example a lean distribution framework consisting of five main constructs including customer service, process capability, buffer strategies, replenishment cycles and pull approaches, was developed by (Zylstra, 2006). Other studies considered inventory control, product flow, transportation management, companies' workforce behaviours and leadership as basic lean distribution dimensions (Baker, 2004, Mulcahy, 1994, Hopp and Spearman, 2004). The development of lean distribution (e.g. JIT distribution) has taken place in retailer manufacturer as a key extension to JIT production creating a more smooth flow of products as well as more efficient transport operations (Christensen, 1996). The author showed that the centralisation of stockholding, improving customers-suppliers communications, using advanced distribution technology and utilising effective transportation methods all contributed to successful JIT implementation in the distribution environment.

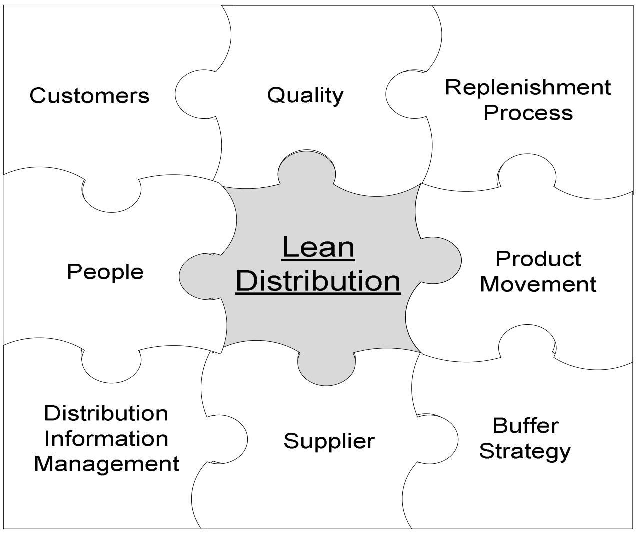


Figure 2-2 Lean distribution dimensions (Source: Author).

Many lean distribution aspects have yet to be investigated such as people, managing information flow, workplace organisation, quality assurance and continuous improvement. In general, lean distribution literature is considered to be spare and lacking depth (Reichhart and Holweg, 2007). Baker (2008 a) has addressed four main levels of distribution functions with their correspondent constructs as illustrated in

Figure 2-3. The distribution constructs are reviewed in the following section aiming to encompass a generic presentation of lean distribution concept and dimensions. Distribution centres are viewed as a part of wider system (i.e. supply chain network) (Christopher, 1998).

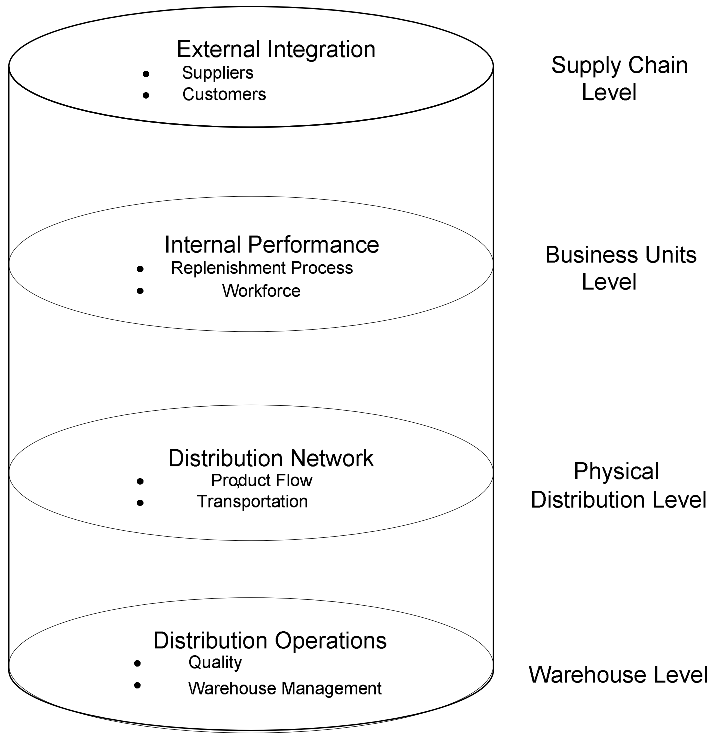


Figure 2-3 Distribution centre levels (Source: Baker, 2008a).

2.5 Lean Distribution Dimensions and Practices

2.5.1 Customers

Understanding and precisely identifying customer needs is a mandatory step for a successful lean transformation processes (Womack *et al.*, 1991). The full identification of customer demand allows managers to leverage the knowledge of their customer preferences and hence improve the accuracy of forecast plans and service quality level (Reichhart and Holweg, 2007). It also allows decision makers and distribution planners to create more efficient replenishment strategies, buffering control, supplier delivery schedules and distribution network structure. In automotive distribution centres for example, a better understanding of consumer requirements was considered a significant practice that influenced the design and development processes as well as distribution performance (Kiff, 2000). Having interviewed a large group of distribution companies in various sectors (e.g. beverages, computers, motor vehicles, electronics, forest products and health and beauty) Daugherty and Pittman (1995) have suggested three key factors for effective lean distribution; (1) effective relationship with customers, (2) flexibility with market changes, and (3) available real-time information for all distribution parties (i.e. suppliers and manufacturers).

In addition to the identification of customer requirement, customer demand management is also considered a key in increasing customer value and service level (Chua and Katayama, 2009). Demand levelling, by offering discounts to customers according to the period of time by which they are willing to postpone their orders, have been employed to minimise the variability of customer demand and create virtuous ability in customer retentions (Jones *et al.*, 1997). Developing accurate predictions for customer requirements and establishing robust communication channels between the distributors and their customers also contributed in adding value to customers and efficiently managing their demand (Kiff, 2000).

Customers segmentation, postponement, cross-docking and mass customisation are a number of improvement initiatives that were addressed to enhance customer service level (Baker, 2004). The use of customer segmentation has improved the capability to decrease order lead time and cost (Crowe *et al.*, 2010). A postponement strategy also provided a precise response to market demand by postponing the product configuration phase to the last stage in the distribution centres (Van Hoek *et al.*, 2001). Mass Customised Distribution (MCD) – based on *'mass customisation'* concept in production systems – offered more distribution flexibility against customers demand volatility (Mason and Lalwani, 2008). It focused on converting distribution activities such as warehousing, freight transport and retailing into more efficient customer oriented by improving the flow in distribution pipeline and tight inventory holding stock.

Finally, Cross-docking plays an important role in decreasing order lead time as customer orders could be fulfilled directly from the suppliers and manufacturers with a short lead time – not more than 48 hours (Napolitano, 2004). It focused on merging the delivered items to the same destination and managing their flow to reduce orders cycle time (Apte and Viswanathan, 2000).

2.5.2 Replenishment Process

Lean distribution is an extension of the demand-driven 'pull' signal that moves from end-customers to the supply chain downstream and aims to create products only when customers demand (Reichhart and Holweg, 2007). Speed and a consistent replenishment process, are the foundation of lean distribution implementation. The faster the products can flow from the sources to the destinations with the less uncertainty, the faster the replenishment orders can be received and satisfy customer orders on time (Jones *et al.*, 1997).

Establishing an effective pull approach is closely dependent on three significant factors; customer service policy, replenishment strategy and buffer placement (Enns, 2007). The right combination of these components results in a smooth replenishment process and a fast response to the changes in demand. 'Toyota's logistic system' resulted in significant improvements in both ordering and logistics activities *via* actions that led to the improvements in company's value stream as described by Jones et al. (1997). This is shown in Table 2.4. In the delivery process for instance, the traditional replenishment approach was changed to a "Milk Round" approach in order to achieve a regular and relatively short replenishment intervals with small lot sizes. In the ordering process, "sell one order one" replacing the traditional forecast-based orders resulted in standard frequent good deliveries to the dealers which in turn reduced the customers waiting time.

Table 2-4 Toyota's Lean distribution practices (Source: Jones, 1997).

Activities	Actions	Results
Delivery	Picked up the parts from suppliers using "milk round approach" at regular and relatively short intervals.	1- Sourcing many more part types from each supplier. 2- Number of labour hours decreased for incoming parts at any one time. 3- Caused higher transport utilization
Ordering	Transform the traditional standard reorder quantity with long lead time to "sell one order one" basis	1- Orders arrive to Toyota in predictable arrival time. 2- The move from monthly to daily orders causes a steady flow of demand to Toyota system.
Warehouse Management	A similar type of logic that applied in the factory is applied for warehouse management: 1- Reduced bin sizes. 2- Storage by part type with frequently used parts near warehouse front or end. 3- Standard binning and picking route for each part type. 4- Division of working day and tasks into standard work cycles. 5- Synchronized order-pick-pack-dispatch and delivery for each delivery route out to a group of dealers. 6- Control the processes through binning and visual control board.	1- The stock of the Toyota's regional DCs is down from 24 to 4 weeks. 2- The service rate and productivity are improved to three times a similar organized facility- with no automation.
Retailers	Daily delivery to retailers.	1- Reduce stock levels by over half while carrying a wider range of parts. 2- Improve service rate to waiting customers.

It is also necessary for the replenishment process in the lean environment to tighten the linkage between customer demand and item upstream flow by eliminating waste and non-value added activities (e.g. supplier negotiation, customer orders revision, evaluation and approvals) (Holweg and Pil, 2004). Eliminating demand and supply variation is also a substantial requirement for achieving more reliable replenishment process. Various lean practices and strategies were applied to reduce or nearly eliminate the source of customer and supply waste and variations including operating daily constant rates of customer orders (i.e. demand levelling), applying standard procedures for company's operations, keeping optimal SKUs inventory level and safety stock and facilitating item flow across the distribution facility (Crowe *et al.*, 2010).

2.5.3 Product Flow& Transportation

The items internal and external flows are affected by various distribution parameters including facility layout design, SKUs storage policies, picking approaches, distribution network structure and transportation activities (Chua and Katayama, 2009). Creating an efficient design for the distribution centres layout is a complex process as it aims to satisfy contradicting objectives (e.g. space minimisation, easy products picking, efficient item flows, safe working environment, minimum material handling cost and throughput rate) and include different parameters and variables that should be considered simultaneously (Mulcahy, 1994, Rouwenhorst *et al.*, 2000). A framework showed that developing optimal plans for warehouse spaces (e.g. receiving, storage and shipping spaces), material flow and process locations were important to develop an optimal layout design for the warehouses (Hudock, 1998; Frazelle, 2002b). Another framework, developed by Hassan (2002), focused on other layout parameters including arrangement of warehouse functional areas, number and locations of docks and I/O points, flow pattern and assignment of items to storage locations.

In addition to warehouse layout, storing policies are important for items flow. Because more numerous SKUs have to be delivered more frequently and quickly, distribution planners have no choice but to improve their order fulfilment operations through better storage policies and routing strategies (Petersen and Aase, 2004). Several storing approaches including random, dedicated, volume-based and class-based storage were addressed by various authors (Chua and Katayama, 2009, Chen et al., 2005, Petersen and Aase, 2004, Gagliardi et al., 2008). Integrating the advantages of these storage strategies efficiently reduces the waste in the storage space and increases the efficiency and utilisation of the picking operations and handling equipments units (Roodbergen and De Koster, 2001, Van den Berg, 1999, Chen *et al.*, 2005). For instance, although volume-based and class-based storage policies reduce the picking time in a more efficient manner then the random storage approach, random storage fully utilises the entire picking area more evenly and reduces worker congestion (Petersen and Aase, 2004). In the case that a large number of SKUs have to be picked in small quantities, the buffer facility is usually divided into two storage areas for easier item retrieval; reserve area, where products are stored on pallets, and the forward area where products are stored in delivery packages (Rouwenhorst *et al.*, 2000).

External product flow on the other hand focuses on providing smooth items transition across the distribution network nodes and it is influenced by item lead time, transportation cost and inventory turnover. When firms act in geographically-spread markets and have large number of suppliers and customers, developing optimum design for the distribution network becomes essential task. It helps to run efficient operations and avoid any transportation failure (Karlsson and Ahlstrom, 1997). Distribution network design involves many decisions related to the number, size and locations of the distribution centres, as well as whether they should be owned, leased, or outsourced (Lambert *et al.*, 1998, Baker, 2008a). Various network design issues were addressed in the literature including the efficiency of logistics and distribution planning systems (Mourits and Evers, 1995, Lalwani *et al.*, 2006), facility locations and vehicle routing

(Eiselt and Laporte, 1989) and the implications of relocating the distribution centres for freight transport (Lemoine and Skjoett-Larsen, 2004). Simplifying distribution networks is a major task for distribution planners in order to facilitate the product flow and reduce order's cycle time (Gebennini *et al.*, 2009).

Transportation was also recognised as one of the most important activities in the lean distribution context due to its significant impact on total distribution cost and pull replenishment performance (Jayaraman, 1998). Selecting the proper transportation modes (e.g. rail, truck, air or ship), the types of carriage (i.e. common, contract or private) and shipment capacities (i.e. full truck load, half-truck load or flexible) are key strategic decisions that directly affect transportation cost and efficiency (Narus and Anderson, 1996). For example, using a half-truck load may result in higher transportation costs compared with full-truck load capacity; however it is a better option regarding product lead time and entire distribution cost.

*2.5.4 **Buffer Strategies***

Buffers are required to isolate the distribution operations away from the variability of customers demand and suppliers delivery. The buffers may be in the form of inventory, capacity or time (Baker, 2007). In a typical lean environment, distribution companies should have zero inventory level and replenish their goods directly against customer orders (i.e. pull systems). Nevertheless, the typical implementation of pull replenishment approach is ineffective for some products and market sectors such as food, groceries and fashion. Lean distribution cannot simply be defined as stockless distribution or build-to-order, but as efficient inventory control along with high responsiveness to customers demand (Baker and Halim, 2007). Various lean practices were employed to effectively control the inventory level such as cross-docking and postponement strategies. Replacing the traditional distribution role – holding inventory and breaking bulk for customer orders – with these strategies eliminates large portions of excess inventory and maintains a high customer service level (Baker, 2004). Automated warehouse equipments (e.g. automated conveyors and storing systems) are required to support both strategies due to their ability in rapidly directing the finished products into the warehouse areas without the goods ever being placed into storage (Van Hoek *et al.*, 2001).

Inventory should also be placed as far back as possible in the supply chain because the fluctuation of demand for a single SKU at the customer site is much higher than the fluctuation for a group of customer demands for the same SKU. The closer the buffer to the sources (i.e. suppliers and manufacturers) the better the response to demand swings (Apte and Viswanathan, 2000). For instance, in automotive dealerships, it was clear that keeping a stock of cars and parts at each outlet was very wasteful. The studied company kept stock as centrally as possible and supplied the SKUs to the outlets within the time that the consumer willing to wait in order to eliminate the buffer waste (Kiff, 2000).

2.5.5 <u>Suppliers</u>

Suppliers with effective replenishment mechanisms and fast response to demand variations can effectively add value to the customers (Avery, 2003; Li *et al.*, 2005). Honda America, for instance, applied a successful supplier development project in its suppliers sites which resulted in a large improvement in the quality of its supplying and delivery processes (MacDuffie and Helper, 2002). The Ford Motor Company also implemented JIT distribution approach to create more efficient and cost-effective supplier relationship by consolidating suppliers products and takes full loads to production plants instead of each supplier delivering its own part (Christensen, 1996). Using value stream mapping, a leading UK distributor has achieved a great improvement in customer service level by converting his company processes from a limited supplier integration system to a highly integrated one (Hines *et al.*, 1999).

Other practices such as supplier partnership, long-term commitment and closer customer relationships have been suggested to strengthen buyer-supplier relationships (Jayaram *et al.*, 2008, Wu, 2002, Gentry, 1996). A group of US automotive companies achieved on-time parts shipment at low cost in a JIT environment thanks to its effective collaboration with their suppliers (Wu, 2002). Strategic partnerships between distribution companies and their suppliers as well as the accurate data exchange between them were highlighted as crucial practices that encourage the mutual planning and problem solving efforts in the supply pipeline (Christensen, 1996, Morgan and Hunt, 1994). It is very useful for these kinds of partnerships to be assessed continuously through customers feedbacks in order to keep them robust and effective for the benefits of overall system (Lamming, 1996, Cagliano *et al.*, 2006).

Different authors have addressed various lean supplier features. Wu (2003), for example, has described three of them:

- Lean Suppliers understand that they have to employ frequent and quick changeovers to meet their customers demand for an ever increasing variety of products.
- Lean suppliers are expected to be responsive to shop floor quality problems so defects can be prevented.
- Lean suppliers need effective telecommunications networks with their customers to get information on orders and production schedules and to track and manage material flows and inventories.

2.5.6 ***People***

The Lean paradigm is not only a collection of tools and practices to improve firm performance, but also a set of new cultural issues that people need to embrace in order to achieve sustainable lean performance. The successful implementation of lean distribution is critically dependent on the human behaviours and social norms. It is essential to address three fundamental cultural issues before adopting any major culture-changing initiative such as lean; leadership, workers motivation and problem solving (Wilson, 2010).

Leaders with the ability to articulate clear plans to their people are essential for a successful lean implementation process. Acting on the plan by exhibiting skills to not lose sight of the goal and overcoming all roadblocks, obstacles and resistance are mandatory traits in leaders in the lean environment (Ignizio, 2009). Many lean implementation plans have failed because the leaders did not have the courage and character to make difficult decisions and the lack of support and involvement of firms managers (Wilson, 2010, Ignizio, 2009). Motivating workers to effectively contribute to the lean implementation and accept all its associated changes is not an easy task (Achanga *et al.*, 2006). The role of leadership here is critical that they have to prepare the people for the changes and the consequences that may come. This can be done by allowing workers to join managers and supervisors in determining facility goals and by spreading out the fact that to keep survive you have to change and improve (Bhasin and Burcher, 2006). Involving the workers in problem solving procedures and activities is another important practice towards perfection.

The chances of a successful lean implementation are increased where workers commitment and cooperative labour-management relations are adopted in the workplace (Rinehart *et al.*, 1994). In addition, supply chain partners, from upstream suppliers to the downstream distribution, have to collaborate as a team to provide values to the end-consumers (Manrodt *et al.*, 2008). Sales teams in automotive dealership, for instance, play essential role in “hunting” the customers and retaining them through offering high quality sales and after-sales services (Kiff, 2000). Clear communication between managers, engineers and supervisors with the workforce by periodic meetings, discussions and exchange information is also important (Armistead, 1999). Training, sharing mutual values between group members, improving communication channels and human capital development ensure the growth and wellness of the employee (Chua and Katayama, 2009). Volvo Car Company (VCC) has addressed the importance of the effective communication between the people within the company and its influence on resource utilisation, process mapping, line balancing and layout design (Hertz *et al.*, 2001). The Chief Operating Officer at Turtle Wax has emphasized that companies get it wrong when they put too much attention on the tools, and not on the people. OfficeMax Company has also applied training workshops to help the workers to see lean operations differently due to its believe that company’s lean strategy is an operational part of its customers culture (Manrodt *et al.*, 2008).

2.5.7 <u>Quality Management</u>

Efforts to retain process stability and meet the customer needs are two foundations of the lean philosophy. They help the systems to generate value for the customers while reducing cost, improving delivery times and improving quality. Total quality management (TQM) has been defined as the philosophy that embraces the necessary quality concepts, methods, tools and techniques for both operational and strategic levels (Samson and Terziovski, 1999, Brah and Lim, 2006). Since variations in the processes performance have negative implications on systems quality, several practices and tools are used to stabilise processes performance such as overall equipment effectiveness

(OEE), measurement system analysis (MSA), process capability indices (CPI), availability, cycle time reduction, standard work, transparency, 5S and process simplification (Wilson, 2010).

The quality function is a continuous process that is applied on all logistics activities and elements to ensure efficient distribution and logistics performance. Acquiring the quality culture in addition to the successful implementation of its practices are essential to achieve reliable and consistent services, short delivery lead time, operating at low cost and flexibility in accommodating system changes. Customers, suppliers and internal logistics processes quality were studied using an eight-factor quality framework (top management leadership, quality data and reporting, training, employee relations, process management, product design and supplier quality management) Saraph *et al.* (1989). TQM in distribution was modified to embrace aspects like employees training and empowerment, customer focus and top management commitment, in addition to some traditional quality methods (e.g. continuous improvement, problem solving methodologies, quality verification, inspection procedures and corrective actions process) (Read and Miller, 1991, Brandimarte and Zotteri, 2007, Waters, 2003, Bhasin and Burcher, 2006, Nabhani and Shokri, 2009).

In a lean distribution context, providing an efficient and error free transaction for distribution information has a significant influence on customer service level and system quality level (Chen *et al.*, 2005). JIT in distribution has been fostered by the technological development and especially by improving the information and tracking systems (bar-code and sales-based ordering systems) (Christensen, 1996). Information technologies such as Enterprise Resource Planning (ERP) or warehouse and transportation management systems have played vital role in providing a high quality lean implementation in the distribution (Frazelle, 2002a). Additionally, the internet became the enabler that ultimately improved the management of the supply chain and was efficiently used to support the supply chain information technologies (Humphreys *et al.*, 2005, Cottrill, 1997).

Many lean practices have been mentioned in the above literature review. They were categorised into seven factors representing the main constructs of lean distribution. Identifying lean factors and practices by analysing the literature review was presented by various authors in the literature in the manufacturing domain (Saha and Ward, 2007). Figure 2-4 summarises the lean distribution factors and their correspondent practices composing a preliminary lean distribution structure. The preliminary structure will be refined through two steps; (1) face validation by interviewing distribution managers and (2) statistical validation tests, and then used as the foundations of the final lean distribution measurement and structure models as will be shown in Chapter 4.

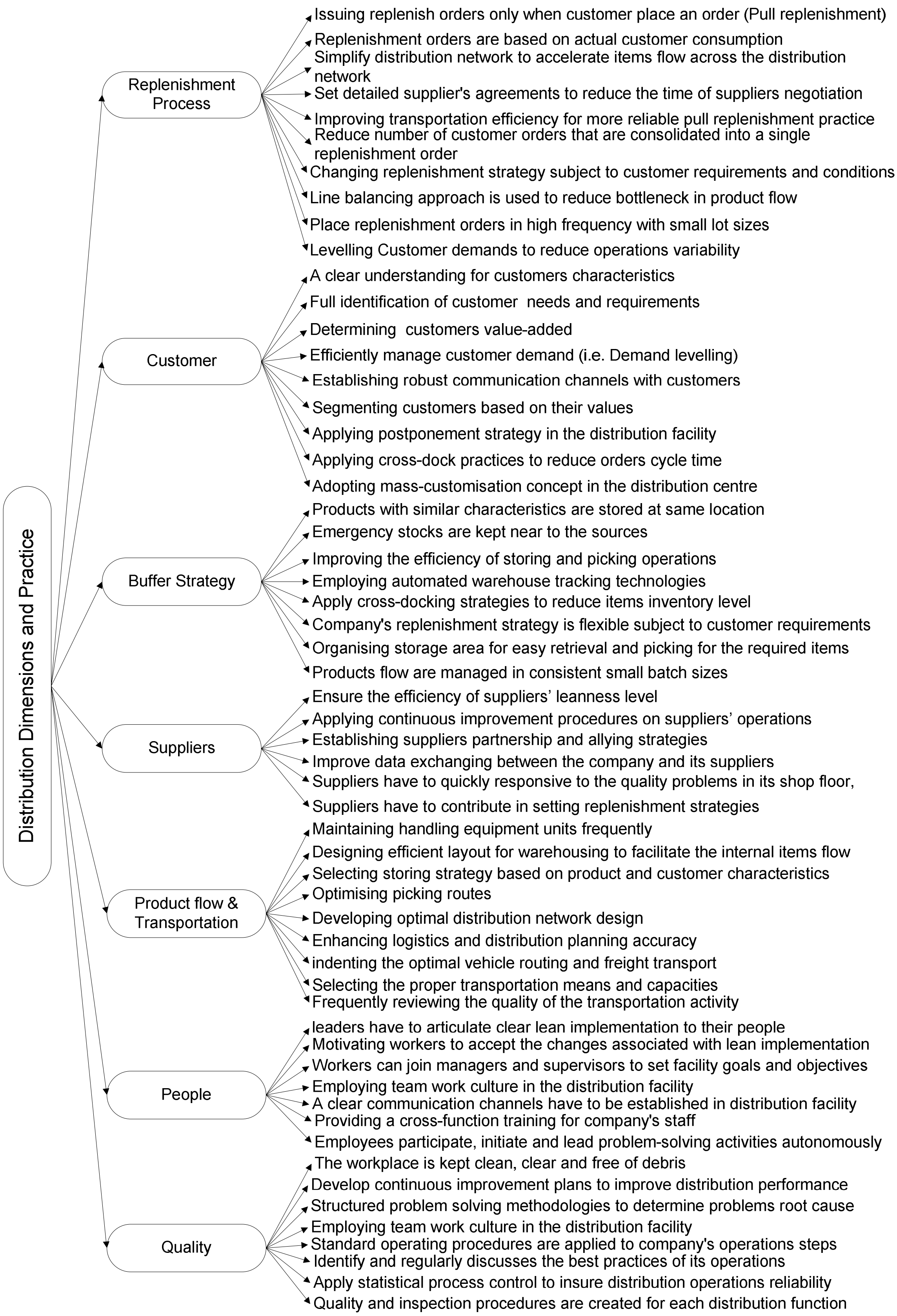


Figure 2-4 A summary for distribution dimensions and improvement initiatives

(Source: Author).

2.6 Lean Measurement and Assessment

Two main questions are discussed in industry forums: (1) how can leanness be implemented? and (2) how can it be measured? Although many companies have applied lean concepts across their operations, more than 90% of them failed to recognise measurable improvement in performance (Bhasin and Burcher, 2006, Ignizio, 2009). This was attributed to the lack of appropriate models to monitor, assess and compare leanness levels during the lean implementation process (Soriano-Meier and Forrester, 2002). Developing a standard measure that integrates the results of the lean practices into one scalar becomes necessary for a successful lean implementation (Bayou and De Korvin, 2008). The 'Leanness Level' has been defined as the performance level of a value stream compared with perfection (Wan and Chen, 2008), while another definition described 'leanness' as a relative measure to assess whether a company is lean or not (Comm and Mathaisel, 2000). Lean assessment methods were categorised into five categories namely, value stream mapping, qualitative lean assessment tools, principle component, lean metrics and benchmarking (Wan and Chen, 2008).

2.6.1 Value Stream Mapping (VSM)

The value stream is conceptualised as the collection of activities that are operated to produce a product or service or a combination of them to a customer (Singh *et al.*, 2006). The logic behind the lean thinking is pursuing the optimisation of the value streams performance from the consumption point of view to products delivery to the end consumer by eliminating waste and non-value added activities. Mapping with the 'seven types of wastes' addressed by Ohno (1988), seven value stream mapping tools were developed to help lean practitioners to identify the sources of waste and the appropriate steps of improvement as well as assess the leanness level (Hines *et al.*, 1998, Hung-da Wan *et al.*, 2007). These are process activity mapping, supply chain response matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis and physical structure mapping. However, the implementation of this tool set has revealed some elements of weakness including limited coverage of wastes, missed improvement opportunities, and being difficult to understand and implement (Brunt *et al.*, 2001).

VSM was then used to assess leanness level by developing and comparing system's current and future state maps (Rother and Shook, 1999). In addition to its simplicity, it emphasis on time-based evaluation as system performance is demonstrated through a time horizon (e.g. cycle time, changeover and time in inventory). The tool was employed in several applications, manufacturing and non-manufacturing, due to its simplicity and effectiveness (Duggan, 2002, Tapping and Shuker, 2003). It was carried out in the distribution environment aiming to map firms activities, assess the impact of the firms suppliers relationship on company leanness and identify the opportunities of improvement (Hines *et al.*, 1999). Although the efficiency of VSM in clarifying systems status and process sequences regarding to the customer values is high, it is not able to quantitatively measure the overall leanness level due to the absence of an integrated leanness measure (Wan and Chen, 2008). In addition, the limited capabilities of VSM in representing the dynamics of systems negatively impact on the provision of accurate evaluation for system's leanness.

2.6.2 Qualitative Lean assessment Tools

Qualitative lean assessment tools are more efficient in terms of measuring the overall leanness level and guiding the users through lean implementation (Jordan and Michel, 2001). Typical qualitative assessment tools rely on questionnaires which survey to what extent lean principles are adopted within the organisation. The resulting scores represent the difference between the current state of the system and the ideal state after applying the lean principles. The Lean Enterprise Self-Assessment Tool (LESAT) a model presented by Nightingale and Mize (2002) gauged the state of a company's leanness and measured its readiness to change by evaluating three groups of processes; life-cycle processes, enabling infrastructure processes and enterprise leadership processes. Their data collection phase included collecting answers to 54 questions (i.e. lean practices) from individual senior enterprise employees. The model outcomes addressed the failure of the company's traditional accounting methods and also identified some financial measures that conflict with the lean concept. In the same year, Soriano-Meier and Forrester (2002) applied a lean assessment model composed of two questionnaires to assess the leanness levels of 30 UK ceramic tableware manufacturers. The model was based on nine groups of 'measurable determinants' which focused on technical lean practice such as waste elimination, continuous improvement, zero defects, just in time deliveries, pull of raw materials, multifunctional teams, decentralisation, integration of functions and the use of vertical information system (Karlsson and Ahlstrom, 1997). Peking University employed user interface based questionnaires to evaluate the leanness of nine key areas of the Chinese Hi-Tech industry (inventory, team approach, processes, maintenance, layout/handling, suppliers, set-ups, quality and scheduling/controlling) (Taj, 2005). The model offered a qualitative approach with an immediate feedback mechanism for assessing the leanness of a manufacturing environment, and showed a significant gap between the current and the acceptable level of leanness in the Hi-Tech industry.

Another application – based on the Balanced Scorecard – identified 36 indicators classified into six groups based on Karlsson and Ahlstrom (1997) to assess the changes associated with lean manufacturing (Sanchez and Pérez, 2001). An operational measure model for the lean production was developed by Shah and Ward (2007) identifying the most salient ten dimensions of lean production. These dimensions have been distilled from 48 lean practices and tools which were evaluated based on how extensive their implementations are in the lean manufacturing systems. Finally, Goodson (2002) assessed companies leanness with a rapid plant assessment tool (RPA), using a tool kit that aided experts to decide if factories are truly lean. RPA involved a team of experts taking a tour through the target factory, observing all plant aspects and seeking evidence that the studied plant adhered to best practice.

2.6.3 Principle Component Analysis

Principle component analysis was selected by several authors to describe patterns of relationships among quantifiable variables that cannot be measured directly (Pett *et al.*, 2003). It can be described as a multivariate group of methods that produce various dimensions of measurement within data sets (Hair, 1987). Its main purpose is to derive interpretable common factors from a wide set of data and evaluate variables that cannot be quantitatively measured or collected directly from the companies involved (e.g. leanness level, product evaluation index and competitive strategy) (Zhang and Ray, 1995, Afifi *et al.*, 2004). Applications of this approach ranged from detailed production systems to macro level strategic applications. For example, different dimensions of competitive strategies in the hardwood industry were identified by utilizing factor and cluster analysis models (Bush and Sinclair, 1991). The study has present how two dimensions – cost leadership and product differentiation – impacted on the degree of competition in the wood industry. The principle component was also integrated with fuzzy set theory, the eigenvector method and the fuzzy Delphi method into a single framework to support decision makers in evaluating the external performance of DC logistics (Chen, 2002). In addition, it was used to assess the leanness level in the wood industry (Ray *et al.*, 2006).

2.6.4 Lean Metrics

Lean metrics are utilised to quantitatively assess the leanness level based on organisations' actual performance (Nightingale and Mize, 2002). The challenge of using lean metrics in the lean assessment process is that a group of metrics are needed to include all lean dimensions and outline the overall leanness level (Baker, 2008b). In addition, synthesizing a group of metrics into an integral leanness measure is also a challenge due to the different nature and measurement units of the metrics. Manufacturing cycle efficiency (MCE) is used to represent the leanness level in terms of time based performance (Levinson and Rerick, 2002). It is an index for cycle time reduction compares value-adding time with total cycle time to show the efficiency of the manufacturing process. Aspects such as value added index, system flow time, orders cycle time, average inventory level, resources utilisation and labours productivity were all addressed as leanness manufacturing metrics (Fogarty, 1992; Katayama and Bennett, 1999).

In the distribution context, various performances metrics are addressed including order lead time, order cycle time, fill rates, forecast accuracy, order stock-out level and on-time delivery to evaluate distribution leanness (Detty and Yingling 2000). Inventory level, throughput rate and resources utilisations are classified as operational metrics that focus on lean distribution operations performance (Chua and Katayama, 2009). A set of metrics contains the level of stock, orders-to-delivery and lead time were also employed by Reichhart and Holweg (2007) to measure lean distribution. In an automotive dealership, leanness evaluation is based on customer retention and therefore the majority of its performance metrics are related to the customer satisfaction dimension (e.g. on-time delivery, quality of delivery and speed of retrieving customer information) (Kiff, 2000). JIT is utilised in the distribution environment to improve the vehicles utilisation, number of vehicle movements and distribution information flow and sharing (Christensen, 1996). Obviously, most of lean distribution metrics have focused on specific constructs (e.g. ordering process, customers, distribution operations and buffer management) while no metrics are addressed for many others including distribution cost, distribution quality & capacity, people and suppliers.

*2.6.5 **Benchmarking***

Although lean metrics are designed to include the critical lean principles, a fixed set of indicators cannot be utilised for all systems (Wan and Chen, 2008). Hence, a number of authors have employed a benchmarking approach to quantitatively measure the level of leanness by comparing the current state of the system with the benchmarked performance (Gurumurthy and Kodali, 2009, Kojima and Kaplinsky, 2004). Data envelopment analysis (DEA) quantified leanness manufacturing level based on a benchmark of the ideal leanness frontier (Wan and Chen, 2008). In another study, the benchmarking against exemplar companies was successfully used to assess leanness level using the Mahalanobis Taguchi Gram Schimdt system (MTGS) (Srinivasaraghavan and Allada, 2006). Ford and General Motors employed a fuzzy logic methodology to calculate a leanness scale through benchmarking in a study that involved three lean practices – JIT, Kaizen, and TQM (Bayou and De Korvin, 2008). The main drawback of using benchmarking approach in the lean assessment process is the difficulty of the data collection phase as large data sets are required from companies in the same sectors which oftentimes are competitors.

Based on the aforementioned lean assessment literature review, Table 2-5 presents a summary of the lean assessment approaches along with their strength and weakness points. It is obvious that an accurate and representative leanness score cannot be obtained by employing any approach in isolation. It is necessary to integrate different lean assessment approaches into a one assessment framework that can overcome their weakness and employ their strength issues (Wan and Chen, 2008).

2.7 Conclusion

After reviewing the literature of different research areas including lean supply chain, distribution industry and lean assessment, substantial research gaps in terms of lean distribution implementation and assessment have been clarified. The literature on lean supply chain has so far focused on the manufacturing systems as the main application domain and has not yet been extended widely into other supply chain entities in particular distribution industry.

Lean Distribution literature provided efficient initiatives for improving distribution performance. However, these initiatives offered partial solutions for the distribution issues being focus on specific distribution constructs (e.g. customers, suppliers, transportation and inventory) in isolation nature. The literature was found to be lacking in providing a comprehensive lean distribution structure that uniformly improve the performance of the different distribution constructs.

The literature on lean assessment methods has focused only on assessing lean manufacturing. Various lean assessment approaches were employed in the previous publications including VSM, surveys, benchmarking and mathematical models. Nevertheless, there is still no integrated lean assessment framework that can provide a quantitative leanness index that represents the overall leanness level of the distribution companies.

Table 2-5 Categorisation of lean assessment model (Source: Author).

Category	Lean Assessment Model/Approach	Authors	Input Data Type	Strength	Weakness
Value Stream Mapping	Value Stream Mapping Approach	(Hines *et al.*, 1999, Hines *et al.*, 1998, Rother and Shook, 1999)	Qualitative	Effective mapping tool focuses on creating continuous value stream	No integrated measure for the overall leanness
Lean Assessment Tool	LESAT	(Nightingale and Mize, 2002)	Qualitative	Can assess the overall leanness level based on different lean constructs (e.g. People, operations, quality, suppliers and the customers)	The output is subjective based on individual Judgements
	Soriano-Meir and Forrester Model	(Soriano-Meier and Forrester, 2002)			
	Chinese Hi-Tech Model	(Taj, 2005)			
	Balanced Score Card	(Sanchez and Pérez, 2001)			
	Shah and Ward Model	(Shah and Ward, 2007)			
	RPA Model	(Goodson R., 2002)			
Benchmarking	Data Envelopment Analysis	(Wan and Chen, 2008)	Quantitative	Quantitatively measure the overall leanness comparing the system's state with benchmarking performance	Exemplar performance benchmark needs to be collected from peers and competitors. In addition, the outcome is heavily depending on the quality of the benchmark
	Mahalanobis Taguchi Gram Schmitt System	(Srinivasaraghavan and Allada, 2006)			
	Fuzzy Logic Methodology	(Bayou and De Korvin, 2008)			
	Benchmarking Lean Assessment	(Gurumurthy and Kodali, 2009)			
Lean Metrics	Manufacturing Cycle Efficiency Model	(Levinson and Rerick, 2002)	Quantitative	Assessing leanness level quantitatively based on the actual performance	Although an integrated group of metrics are required to measure the overall leanness level, synthesizing various metrics in one integral leanness measure is difficult due to their different nature and measurement units
	Discrete Event Simulation	(Detty and Yingling, 2000)			
	Value Added index	(Fogarty, 1992)			
	Labour Productivity	(Katayama and Bennett, 1999)			

Chapter 3: RESEARCH METHODOLOGY

3.1 Introduction

The importance of having appropriate research methodology for the conducted research was emphasised by Irani *et al.* (1999). In deciding how to conduct research or to select its methods, Robson (2002) and Bell (2005) stated that there is no definitive rule regarding the selection of the research approach or the timeframe of the research project. A generic approach to research was suggested by Saunders (2003), where a research model was used to depict issues underlying the design of the research process, see Figure 3-1. The layers of the research process were made up of

- Research philosophy
- Research approach
- Research methods
- Data collection methods

As approaches in the different layers of the research process have dependencies, it was suggested that a research design should be applied from the outside layer thereafter peeling away each layer until the final layer is reached. The research process in Figure 3-1 includes different research philosophies, approaches, methods and data collection techniques. The boxes in the diagram are the research elements that are used to answer the research question and meet the set of study objectives – presented in Chapter 1.

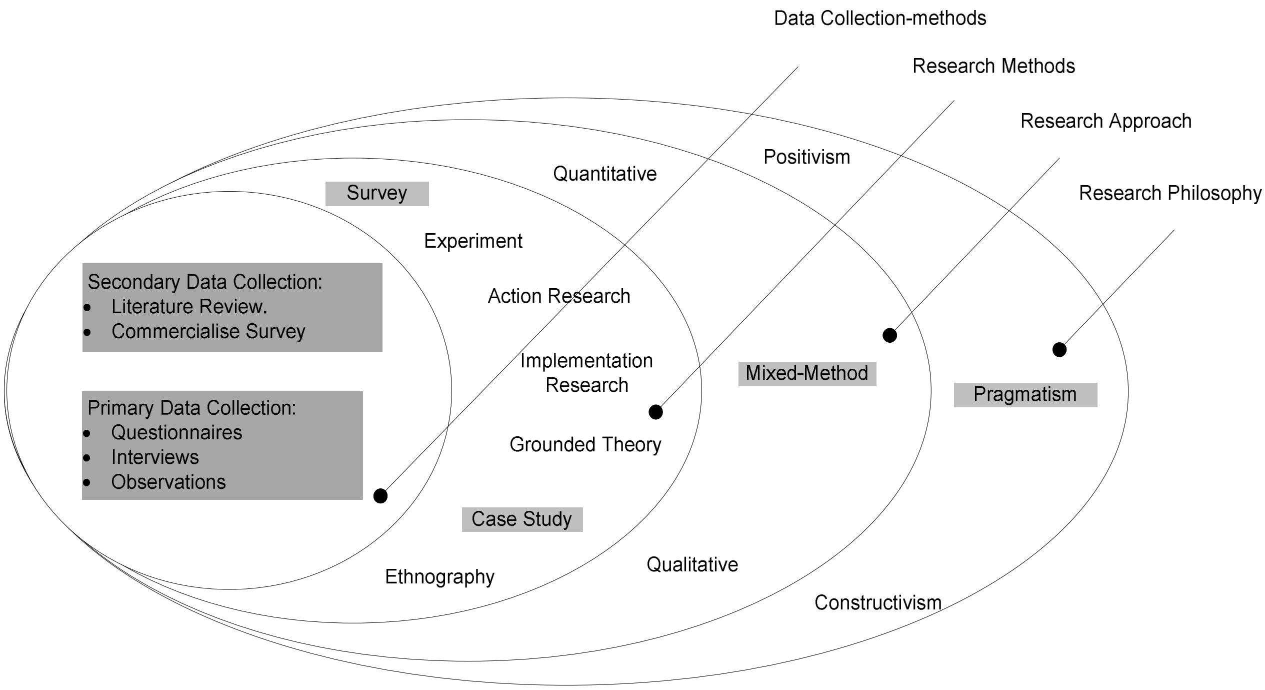


Figure 3-1 Research methodology 'Onion' (Saunders, 2003)

3.2 Research Philosophies

The identification of research philosophy is important as it indicates the beliefs and outlook which frames the manner in which knowledge is gathered, constructed and analysed. Different research philosophies are widely addressed in the literature and therefore they are used for informing and guiding the investigative nature of this research. The constructivism philosophy views the knowledge in a subjective form as encompassing beliefs, personal values, social context and sometimes historical background (Schwandt, 2000, Neuman, 2003). It is a dynamic research philosophy as knowledge inevitably changes with the changes in time and context. In contrast to the constructivism, positivism philosophy presents the knowledge and information of the research topics into facts. It is driven from real observations, objectives and measurable phenomena and where personal values or social interactions are involved.

A mixture of constructivism and positivism philosophies (i.e. pragmatism philosophy) is used to satisfy all research objectives simultaneously. In pragmatism philosophy, the research can be carried out in the stance of constructivism in order to determine a theory or hypotheses followed by the adoption of a positivism approach to test out the hypotheses (Tashakkori and Teddlie, 2003). The knowledge in the pragmatism philosophy is driven from actions, situations, and consequences rather than antecedent experiences or beliefs (Rossman and Wilson, 1985). This suit this research as to achieve the study objective lean distribution structure has to be defined first and then analysed and assessed. After identifying research philosophies, accurate selection of the research approaches is necessary to identify the appropriate research methods and data collection techniques.

3.3 Research Approaches

Different authors have argued that there is a mutually exclusive relationship between the research approaches and research philosophies (Saunders *et al.*, 2009). However, there is a common misalignment between them which sometimes creates confusion through the research process. In positivist research, the system's parameters under study are considered measurable, controllable and explainable. Therefore many researchers align the epistemology of positivism with the quantitative approaches (Easterby-Smith *et al.*, 2002). Similarly, Qualitative methods are associated with the constructive research as the approach can effectively deal with the human perspectives, opinions and experiences. In addition it can conclude findings based on the relationship between the subjective parameters within the system (Ticehurst and Veal, 2000).

The placement of quantitative and qualitative methods as polar opposites was reinforced by several authors. For instance, Ticehurst and Veal (2000) has argued that the merits and values of the qualitative and quantitative business research are always aligned with different philosophical positions. Saunders (2003) also encouraged the concept of polar opposites between both research approaches. They argued that followers of qualitative research are consistently criticizing the quantitative approach because its rigid methodology does not always permit a more detailed explanation of many real life phenomena. Recently, research trends have become less polarised regarding the differences between quantitative and qualitative research approaches. It tends to fall somewhere between them to presenting the complex behaviour of real world cases (Creswell, 2003). Various authors emphasised this and stated that researchers who focus on one research approach all the time will possibly lose sight of the bigger picture (Waring, 1996). Blending both research approaches (i.e. quantitative and qualitative) is necessary to include a wider range of research aspects and parameters (Crotty, 1998). Quantitative approaches, for example could be effectively employed in social sciences research – constructive stances (Yates and Yates, 2004).

Many terms are used for the mixed research approach including integrating, quantitative and qualitative, multi-method and multi-methodology (Tashakkori and Teddlie, 2003). In mixed approach, quantitative and qualitative data can be collected sequentially – in different phases – or concurrently – at the same time – based on the research design and sequences. Unfortunately, mixed-methods research is not that common within the research literature (Knox, 2004). Three basic strategies are identified for the mixed approaches including (Creswell, 2003):

- Sequential Explanatory Strategy: is applied when qualitative interpretation for the findings of primary quantitative study is required (Morse, 1991). It starts by collecting and analysing the quantitative data and then followed by a collection of the qualitative data that interpret and support quantitative results.

- Sequential Exploratory Strategy: is appropriate when a new theory or hypothesis, generated by a qualitative approach, need to be quantitatively tested or evaluated (Creswell, 1999). The collection and analysis of the qualitative data precedes the quantitative analysis to identify the parameters and variables of the studied theory or hypothesis. The findings of both approaches can be integrated throughout the interpretation phase.
- Concurrent Triangulation Strategy: fits when a research requires two different methods to confirm, cross-validate or corroborate findings within a study (Morgan, 1998, Steckler *et al.*, 1992). The quantitative and qualitative data are collected concurrently in one phase and the results of the two approaches are also integrated in the interpretation phase.

3.3.1 Lean Distribution Research Approach

Integrated framework for assessing lean in distribution is a relatively new topic with limited publications on integrating solution techniques. Hence, a deductive approach is useful to use in order to test and validate the proposed framework. This is followed by a case study approach to apply the proposed framework and achieve the research objectives. The integration of the qualitative and quantitative approaches occurred in several stages in this research; data collection, data analysis and results interpretation. Sequential exploratory strategy was selected to conduct the research being the most appropriate strategy for the research characteristics.

The research was divided into two main phases based on the two research objectives that were mentioned in Chapter 1:

1. Identify lean distribution underlying factors and their corresponding practices

2. Develop a quantitative and synthesized lean distribution assessment models to assess the overall leanness level and set a lean benchmark

The first objective aims to clarify the ambiguity that surround lean distribution concept. Several authors have attempted to provide a conceptual definition of lean distribution. Kiff (2000 – P. 116) defined the concept as, "the approach that would compromise the removing of operations waste, reducing distribution cost, delivering great customer value and improving customer retention", while in another definition lean distribution was stated as "the concept which minimize waste in the downstream supply chain, while making the right product available to the end customer at the right time and location" (Reichhart and Holweg, 2007 – P. 3701). These definitions and interpretations illustrated that lean distribution is a multi-dimensional concept. Lean as an industry standard was not clearly defined with specific regard to distribution industry.

There is a lack of the publications which address the theoretical logic of lean distribution and determine its underlying factors and the interrelationships between them. Lean distribution characteristics were examined by various authors such as Womack et al. (1991) and Kiff (2000). Various publications described significant lean distribution dimensions including reducing demand variability, managing customer expectations, increasing operations reliability, facilitating replenishment process and controlling inventory and operations cost (Jones, 2002). Other dimensions such as product flow, transportation management, workforce behaviors and leadership have also received more attention (Baker, 2004; Hopp and Spearmman, 2004; Mulcahy, 1994). Despite that, lean distribution literature is considered scarce and lacking depth as many lean distribution factors are not investigated yet. Furthermore, there are no published studies which empirically address the simultaneous synergistic effects of multiple lean distribution factors as well as their interrelationship and performance implications.

Hence the research started by identifying an initial set of lean distribution factors and practices based on the literature review and practitioners experience – qualitative approach. In order to confirm the identified set of factors and practices, a wide variety of distribution companies were surveyed. This step was followed by an extensive analysis for the survey responses to identify the structural dimensions of lean distribution – quantitative approach. By the end of this stage, lean distribution measurement and structure models were developed satisfying the first study objective.

Following this phase, lean distribution assessment phase has commenced aiming to assess the overall leanness level and set a lean benchmark – objective 2. It is a basic phase in the proposed lean distribution framework as without such leanness measure, two distribution companies cannot be rated objectively based on their leanness level. Different studies have defined a portfolio of tools and techniques to support lean assessment (Hines and Taylor, 2000). However, the majority of these studies fell short of delivering a systematic measure of leanness by which companies can be compared and lean efforts can be prioritized.

Lean assessment models in the literature, including qualitative lean assessment models, surveys, benchmarking, graphical presentations, and analytical models (e.g. Hines et al., 1998; Taj, 2005). Applying these techniques in an individual manner led to inefficient assessment for the leanness level. For example, the qualitative lean assessment models are always criticized due to their subjective nature. Also, Value Stream Mapping (VSM) is not able on its own to quantitatively assess the overall leanness level despite its efficiency in visualizing system status based on customer value and time performance

(Wan and Chen, 2008). Different authors employed the benchmarking approach in lean assessment process (e.g. Kojima and Kaplinsky, 2004). However, collecting the exemplar performance benchmark from peers and competitors is a considerable barrier especially in today's competitive market. Finally, mathematical and analytical models such as simulation modeling and data-envelopment analysis have been used in lean assessment articles (Wan and Chen, 2008; Detty and Yingling 2000). Ray et al. (2006) has also employed principle component analysis (PCA) to quantify the leanness level. These approaches evaluated organizations leanness through a group of different lean metrics since an individual metric cannot represent the overall leanness level. The challenge is to synthesize a group of lean metrics into an integral leanness measure despite the differences of their nature and measurement units.

Hence, the assessment phase was started by identifying the lean distribution performance metrics. It was essential that the selected metrics cover the whole lean distribution dimensions in order to ensure that the developed leanness indices accurately represent the distribution leanness level. After that, two lean assessment models were developed to assess the tactical and operational levels of lean distribution. Various techniques were involved in these models including PCA, VSM, Simulation and DEA. The resulting leanness indices are used to evaluate companies' current leanness state against the ideal leanness state in order to evaluate companies' leanness level and explore the potential areas of improvement (i.e. Benchmarking) – Objective 2. Figure 3-2 illustrates the sequence of the research phases and their corresponding research philosophies and approaches.

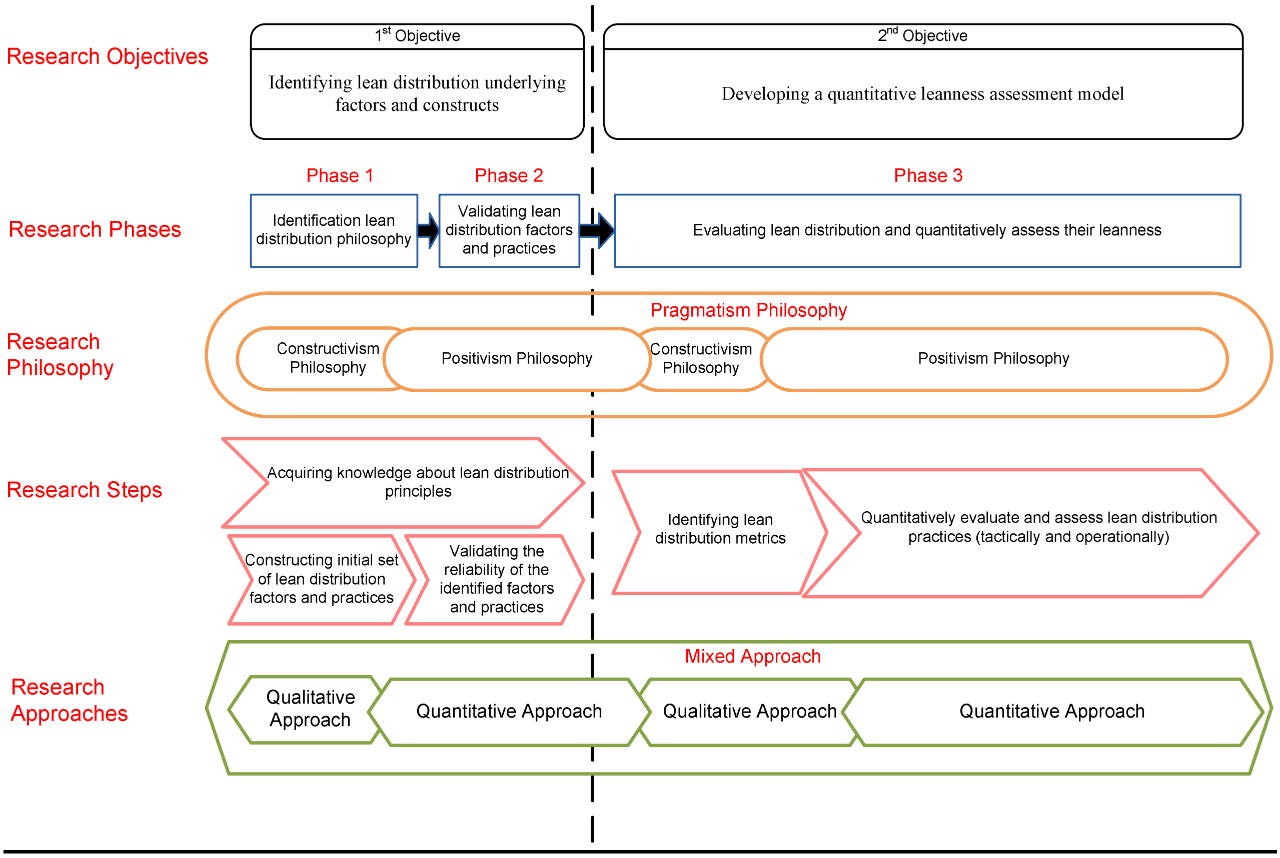


Figure 3-2 The map of research methodologies and research phases (Source: Author).

As the research approach is connected to the research philosophy in one end, it is also strongly coupled with the type of data in the other end. Qualitative data generated an understanding of the lean distribution concept in a verbal description through non-numerical forms of information such as distribution staff people insights, opinions and backgrounds. On the other hand, quantitative data is in the form of numerical metrics and were used to describe the relationships between the lean distribution parameters using analytical and mathematical models. Several qualitative data collection techniques were applied including face-to-face interviews, field notes, case studies, literature review, analysing written documents and accessing archives. Employing these techniques provided systematic and empirical collection methods for the data which were bounded by people's own background and experience (Locke *et al.*, 1993). On the other hand questionnaires, observations, site visits and multi-source historical data were applied to collect the quantitative data. Figure 3-3 maps the employed data collection methods with research phases, steps and methods.

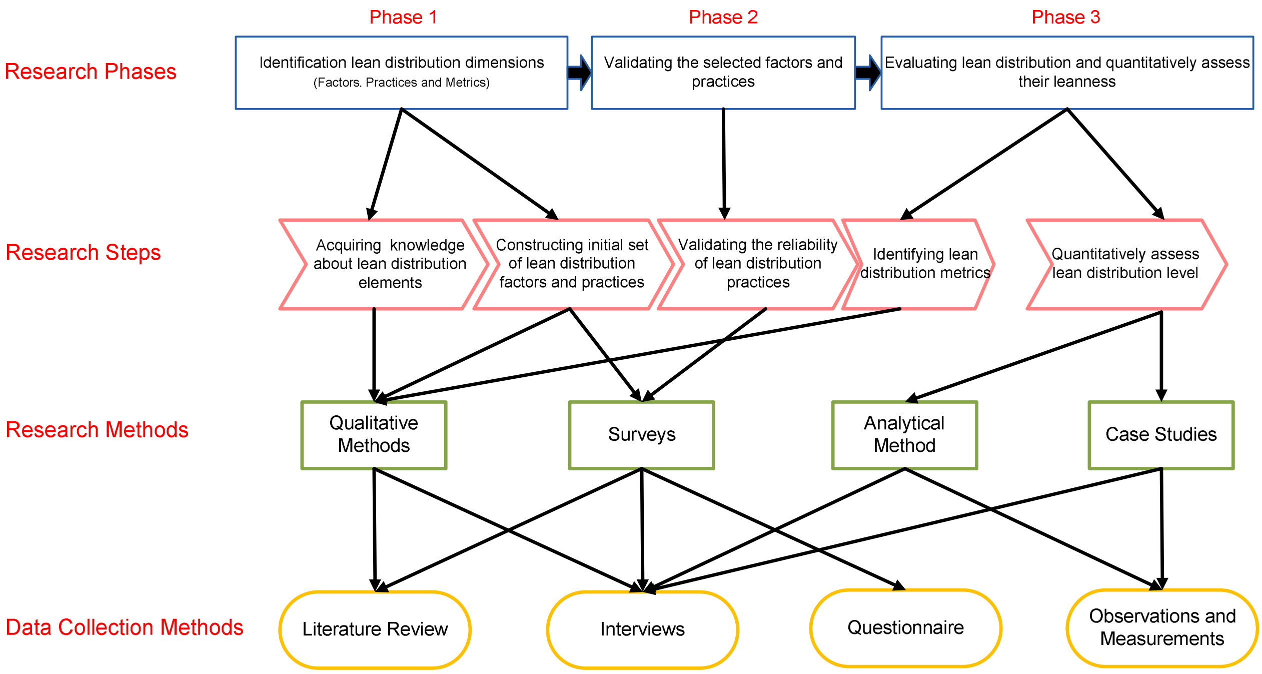


Figure 3-3 Research phases, steps, methods and data collection techniques (Source: Author).

3.4 Research Methods

It is necessary to select appropriate research methods corresponding to the aforementioned research approach and philosophies towards achieving the research objectives (Yin, 2003). Selecting research methods should be based on their ability to clearly answer research questions and to efficiently meet study objectives. Nine research methodologies are commonly used in the business literature including experiment, survey, case studies, action research, grounded theory, narrative and Ethnography (Saunders, 2003). The majority of operations management research tends to gravitate towards two or more of these methods in order to achieve research targets.

3.4.1 Secondary Data Collection (Literature Review)

Secondary data is useful source of knowledge as it provides a wide range of related information that is collected and analysed in other studies. It includes raw data – not processed before – or compiled data which received some kind of summarising or analysis (Saunders *et al.*, 2009). Starting research data collection with secondary data saves a lot of time and is cost effective as research objectives can be met by reanalysing or manipulating the collected data. Many categories of secondary data are defined by several authors including documentary data, survey-based data and multiple source data (Dale, 1988, Hakim, 1982, Robson, 2002). The majority of these sources are generated by specialised firms are in a form of reports (e.g. financial reports and market reports) and commercial surveys and statistical studies.

Distribution literature was reviewed to generate preliminary information about lean distribution principles, elements and practices. As illustrated in chapter 2, literature was used to identify distribution functions, components, dimensions and performance metrics as well as its role in improving the supply chain performance. This was followed by introducing the background of lean thinking and how it was employed in the distribution environment to support the development process of lean distribution measurement and structure models. The literature review provided a clear vision about leanness-assessment research records and the drawbacks of the previously developed assessment tools and techniques. As mentioned above, secondary data alone is ineffective approach to accomplish the first stage of the study due to the lack in the lean distribution literature.

3.4.2 <u>Primary Data</u>

It is defined as the data that is gathered specifically for the conducted research and has not been collected or analysed before in any other study (Saunders *et al.*, 2009). The collection of the primary data is time and cost intensive because researchers often need access to the organisations or research participants on more than one occasion to gather the data. Most research objectives in the literature were achieved using a combination of secondary and primary data. However if there are limitations on providing secondary data, the study has to completely rely on the primary data. Two basic methods for primary data collection were used in this study.

3.4.2.1 Interviews

Interviews permit face to face discussions with experts and practitioners to obtain holistic insights about the concept (Easterby-Smith *et al.*, 2002). They can be highly formalised (i.e. structured) or can be informal (i.e. unstructured) conversations. Before structuring the survey questions, a number of interviews took place with various distribution managers to acquire a general understanding of the lean distribution concept from the perception of a real life application. Senior members of four distribution companies were interviewed to gather general information about the distribution companies in Ireland, the current shape of their supply chains and their awareness of lean concepts and practices. Significant field work preceded the interviews to ensure familiarity with distribution operations which positively impacted on the accuracy and effectiveness of the questionnaires. A wide understanding of distribution activities, characteristics and parameters were acquired with valuable insights about lean distribution practices and the challenges to be addressed. The interviews provided a significant support for the development and structure of the questionnaires.

3.4.2.2 Questionnaires

A survey methodology was selected due to its ability in describing, highlighting and measuring certain features within a sizeable population. It is appropriate where a positivist view is sought in the research and the primary data needs to be gathered from different places (Easterby-Smith *et al.*, 2002). Since it applies the research on a representative sample for the population instead of the entire population which is cheaper, survey is considered one of the cost-effective research methodologies. It is a popular research methodology in operations management (OM) literature.

Although the questionnaire is a widely used data collection technique within the survey research methodology, it can also be used in action research and case study methodologies (Oppenheim, 2000). Some authors reserved the questionnaire term where the collection of questions is gathered and distributed to a sample of the population under study (Saunders *et al.*, 2009), while others generalised the term to include interviews that are administered either by telephone or face to face (Bell, 2005). The developed questionnaire in this research was quantitative in nature and passed through several sequential steps started by constructing survey's questionnaires, creating a contact list, follow-up with the companies, gathering and analysing the responses and finally deriving the conclusions. It relied on a careful review of the available literature, deep discussions with the research participants (e.g. academics and practitioners) and a clear conceptualisation of the formulated research objectives.

The questions focused on identifying the degree of the lean practices implementation in the surveyed distribution companies. The responses were measured on a 5-point Likert with '1' equated with no implementation of the practice and '5' equated with a full implementation. A comprehensive database of Irish wholesalers and distribution companies were employed to establish a list of 700 distribution and warehouse companies working in the Irish market and representing the study population. The companies were selected based on four factors:

- Large Staff Capacity (i.e. over 100 staff): Because of lean implementation is a sophisticated task to be accomplished in a small distribution company, the study has focused on the large companies where the chance of applying the surveyed lean practices is high.
- Large Warehouse Facility (i.e. over 50,000 square feet in area): Various companies are classified as distribution centres where in fact they just focus on the transportation and trade activities with no warehousing facility in their sites.
- Irish Distribution Companies: The results are relevant to Ireland, however they can be generalised due to the similarity in the distribution process characteristics around the world.
- Warehouse and Distribution Managers are the Selected Respondents: The contact list of the survey focuses on the warehouse and distribution managers being involved in the majority of distribution activities from a managerial perspective which fits the nature of lean.

The questionnaire was pre-tested with different supply chain academics and distribution practitioners before distributing – Appendix 1. Aiming to help respondents to become familiar with lean distribution terms, a brief explanation of lean distribution concept, elements and practices was provided. This information positively contributed to receiving more accurate responses to the surveyed questions and in turn helped to construct a more reliable lean distribution model. A packet containing a cover letter, copy of the survey and introduction about lean distribution was sent to the selected companies by post and online. After two weeks, follow-up phone calls were conducted for all participating companies followed by three reminders sent by e-mail as suggested by (Dillman, 2000). The number of companies decreased from 700 to 600 due to companies shutting down and changing company's activities. A 13% response rate was received where the majority of respondents (about 85%) were from manufacturing companies and wholesalers. Over 70% of the respondents were technical managers (i.e. distribution managers, warehousing managers and purchasing managers) while the rest were top-executives and directing managers.

By analysing the survey responses, a validated set of lean distribution constructs and practices was generated. Various statistical analysis tools including Exploratory factor analysis (EFA), Confirmatory factor analysis (CFA) and Structured equation modelling (SEM) were used to analyse survey responses and develop the lean distribution structure model.

3.5 Statistical Data Analysis

Empirical data analysis was conducted to develop a lean distribution measurement and structure models based on the survey responses. Figure 3-4 summarises the steps of the statistical data analysis phase. Following the research tradition of other research fields (e.g. psychology, sociology, marketing and information system), the lean distribution analysis was started with the exploratory phase. It is essential in the early stages of scale development where a strong theory may not be clearly available. According to (Shah and Ward, 2007), Corrected Items Total Correlation (CITC), EFA and Cronbach's alpha (i.e. reliability estimation) were applied to discover and detect the characteristics, features and relationships of the lean distribution variables.

The exploratory techniques are considered the stepping stone for further analysis phases like confirmatory studies. CFA approach was applied to confirm the exploratory lean distribution model by more rigorous statistical techniques and evaluated the unidimensionality of lean distribution scale (O-Leary-Kelly, 1998; Hunter and Gebring, 1982). Assessing unidimensionality was essential to ensure that the proposed lean constructs converged to represent the lean distribution – latent variable (Hattie, 1985). The confirmatory phase began with examining the convergent validity and items reliability of the studied variables using measures such as *t*-value and R^2, followed by testing the fitness of the developed model (Joreskog and Sorbom, 1989). Various diagnostics, such as standardised residuals, Q-plots and modification indices were applied to determine the source of misspecifications in case of the poor fitting.

After the confirmatory phase, a structure equation model (SEM) was adopted. SEM has the ability to measure latent variables in terms of the observed indicators (i.e. measurement model) and determine the causal relationships among these variables and the studied latent variables (Anderson and Gerbing, 1982). It was developed to get the correlation between lean distribution constructs and the concept and rank them according to their importance (i.e. Correlation Coefficient).

A path diagram is an important presentation tool for the interrelationships between the latent and observed variables. In Figure 3-5 circles signify the latent variables of the lean distribution model (e.g. Quality, Item Flow, Customers and others) and are specified as Ksi (ζ). These latent variables are measured by their observed variables (Xs) enclosed in squares (i.e. lean practices), whereas their measurement errors are represented by theta delta (Θ_δ). The relationships between the latent and observed variables are the factor loadings – regression coefficient, indicated as straight arrows and symbolised as lambdas (λ), while the correlation between the latent variables are indicated by (Φ_{ij}).

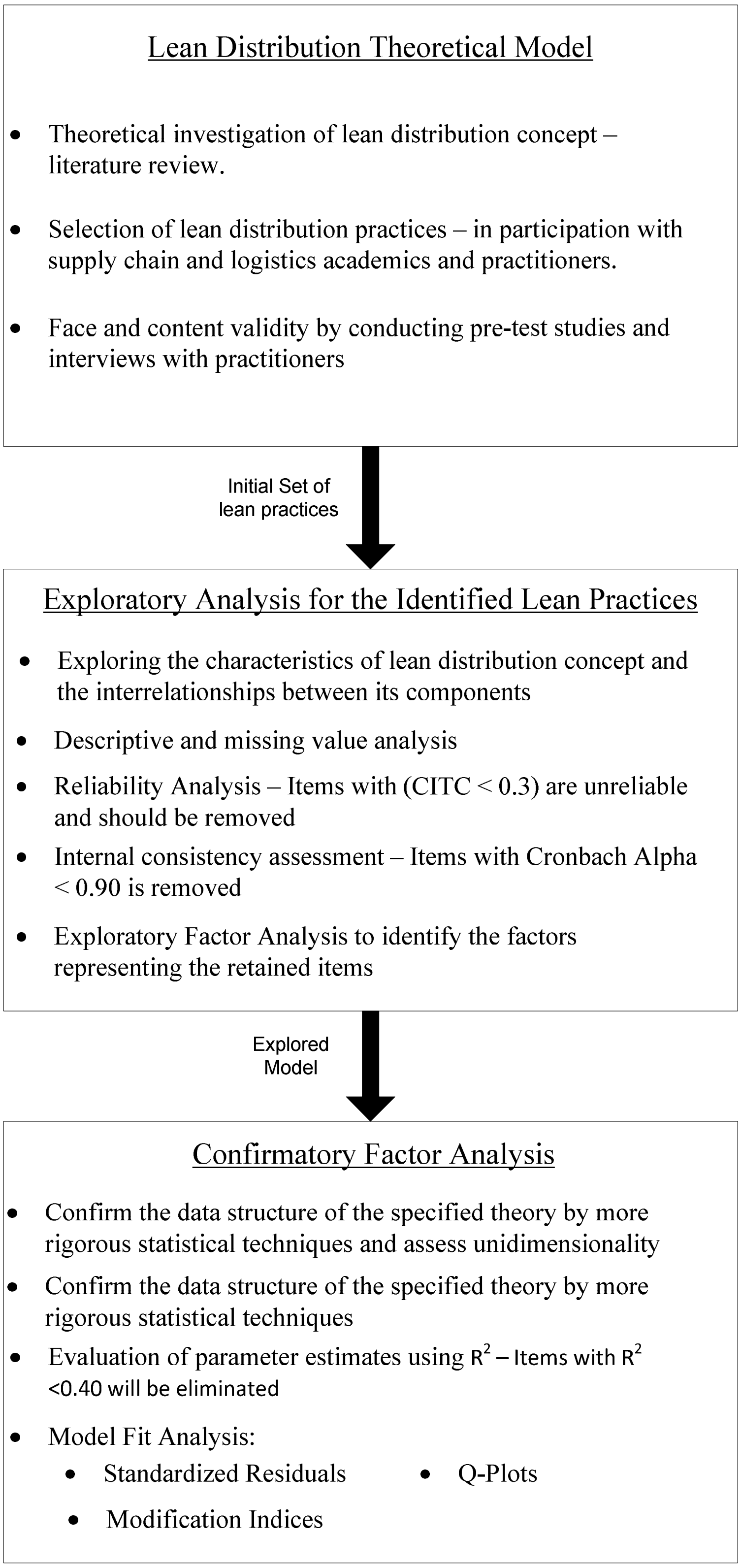


Figure 3-4 Schematic presentation for scale development and validation steps
(Source: Shah and Ward, 2007).

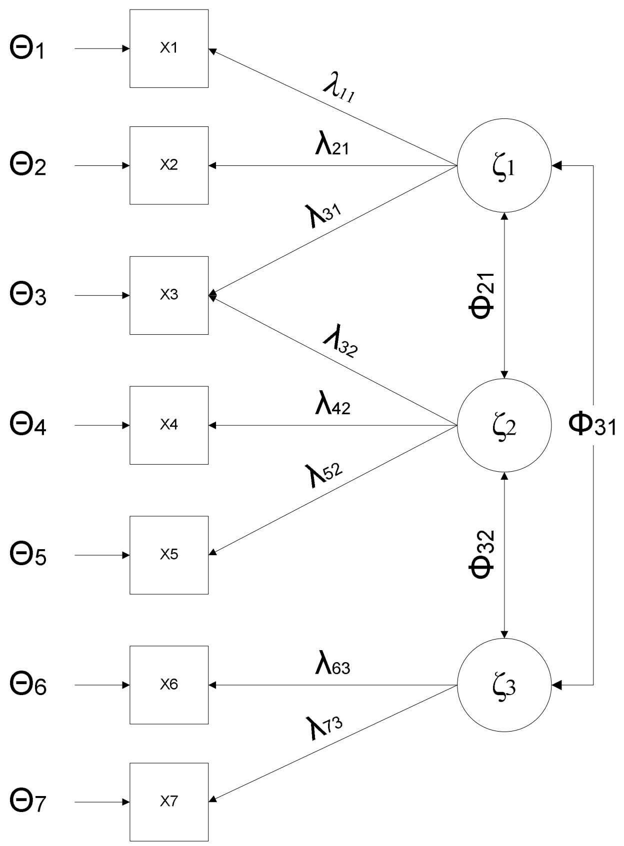


Figure 3-5 Path diagram elements and notations.

3.6 The Design and Development of Lean Assessment Models

After developing the lean distribution structure model, the lean assessment phase (i.e. third phase) commenced. It started by developing a set of lean performance metrics to represent the distribution leanness level. Due to the scarcity of lean distribution literature, it was necessary to use the distribution managers' experience in addition to the literature review to identify the leanness metrics. Several unstructured interviews were conducted with seven wholesalers and distribution companies to develop a leanness metrics set and ensure its validity. It was agreed that the defined metrics could be divided into three basic categories; tactical, financial and operational. Given the difficulties of collecting financial data due to its confidentiality in most companies, two lean assessment models were developed to only assess the tactical and operational leanness levels.

The tactical lean assessment model developed a statistical relationship between the leanness (i.e. dependent variable) and the tactical performance metrics (i.e. independent variables) using a principle component approach. A data collection process was conducted on five distribution companies to gather one year historical data for values of metrics. Standardisation and normalisation steps were then taken to overcome the variations in metrics' natures and measurement units. The generated leanness index helped to uncover the inefficiency elements and explore the potential improvement opportunities in each company. For the operational lean assessment model, many techniques were integrated including VSM, modelling and simulation and Slack-based measure (SBM). The model was called VS2 using the first three letters for the integrated techniques (i.e. VSM, Simulation and SBM).

3.6.1 Value Stream Mapping

Value stream mapping has become one of the most commonly used analytical tools for implementing and assessing lean paradigm (Duggan 2002; Tapping *et al.* 2002). Current and future state maps visually present the flow of value streams based on time performance guiding the improvement efforts and initiatives (Wan and Chen, 2008). As well as the benefits of VSM, it has several criticisms of the tool when be used in lean implementation or assessment. VSM is a static representation of the system as it does not include any variability information or mechanisms of performance validation (Marvel and Standridge, 2009). No interference about system performance can be drawn by mathematical analysis or computer experimentation. Implementing lean approach without validating the future state and monitoring system changes contribute in a poor performance for the newly designed lean systems. Furthermore, the performance information associated with a VSM has an emphasis on the time-based competitiveness while neglecting other lean metrics such as throughput rate, resources utilisation and inventory capacity. Hence, VSM itself does not provide a quantitative measure of the overall leanness level (Wan and Chen, 2008).

3.6.2 Modelling and Simulation

Sullivan *et al.* (2002) used simulation to address the questions that could not be addressed by VSM. Simulation improved the use of VSM by addressing the complexity and variability of the studied system. In addition it had the ability to concurrently evaluate various performance metrics regarding their nature or measurement units. Simulation was integrated with VSM in a steel industry to identify the impact of the system variations on the performance. The integration of VSM and simulation was again presented to manage systems uncertainty and create a dynamic approach for evaluating leanness future state map (Abdulmalek and Rajgopal, 2007). McClelland (1992) identified simulation as a method that can be used effectively to evaluate the impact of the implementation of new systems strategies such as lean and analysing possible alternative system states. Simulation model is developed through two main phases; (1) creating a conceptual model for the generic distribution structure using business process modelling and (2) developing discrete event simulation model mimics the general features of the distribution systems.

3.6.2.1 Business Process Modelling

Business process modelling is a presentation for the sequences of system's processes, procedures and resources. It also shows the relationship between system's objects and their status during system's life cycle. IDEF family is a group of methods that provide the capability of modelling the business area from different perspectives (e.g. process, objects, information, etc). IDEF methods have hierarchical structure capability and language simplicity that give them an advantage on other modelling approaches. They are initiated from a top-level diagram, and decomposed to several bottom-levels. IDEF0, IDEF1X, IDEF2 and IDEF3 are the most relevant methods for business process modelling. IDEF0 and IDEF3 were found to be adequate for modelling the dynamic nature of the distribution systems. IDEF3 enables the modeller to consider the combination between activities and objects flows. The hierarchical modelling approach using IDEF0 allows users (e.g. strategic managers, operational engineers and system analysts) to comprehensively understand the sequence of system's functions. An activity block which is the main unit for IDEF0 describes the main function of the process. ICOMs (Input, Control, Output and Mechanism) are represented by horizontal and vertical arrows as shown in Figure 3-6. Process control (top arrow) can be company regulations, standards or legislation, whereas process mechanisms are usually the agents which facilitate the activity (Pubs, 1993, Mayer *et al.*, 1997). IDEF0 is used in conjunction with IDEF3 as a modelling approach to conceptualize the distribution system processes before developing the simulation model.

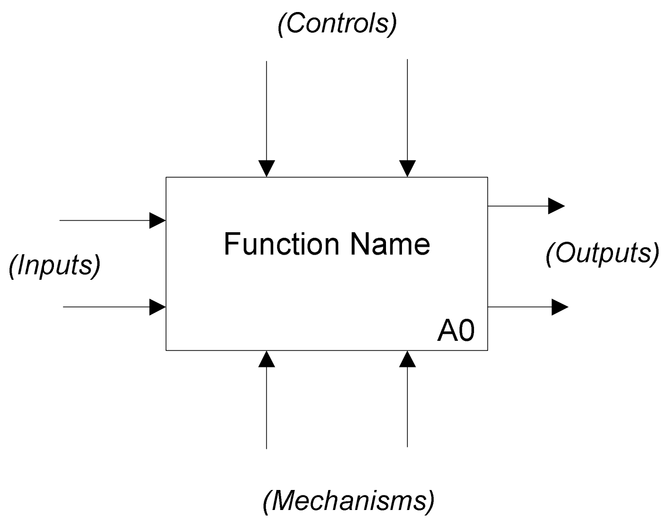


Figure 3-6 main activity block for IDEF0 modelling language (Source: Author).

3.6.2.2 Simulation Model

The stochastic discrete-event simulation is chosen due to its capability in manipulating the randomness of customer demand, the variability of operations times and resources utilisation in addition to systems uncertainty. A computer simulation model based on IDEF conceptual models was developed. The developed simulation model uses system entities to describe the items movement through the distribution facility, while resources represent the handling equipments, tools and labours which modify the entities. Resources are characterized by their capacity and availability, whilst the attributes of the entities are arrival time and processing time. Logical entities simulate the decisions for creating, joining, splitting, buffering and branching entities. Each product type has its own information (i.e. level of inventory, safety stock level, forecasting range and its supplier). As aforementioned, the original purpose of the model is to accurately assess the system's leanness by handling all sources of variations and uncertainty as well as clearly estimate system's future state before the implementation of lean practices. The Simulation process in this study has used a generic simulation package – ExtenSim7 – and customised it using Java and XML technologies. This selection provides flexible and efficient simulation model for three reasons; (1) it helps to provide object-oriented hierarchical and event-driven simulation capabilities for modelling such large-scale application, (2) It utilises breakthrough activity-based modelling paradigm (i.e. real world activities such as assembly, batching and branching), and finally (3) it also used to customise objects in the package to mimic the real-life application characteristics.

In an effort to make simulation-based decisions more accurate, efficient methods of verification and validation were employed. For the verification process, a simulation software built-in debugger and decomposition model (i.e. to verify every group of blocks) were used. A decomposition approach is effective in the detection of errors and insuring that every block functions as expected. The studied model has been validated using 'Face Validation' methodology through several meetings with distribution managers in order to validate the structure of the conceptual model, simulation model and the final results.

Finally, after the illustration of the VSM and Simulation roles in the VS2-lean assessment model, the role of SBM – the third technique – will be elaborated in the next section. Because it is a special case of the Data envelopment analysis (DEA) model, the illustration of DEA will be represented first followed by the SBM model.

3.6.3 Slack Based Measurement Model (SBM)

The concept of DEA has been addressed for measuring systems' performance based on the efficiency concept. The mathematical model of DEA is employed to move from the 'partial efficiency ratio' to the 'total efficiency ratio' by getting into consideration the multi inputs and outputs variables for the system and handling large number of variables relations (i.e. constrains).

In DEA, Decision Making Units (DMUs) are the main entity of the technique where its efficiency degree is pursued. DMU could be the job which flow through the production system or the customer orders in supply chains. The inputs and outputs of DMU have to reflect the manager's interest in the elements that will used to evaluate the efficiency of the studied system. DEA identifies the best practice of the DMU – highest efficiency score – and consider it a technical efficiency frontier that envelops all other DMUs of the dataset and serves as the performance benchmark for scoring as illustrated in Figure 3-7. The DMU's efficiency scores are evaluated by calculating the distance between the efficiency frontier and DMUs' efficiency values. The path between the studied DMU's and the developed efficiency frontier can be identified as the potential improvement to enhance DMU's efficiency. By using these improvement paths, decision makers can easily identify and avoid the causes of inefficiencies. One of the most basic DEA approach is Charnes-Cooper-Rhodes (CCR) which is based on mathematical model – fractional programming – that compares input/output variables for a set of DMUs (Charnes, 1978, Cooper *et al.*, 2004).

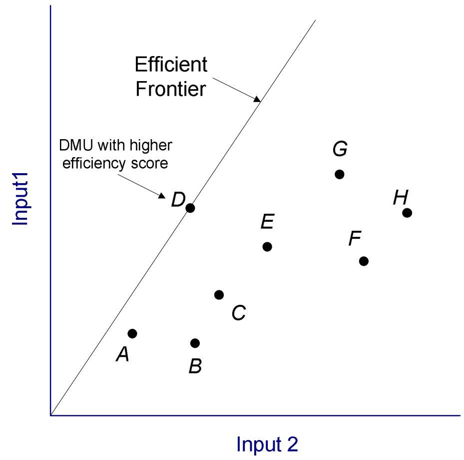


Figure 3-7 The main concept of DEA approach (Source: Cooper *et al.*, 2004).

Despite the effectiveness of CCR model and its ability to assess the efficiency score of systems DMU's, it does not take into account the input excess and output shortfalls (i.e. slacks). An overestimates of efficiency is resulted when CCR model is employed as it assumes a 100% efficiency of the IDMU (i.e. Ideal DMU) – efficient frontier – which is considered a wrong assumption since no operation runs without waste. The additive and SBM models have resolved these challenges and encountered directly the slacks in their objectives functions. When large amount of slacks exist in inputs and outputs dataset, the additive or slack based models (SBM) have to be employed (Tone, 2001, Ramanathan, 2003). Both models use input-output slacks in evaluating efficiency scores, however SBM offers an advantage over the additive model by providing an efficiency evaluation invariant of model's inputs-outputs measurement units. This property is known as "dimension free" or "units-invariant" and provides SBM the capability to evaluate the efficiency score in multi input-output models. SBM scalar is also monotone decreasing in any increasing in the inputs and outputs slack. The two properties, free dimension and monotone decreasing regarding the slacks, can be clearly demonstrated using the SBM mathematical model:

(*SBM*)

$$Min.\ \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_i^- / x_{i0}}{1 + \frac{1}{s} \sum_{r=1}^{s} s_r^+ / y_{r0}} \quad (3.1)$$

Subject to

$$x_0 = X\lambda + s^- \quad (3.2)$$

$$y_0 = Y\lambda - s^+ \quad (3.3)$$

Where $\lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0$

ρ: Efficiency score (i.e. leanness score)

x_0: Input variable of DMU_0

y_0: Output Variable of DMU_0

m and s: Number of input/output variables

λ: Weight for DMUs

s^- and s^+: Slacks associated with inputs/outputs

According to Cooper *et al.* (2004), equation 3.1 can be transformed into

$$\rho = \left(\frac{1}{m} \sum_{i=1}^{m} \frac{x_{i0} - S_i^-}{x_{i0}} \right) / \left(\frac{1}{s} \sum_{r=1}^{s} \frac{y_{r0} + S_r^+}{y_{r0}} \right) \quad (3.4)$$

The 'unit-invariant' propriety was verified as the numerator and denominator are measured in the same units for every item in the objective function with a value of $\boldsymbol{\rho}$ between 0 and 1. It is also obvious that any increase in $\boldsymbol{s}^-$ or $\boldsymbol{s}^+$ will decrease the objective value in a monotone manner – second property. These two proprieties have provided SBM the ability to directly calculate the optimal efficiency score rather than scaling the input-output axes to get a unity score. From other perspective, using the inputs and outputs slacks – inefficiencies – directly in SBM's objective function identically fits the concept of lean which focuses on decreasing the non-value added activities and sources of waste towards achieving the optimal leanness level. Hence, SBM has been found an ideal model to quantitatively assess the leanness level with efficiency score ρ equivalent to the leanness score.

Three steps were followed to develop the VS2 model, (1) developing system's current state map to illustrate and identify the value-added and non-value added portions in the distribution system using the VSM technique, (2) model system's current and future state to evaluate the impact of the proposed lean practices on a company's performance metrics using simulation modelling approach and (3) developing a quantitative leanness index using company's input/output variables by employing SBM model.

3.7 Case Studies

OM is different from many other research areas since both physical and human elements are addressed at the same organisation (Drejer *et al.*, 2000). The majority of OM articles focus on the physical elements of the systems and the arrangements of the human entities to support them. In order to concern the combination between physical and human elements and to cope with the growing frequency of changes in managerial concepts, field-based research (i.e. case research) is addressed by OM authors (Wright and Lund, 2006, Hines *et al.*, 1999, Shah and Ward, 2007). It has advantages over other OM methods; i.e. rationalist research methods, primary statistics survey analysis and mathematical modelling (Meredith, 1998). The ability to ground the theoretical concepts in reality by introducing the intersection between the theory and systems' parameters is the basic advantage in applying the case study approach (Saunders *et al.*, 2009).

Various authors suggested that only through the case study method it will be possible to examine and understand the non-standard forms of actions and behaviours and also identify the conditions under which the theories are applicable (Schein, 1987). Moreover, case research is an efficient method for examining the operations time-dependent relationships, for instance, the link between supplier partnership and plant productivity or the effect of TQM on system's performance. The complexity of operation systems and the large number of factors that impact on the outcome is another reasonable explanation for the usage of case-research methodology in OM research (Hayes and Wheelwright, 1984). Well designed case research would quickly reveal the relationships between these factors more than any other form of empirical research (Stuart *et al.*, 2002).

Case research contributed to development of lean philosophy through illustrating the implication of its practices on the real OM systems (Harrell and Gladwin, 2007, Green *et al.*, 2010). The case studies included manufacturing systems, supply chains, logistic activities and service functions. The methodology provided a clear map of the relationship between system parameters and also illustrated the influence of lean practices on operations and overall systems performance. It was also considered an essential tool for the lean assessment process. Leanness level has been evaluated by various models in many real case studies including the wood industry, hi-tech industry, and in the supply chain and logistics sectors (Ray *et al.*, 2006).

In this research, understanding the configurations of distribution companies and their relative operations were critical for an efficient lean assessment process. Applying the developed lean assessment models on real distribution companies provided deeper understanding of the lean distribution dimensions and their interrelationships with the real system parameters. It also illustrated how systems dynamics, variations and subjectivity effect on the companies' leanness level. Five distribution companies in different sectors were used as case studies emphasising the generality and validity of the proposed lean assessment models. Many site visits and interviews with companies' managers were held to identify system's variables and parameters, in particular in the simulation modelling phase. The participated managers were also involved in the validation process for the developed models.

Chapter 4: LEAN DISTRIBUTION FRAMEWORK: IDENTIFICATION AND DEVELOPMENT PHASES

4.1 Introduction

The literature review in Chapter 2 showed that lean distribution dimensions (e.g. customers, suppliers, transportation and others) were studied individually in various articles, while no publications reported to include more than one dimension in the same study. Therefore, the need to develop an integrated framework that incorporates the lean distribution structure and assessment models emerged. A brief description for the framework structure is provided in the next section followed by detailed illustration for its different phases.

4.2 Overview of Lean Distribution Framework

The framework encompasses of three key phases – identification, development and assessment – and contains a wide variety of statistical and analytical techniques to provide a practical guidance for implementing and assessing lean in the distribution industry. The detailed structure of the framework has been shown in Figure 4-1. Given the lack of lean distribution publications in the literature, identifying lean distribution dimensions and clarifying their interrelationships is the start for the proposed framework. Getting a better understanding of lean distribution concept is essential for developing an accurate leanness assessment process for the distribution companies. In addition to the literature review, knowledge about lean distribution logic and principles is required from the perspective of the distribution people that are involved in both operational and managerial levels. By the end of this phase, detailed insights about lean distribution concept are gained and an initial set of its factors and practices can be developed – identification phase.

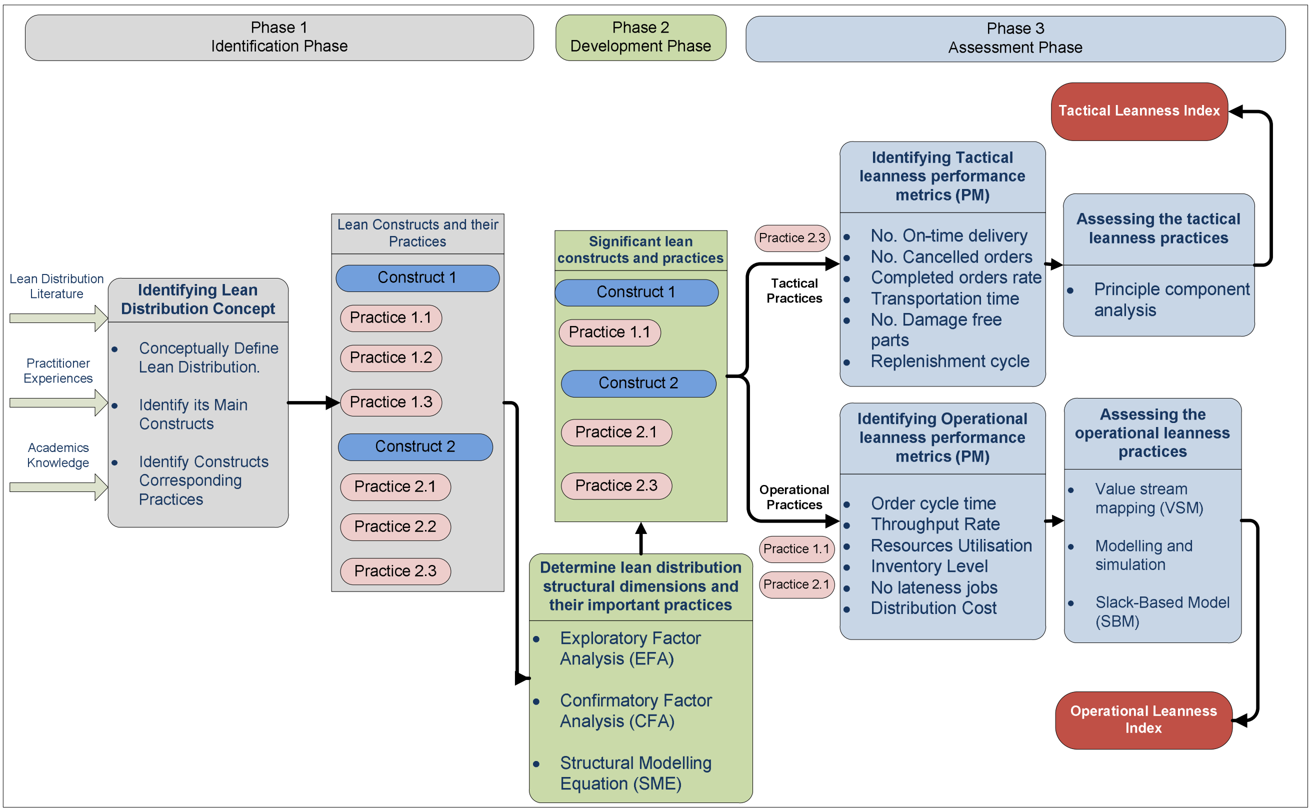


Figure 4-1 Lean Distribution Framework (Source: Author).

To ensure the validity of the identified lean distribution factors, rigorous empirical methods are employed based on data from a sample of distribution companies. Developing lean distribution measurement and structure models helped to show the significant factors to the concept along with their correlation coefficients. This is essential for the continuous improvement (CI) process as it provides the ability to priorities the improvement efforts in the lean implementation process – developing phase.

After the developing phase, lean assessment phase – the key target of the framework – was begun by identifying leanness performance metrics. Lean assessment models are then developed by utilising a number of statistical and analytical techniques such as PC, VSM, modelling and simulation and SBM model. There are two assessment models that are developed; the first is tactical assessment model, where the non-operational practices are evaluated (e.g. practices related to customer, suppliers, transportation dimensions), while the second – operational lean assessment model – is created to assess the operational lean distribution practices and performance. Both models have resulted in quantitative leanness indices that were utilised to compare, rank and assess the leanness level of five distribution case studies. In addition, they will be used to evaluate the effect of specific lean practices ahead of their implementation.

4.3 Phase I: Identification Phase

4.3.1 Overview of Lean Distribution Principles

Extending supply chains across the globe makes the distribution function more challenging than ever. There is no room for inefficiency when planning and moving products across complex and global supply chains. In the past, the distribution process was totally reliant on customer-order forecasts to create optimal distribution plans (i.e. transportation plan, delivery plans, warehousing plans and others). But forecast accuracy became a difficult goal, making forecast-based plans less reliable and cost reduction more elusive. Some companies such as Dell, Wal-Mart and Apple employed advanced approaches based on lean principles to derive new levels of competition. They succeeded to streamline their distribution centres by applying efficient and market-driven approach built around lean principles in distribution.

Lean distribution takes a general approach of lean manufacturing to streamline and optimise the product flow, enabling a more efficient customer service level and inventory replenishment model. It focuses on increasing the simplicity and flexibility of the distribution constructs by reducing lead time, lot sizes and increasing operations reliability. It employs a very different approach from the forecast-based optimisation plans which are based on fixed lead times and lot sizes. Whereas, the optimisation plans seeks to reschedule the orders and inventory within the plan, lean distribution creates flexible distribution operations that respond to market dynamics.

4.3.2 Lean Distribution Theoretical Logic

The concept aims to systematically improve the parameters that drive the performance across the entire distribution network rather than to take individual actions trying to improve departmental cost, service level or inventory. The main levers of lean distribution are cycle time, level of variation and flexibility which become the driver for all lean distribution decisions and practices. The lean distribution paradigm is a multidimensional concept that contains various factors that form the solution to a lean transformation as seen in Figure 4-2.

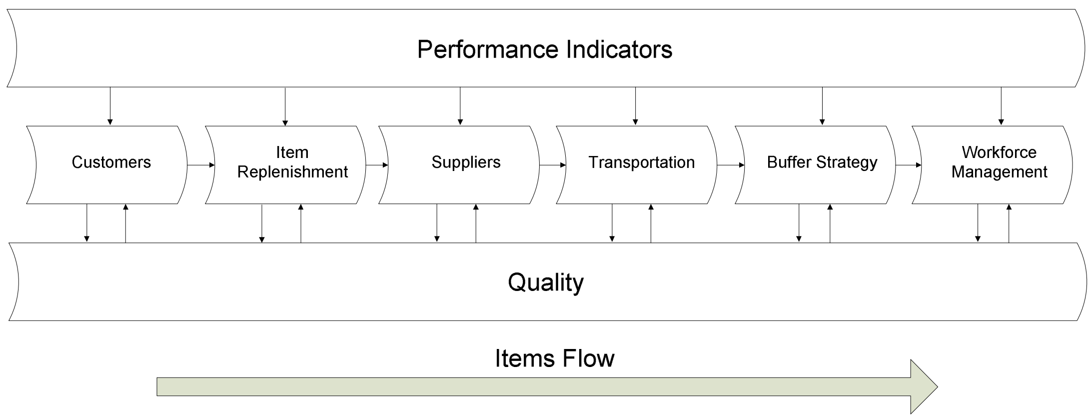


Figure 4-2 The logical sequence of lean distribution elements (Source: Author).

Although statistical assessment is necessary for interpreting the interrelationships between lean distribution's elements, theoretical logic should also be taken into consideration to support and validate the statistical interpretations (Whetten, 1989). The most critical element for lean distribution is the customer being the key focus in the lean environment and the determiner of many important aspects such as order parameters, lead time, service level and delivery specifications. Customer orders trigger all lean distribution operations and are the main entities that flow across the whole facility. Item replenishment is the foundation for the approach since it is the communication between customers and suppliers. It tries to synchronise the ordering process by matching suppliers' delivery features with customer order requirements. Effective collaboration with suppliers plays a pivotal role in the success of the item replenishment process and in turn the whole approach. To reduce order cycle time and isolate system variability, optimal transportation and buffer strategies have to be applied.

High distribution operational capabilities are also a key to ensure that the lean process can be successfully executed. Since most of distribution operations totally rely on human factors, it is essential to efficiently manage the workforce towards high operational performance. Finally, the typical focus of the quality factor is to increase processes reliability and functionality to reduce systems' variation level. Applying best practice procedures, corrective action plans and problem solving processes as well as providing standardised steps for performing the operations are the basic tools for the quality factor. The seven factors combine to form a cohesive distribution system in order to improve distribution cost, asset utilisation and customer service. These factors have to be integrated and implemented as a one unit (i.e. lean distribution) not as a series of disjoint cost reduction attempts. They are tied together by the generic lean philosophy – eliminate the waste and non value added elements.

In chapter 2, an extensive literature review was conducted for each lean distribution factor. A collection of improvement initiatives and lean practices were summarised in Figure 2.4 resulting a preliminary list of lean distribution factors and their correspondent practices. To incorporate these practices with the real life distribution functions, several interview sessions with various distribution managers and supply chain academics along with a number of site visits have been carried out. The findings of these meetings and visits pointed that 7 lean distribution factors with 40 lean practices are representing the initial structure of lean distribution paradigm as shown in Table 4-1. In order to statistically ensure the inter-correlation between these constructs and determine their significance regarding to lean distribution concept, multi-step construct development methods – EFA, CFA and SEM – were developed in the next phase (i.e. development phase). The underlying dimensional structure of lean distribution paradigm has been represented through the validated lean distribution measurement and structure models.

4.4 Phase II: Development Phase

4.4.1 Statistical Analysis of Lean Distribution Constructs

The emergence of empirical research in supply chain and logistics has recently been witnessed in the operations management literature where several measurement instruments and hypotheses testing papers have been published (Handfield and Pannesi, 1995, Sakakibara *et al.*, 1993, Davy *et al.*, 1992). The sophistication of measurement and analysis methods has increased involving many complex variables and constructs that are not readily observed – latent variables. In order to measure these latent variables, researchers used multi-item scales where the latent variable can be measured using more than two items by summing-up their scores to form a composite score (Koufteros, 1999).

Table 4-1 Initial set of Lean Distribution constructs and their corresponding practices.

Distribution Elements	Practice Code	Practice Description
Customers	Cust_1	Clear customer service agreements are issued containing (e.g. service lead time, buffer strategy, replenishment strategy).
	Cust_2	Comprehensive identification of customer needs and expectations is done.
	Cust_3	Change customer service agreement according to customer's condition, value and requirement (i.e. no standard customer service policy for all customers)
	Cust_4	Customer feedbacks are used to enhance operations performance.
	Cust_5	Provides customers the ability to follow-up the replenishment process and get information about replenishment problems.
Replenish-ment	Rep_1	Reduce the number of customer orders that are consolidated into a single replenishment order
	Rep_2	Access to actual customer consumption and uses it as a trigger to the replenishment process
	Rep_3	Company's replenishment strategy is flexible subject to customer requirements, conditions and values
	Rep_4	Take steps to simplify its distribution network in order to decrease shipments lead time and cost
	Rep_5	Line balancing approach is used to reduce bottleneck in product flow
	Rep_6	Place replenishment orders in high frequency with small lot sizes
	Rep_7	Customer demands are levelled to reduce variability and enhance the planning process
Buffer Strategy	Buff_1	Emergency stocks are kept near to the sources (i.e. Manufacturer or main distribution centre) in order to deal with unexpected or rush orders
	Buff_2	Identify the activities that add values to the customers (i.e. value-added activities) and eliminate the non-value added ones
	Buff_3	Products flow are managed in consistent small batch sizes throughout the daily work activities
	Buff_4	Products with similar characteristics are stored at same location
	Buff_5	Products buffer between the internal operations (i.e. Work in Process) are minimised
Suppliers	Supp_1	Getting up to date information about suppliers problems
	Supp_2	The company's suppliers are involved in setting the replenishment policies and strategies
	Supp_3	Establishing continuous cooperation with key suppliers to resolve customer issues
Items Flow	Flow_1	The quality of the transportation activity is frequently reviewed, aiming to increase the efficiency
	Flow_2	Select freight companies that offer flexible capacities for the shipment process
	Flow_3	All mechanical handling equipments are maintained regularly
	Flow_4	Utilise operational methods and solutions to increase the efficiency of the handling equipments
People	Staf_1	Sort-out, organises and visually represents the equipments and tools that are needed in the workplace to maximise workers utilisation
	Staf_2	Employs layout design solutions in order to minimise the internal travel distance and time for both products and workers
	Staf_3	The workplace is kept clean, clear and free of debris
	Staf_4	Employees feedback and concerns are encouraged and included before making changes and taking actions
	Staf_5	Managers, supervisors and employees are involved in determining facility goals and their achievement feasibility
	Staf_6	Daily work activities are organised into teamwork functions in order to enrich work environment and enhance problem solving activities
	Staf_7	Employees participate, initiate and lead problem-solving activities autonomously
Quality	Qu_1	Standard operating procedures are provided to the company's operators, aiming to standardise operations steps
	Qu_2	Identify and regularly discusses the best practices of its operations
	Qu_3	Apply statistical process control procedures (e.g. six sigma) to insure the reliability of the distribution operations
	Qu_4	Advanced technology systems are installed to standardise and simplify the processes, and to reduce the redundancy and transaction errors (e.g. ERP)
	Qu_5	Develop continuous improvement plans to sustain and improve distribution performance
	Qu_6	Structured problem solving methodologies (e.g. 5 whys) are utilised in order to determine the root cause of the problems
	Qu_7	Quality verification and inspection procedures are created for each distribution function
	Qu_8	Develop corrective action procedures in order to rectify quality problems
	Qu_9	Clear goals and key performance indicators (KPIs) are identified

As illustrated in Figure 3-4, a comprehensive multi-step approach was employed to identify the dimensional structure underlying lean distribution concept as well as its measurement model. The approach aimed to examine the lean practices (i.e. indicators) through several validation steps to assure their content validity as well as provide high research design quality. Based on lean distribution constructs and practices list shown in Table 4.2, data analysis phase was started by sample selection – 600 Irish distribution centres and wholesalers.

4.4.1.1 Exploratory Factor Analysis

Since lean distribution philosophy still in its early stage of empirical inquiry and its theoretical model does not yet exist, the data analysis phase has focused on examining the reliability and validity of lean distribution constructs and practices towards identifying dimensional structure and measurement model for the philosophy. Exploratory techniques was utilised to develop a lean distribution exploratory model which subsequently can be tested *via* confirmatory analytic techniques to develop the measurement model. The exploratory analysis started with conducting a missing item analyses on the survey responses with eliminating the records that have missing data. Following that, CITC scores were calculated for each item to assess their reliability. CITC refers to the correlation of an item with the composite score of all the items forming the same latent variable. The item is usually a candidate of elimination if its correlation has recorded 0.3 or below indicting that item measures something different from the scale as a whole (Shah and Ward, 2007).

Table 4-2 Reliability assessment of lean distribution practices.

Lean Distribution Factor	Lean Distribution Practices	Corrected-Item Total Correlation	Cronbach's Alpha
Customer	Cust_1	.387	.907
	Cust_2	.562	.904
	Cust_4	.475	.906
	Cust_5	.622	.903
Item Replenishment	Rep_2	.362	.909
	Rep_3	.569	.905
	Rep_4	.491	.906
	Rep_5	.407	.907
	Rep_7	.522	.905
Buffer Strategy	Buff_4	.326	.909
	Buff_5	.393	.908
Suppliers	Supp_3	.363	.908
Item Flow	Flow_1	.492	.906
	Flow_2	.467	.906
Workforce Management	Staf_1	.541	.905
	Staf_2	.394	.907
	Staf_3	.36	.908
	Staf_5	.531	.905
	Staf_6	.663	.903
	Staf_7	.52	.905
Quality	Qu_1	.417	.907
	Qu_2	.492	.906
	Qu_3	.404	.907
	Qu_5	.614	.904
	Qu_6	.531	.905
	Qu_7	.709	.902
	Qu_8	.673	.903
	Qu_9	.639	.904

Three reliability analysis iterations were conducted and 12 items with CITC values below 0.30 were removed. Table 4-2 shows the final reliability results after the three reliability iterations and eliminating items correspondent with customer, item replenishment, buffer strategy, suppliers, workforce, quality and items flow constructs.

Following the reliability assessment, EFA was conducted to determine the number of latent variables that cover the complete set of items and provide explanation for the variations among the original variables. The items with high loading on a particular factor and low loading on the others were clustered to develop the underlying factors of lean distribution theory.

The suitability of data for the factor analysis was examined with Kaiser-Meyer-Oklin coefficient and Bartlett's Test of Sphericity (Pallant, 2005) recording statistical significance for the studied model – > 0.6 and < 0.005 respectively – and supporting the factorability of the correlation matrix. Principle components analysis has shown seven components with eigenvalues exceeding 1.00 and explaining 73.5% of the variance (Kaiser, 1970), see Table 4.3. Once the number of factors is determined, the next step is to interpret them.

Table 4-3 Significant factors with eigenvalues > 1.00.

Factors	Initial Eigen value			Extraction Sums of Squared Loadings		
	Variance	% of Variance	Cumulative	Total	% of Variance	Cumulative
1	8.725	31.162	31.162	8.725	31.162	31.162
2	3.094	11.048	42.211	3.094	11.048	42.211
3	2.857	10.204	52.415	2.857	10.204	52.415
4	1.869	6.675	59.091	1.869	6.675	59.091
5	1.734	6.194	65.285	1.734	6.194	65.285
6	1.216	4.341	69.626	1.216	4.341	69.626
7	1.099	3.925	73.552	1.099	3.925	73.552
8	.939	3.354	76.906			
9	.915	3.267	80.173			
10	.848	3.028	83.201			
11	.679	2.425	85.626			
12	.590	2.106	87.732			
13	.525	1.873	89.606			
14	.456	1.629	91.235			
15	.374	1.336	92.571			
16	.297	1.062	93.633			
17	.292	1.043	94.676			
18	.257	.918	95.595			
19	.220	.785	96.380			
20	.192	.685	97.065			
21	.190	.679	97.743			
22	.152	.542	98.285			
23	.131	.466	98.752			
24	.112	.401	99.152			
25	.083	.297	99.450			
26	.062	.223	99.672			
27	.049	.176	99.848			
28	.042	.152	100.00			
Kaiser-Meyer-Olkin Measure of sampling Adequacy				0.686		
Bartlett's Test of Sphericity		Approx. Chi-Square		1172.088		
		Df		378		
		Sig.		0.00		

Extraction Method: Principal Component Analysis

The factors have to be ‘rotated’ in order to presents the pattern of loadings in a manner that is easier to interpret. There are two main approaches to rotation, resulting in either orthogonal (uncorrelated) or oblique (correlated) factor solutions (Tabachnick and Fidell, 2007). Since lean distribution factors are highly correlated and have mutual impact on lean performance, a Direct Oblimin rotational technique is employed. It is recommended by Pallant (2007) to always start with Oblimin rotation as it provides information about the degree of correlation between factors. Table 4.4 shows the rotated 7 factors of lean distribution and the items loading in each factor.

Table 4-4 Correlation coefficient of the independent variables with selected factors.

Independent Variables	Principle Component (i.e. Factors)						
	1	2	3	4	5	6	7
Staf_1	.727			-.315			
Qu_9	.701						
Qu_8	.671						
Staf_5	.609						.311
Rep_3	.601						
Qu_7	.528						
Staf_3	.502	.325					.327
Cust_4		-.876					
Cust_1		-.852					
Cust_5		-.736		-.339			
Cust_2		-.577			.366		
Qu_6	.437	-.520					
Buff_5			.848				
Rep_5			.795				
Rep_2			.757				
Rep_7			.738				
Buff_4			.656	-.352			
Staf_7				-.643			.341
Staf_6	.409			-.581			
Flow_1					.836		
Flow_2					.793		
Rep_4					.667		
Supp_3					.479		
Qu_1						.775	
Qu_2				-.455		.697	
Qu_3							.898
Staf_2							.782
Qu_5				-.306			.546

Extraction Method: Principle Component Analysis

Items with cross-section loading exceeding 0.4 with more than 2 factors should be eliminated. Based on Table 4.4, three items are eliminated (i.e. Qu_6, Staf_6 and Qu_2) and EFA is recalculated for another two iterations. Another four extra items are eliminated in the second EFA iteration (i.e. Supp_3, Buff_4, Cust_5 and Rep_3), Table 4.5 present the final list of eigenvalues with 5 factors exceeding 1 and represent 67% of the variance.

Table 4-5 Significant factors with eigenvalues > 1.00 for the final EFA iteration

Factors	Initial Eigen value			Extraction Sums of Squared Loadings		
	Variance	% of Variance	Cumulative	Total	% of Variance	Cumulative
1	6.583	31.346	31.364	6.583	31.346	31.364
2	2.553	12.158	43.504	2.553	12.158	43.504
3	2.296	10.934	54.438	2.296	10.934	54.438
4	1.618	7.706	62.144	1.618	7.706	62.144
5	1.439	6.852	68.995	1.439	6.852	68.995
9	.638	3.040	84.015			
10	.588	2.798	86.813			
11	.523	2.492	89.304			
12	.406	1.932	91.236			
13	.332	1.582	92.818			
14	.313	1.491	94.309			
15	.260	1.236	95.545			
16	.231	1.101	96.646			
17	.192	.913	97.559			
18	.162	.772	98.331			
19	.137	.654	98.984			
20	.119	.569	99.553			
21	.094	.447	100.000			
Kaiser-Meyer-Olkin Measure of sampling Adequacy				0.743		
Bartlett's Test of Sphericity		Approx. Chi-Square		696.702		
		Df		210		
		Sig.		0.00		

Extraction Method: Principal Component Analysis

Before the final decision concerning the number of factors, the retained items loading have to be checked. As illustrated in Table 4.6, all items loadings on the five factors are above 0.4. The five factors were labelled based on items loading and the understanding of the lean distribution theoretical logic. First factor embraces Qu_1, Qu_7, Qu_8, Qu_9, Staf_1 and Staf_3 which are all related to Quality construct and hence factor 1 is labelled 'Quality'. Factor 2 is identified as 'Customer' since it embraces three practices focus on reducing the demand variation and increasing the robustness of communication channels with customers; Cust_1, Cust_2 and Cust_4. Factor 3 is labelled 'Replenishment' with 4 Buffer and Replenishment practices (Rep_2, Rep_5, Rep_7 and

Buff_5). A combination of practices aim to provide effective improvement and planning tool to increase the reliability of distribution operations as well as managing the distribution labours and employees (Qu_3, Qu_5, Staf_2, Staf_5 and Staf_7) were involved in factor 4 which labelled 'Workforce and Planning'. Decreasing transportation cost and time along with simplifying distribution network were the targets of (Flow1, Flow2 and Rep4) practices, creating the fifth factor 'Transportation'.

Table 4-6 Correlation coefficient of the lean distribution variables in final EFA iteration

Independent Variable	Principle Component				
	1	2	3	4	5
Qu_9	.841				
Qu_8	.831				
Staf_1	.667				
Qu_7	.663				
Qu_1	.583				
Staf_3	.545				
Cust_4		.853			
Cust_1		.817			
Cust_2		.659			
Rep_5			.845		
Buff_5			.805		
Rep_2			.752		
Rep_7			.746		
Qu_3			.	.798	
Qu_5				.785	
Staf_7				.737	
Staf_2				.639	
Staf_5				.546	
Flow_1					.869
Flow_2					.853
Rep_4					.554

It was surprising that all supplier's practices were eliminated which indicate that suppliers collaboration issue does not take the appropriate attention from practitioners though its importance for lean distribution paradigm. Discussing this result with the participated distribution managers, they stated that this is a direct result of applying the push replenishment policies – replenishing large lot sizes in long intervals – and keeping high inventory level rather than applying pull replenishment strategy.

The internal consistency of the items – refers to the degree to which the items that make up the scale 'hang together' – was validated using the Cronbach Alpha coefficient which recorded a value above 0.9 for the overall model and ranged between 0.9 and 0.906 for each item. This indicated a very good internal consistency for the scale with the utilised sample (DeVellis, 2011). In conclusion, out of 40 lean distribution practices represented the initial strategic and operational space surrounding the lean distribution concept, the exploration phase extracted 21 practices which are reliable and strongly correlated to the lean distribution concept. The practices have been distilled into five basic factors as illustrated in Figure 4.3 (Shah and Ward, 2007). Once the observed variables were grouped into the related factors, confirmatory factor analysis was developed to confirm the hypothesised structure model of lean distribution paradigm.

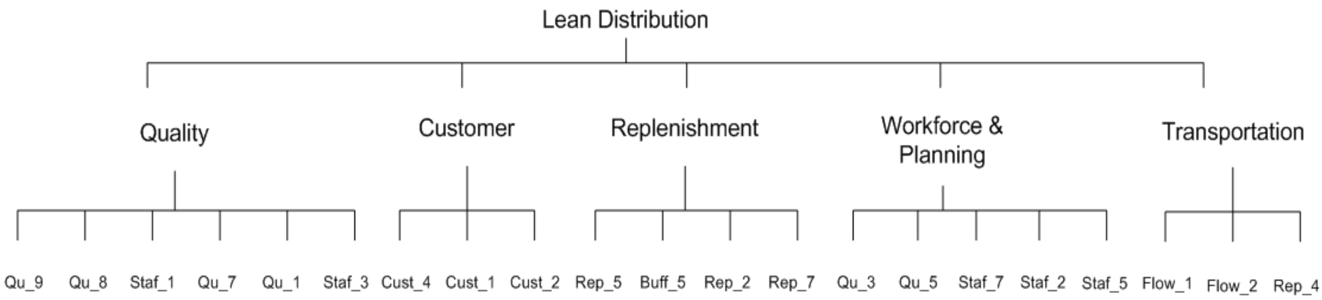


Figure 4-3 Exploratory structure of lean distribution concept (Source: Author).

4.4.1.2 Confirmatory Factor Analysis

Three steps were followed in constructing lean distribution measurement model starting with standardising observed variables in a way to make the latent variables with more than one observed variable comparable (Long, 1983). This could be done by setting one of the loadings in each latent variable to a fixed value of 1.0. Two statistical assessments steps were followed, beginning with convergent validity and item reliability test then model fit test and finally unidimensionality assessment. First, an evaluation on items level was applied through tests of convergent and item reliability. In this step, it is explored how an item behaves within a group of items intended to measure a single construct was done. The items with low reliability index were dropped *via* iterative procedure. After a reliability test, if the satisfactory model was derived, assessment of model fit and unidimensionality assessment were adopted.

Many methods can be used to assess model's unidimensionality and determine its misspecifications including standardised residuals, Q-plots and modification indices. Assessing the fitness of the measurement model to the observed data aims to depict how a particular item relates to other items in the entire set. If a model respecification is required after the model fit assessment, the respecification process should not be data-driven alone but it has to be supported by the theory logic. Developing an adequate measurement model is important before testing substantive theory (Koufteros, 1999). It was recommended that the measurement model be finalised before developing the structural model in order to avoid the possible interaction between both models (Segars and Grover, 1993, Anderson and Gerbing, 1982).

- Convergent Validity and Item Reliability

Convergent validity can be evaluated based on an item's significant load on the latent variable (*t*-value) (Anderson and Gerbing, 1988). While on the other hand, proportion of variance coefficient (R^2) was utilised to assess item's reliability (Bollen and Bollen, 1989).

- ***T-Value***

The larger the factor loadings of the observed variable (i.e. items) on the latent variable (i.e. factors) – expressed by the corresponding *t*-value – the stronger the evidence that the measured item representing the underlying latent variable, in other word indicates the validity of the observed variables (Bollen and Bollen, 1989). Convergent validity is examined by testing the ratio of factor loading on their respective standard errors. Generally, if the *t*-value is greater than |2.58| then the item can be counted as a significant on 0.01 significant level and retained in the model, otherwise it will be eliminated to enhance the model fit (Anderson and Gerbing, 1988). In Table 4-7, the evaluation of *t*-value indicates that all items are significantly related to their latent variables exceeding the critical *t*-value |2.58|.

- ***R^2 values***

A variable's reliability is defined as the proportion of the observed variable that is free from error (Koufteros, 1999). If the item's reliability is less than 0.40, then more than 50% of its variance would be error variance which would be difficult to justify (Hughes *et al.*, 1986). The items with R^2 less than 0.40 should be dropped and a re-estimation of the parameters values has to be performed. Table 4-7 shows the squared correlation for the retained 21 items from the exploratory phase. Staf_3 item was eliminated with very small R^2 and factor loading values. Although Qu_1, Staf_2 and Rep_4 items have recorded R^2 values less than 0.4, they were retained due to their strong theoretical correlation with Quality, Workforce and Transportation factors respectively as well as the fact that they were not far from 0.4. This correlation was also emphasised statistically with high correlation coefficient (i.e. factor loadings) for each item as illustrated in Table 4-7. After dropping Staf_3, no further reliability iteration for the retained items was required as all R^2 values greater than 0.40 – except Qu_1, Staf_2 and Rep_4 – provides evidence of the convergent validity and items reliability for the proposed model. Table 4-8 illustrated the 20 retained items that were employed to assess the model fit and evaluate model unidimensionality.

Table 4-7 Parameters estimates and item reliability values – Iteration 1.

Latent Variable	Variable	Factor Loading	Standard Error	*t-Value*	R2
Quality	Staf_1	0.63	0.12	5.26	0.41
	Staf_3	0.31	0.096	3.22	**0.18**
	Qu_1	0.65	0.15	4.21	0.28
	Qu_7	0.81	0.11	7.38	0.66
	Qu_8	0.79	0.094	8.47	0.79
	Qu_9	0.74	0.092	8.02	0.74
Model Fit d.f = 9 Chi_Square = 10.06 (P = 0.35) RMSEA = 0.026, NNFI = 0.99, CFI = 1.00					
Replenishment	Rep_2	0.91	0.17	5.46	0.47
	Rep_5	0.94	0.15	6.34	0.59
	Rep_7	0.89	0.16	5.73	0.51
	Buff_5	0.91	0.15	6.14	0.57
d.f = 2 Chi_Square = 0.99 (P = 0.61) RMSEA = 0.00, NNFI = 1.00, CFI = 1.00					
Workforce & Planning	Staf_2	0.65	0.14	4.73	0.36
	Staf_5	0.61	0.12	5.06	0.41
	Staf_7	0.71	0.12	5.89	0.52
	Qu_3	0.83	0.15	5.53	0.47
	Qu_5	0.82	0.11	7.14	0.69
d.f = 5 Chi_Square = 8.35 (P = 0.14) RMSEA = 0.092, NNFI = 0.95, CFI = 0.97					
Customer & Quality	Cust_1	0.93	0.13	7.13	0.69
	Cust_2	0.84	0.12	6.89	0.65
	Cust_4	0.85	0.13	6.35	0.57
	Staf_1	0.61	0.12	5.11	0.39
	Qu_7	0.81	0.11	7.41	0.67
	Qu_8	0.81	0.093	8.71	0.83
	Qu_9	0.73	0.093	7.81	0.72
d.f = 12 Chi_Square = 14.68 (P = 0.33) RMSEA = 0.028, NNFI = 0.99, CFI = 0.99					
Transportation & Quality	Rep_4	0.57	0.13	4.51	0.34
	Flow_1	0.86	0.12	7.44	0.81
	Flow_2	0.89	0.14	6.36	0.62
	Staf_1	0.63	0.12	5.27	0.41
	Qu_7	0.82	0.11	7.57	0.69
	Qu_8	0.8	0.094	8.47	0.8
	Qu_9	0.73	0.094	7.78	0.71
d.f = 13 Chi_Square = 17.86 (P = 0.16) RMSEA = 0.078, NNFI = 0.97, CFI = 0.99					

Table 4-8 Parameters estimates and item reliability values – Iteration 2

Latent Variable	Variable	Factor Loading	Standard Error	*t-Value*	R2
Quality	Staf_1	0.63	0.12	5.26	0.41
	Qu_1	0.65	0.15	4.21	0.28
	Qu_7	0.81	0.11	7.38	0.66
	Qu_8	0.79	0.094	8.47	0.79
	Qu_9	0.74	0.092	8.02	0.74
Model Fit d.f = 5 Chi_Square = 1.69 (P = 0.89) RMSEA = 0.00, NNFI = 1.00, CFI = 1.00					
Replenishment	Rep_2	0.91	0.17	5.46	0.47
	Rep_5	0.94	0.15	6.34	0.59
	Rep_7	0.89	0.16	5.73	0.51
	Buff_5	0.91	0.15	6.14	0.57
d.f = 2 Chi_Square = 0.99 (P = 0.61) RMSEA = 0.00, NNFI = 1.00, CFI = 1.00					
Workforce & Planning	Staf_2	0.65	0.14	4.73	0.36
	Staf_5	0.61	0.12	5.06	0.41
	Staf_7	0.71	0.12	5.89	0.52
	Qu_3	0.83	0.15	5.53	0.47
	Qu_5	0.82	0.11	7.14	0.69
d.f = 5 Chi_Square = 8.35 (P = 0.14) RMSEA = 0.09, NNFI = 0.95, CFI = 0.97					
Customer & Quality	Cust_1	0.93	0.13	7.13	0.69
	Cust_2	0.84	0.12	6.89	0.65
	Cust_4	0.85	0.13	6.35	0.57
	Staf_1	0.61	0.12	5.11	0.39
	Qu_7	0.81	0.11	7.41	0.67
	Qu_8	0.81	0.093	8.71	0.83
	Qu_9	0.73	0.093	7.81	0.72
d.f = 12 Chi_Square = 14.68 (P = 0.33) RMSEA = 0.028, NNFI = 0.99, CFI = 0.99					
Transportation & Quality	Rep_4	0.57	0.13	4.51	0.34
	Flow_1	0.86	0.12	7.44	0.81
	Flow_2	0.89	0.14	6.36	0.62
	Staf_1	0.63	0.12	5.27	0.41
	Qu_7	0.82	0.11	7.57	0.69
	Qu_8	0.8	0.094	8.47	0.8
	Qu_9	0.73	0.094	7.78	0.71
d.f = 13 Chi_Square = 17.86 (P = 0.16) RMSEA = 0.078, NNFI = 0.97, CFI = 0.99					

- Model Fit Assessments

In order to assess the matching of the items relationships with the observed data and evaluating scale unidimensionality, model fit evaluation, standardised residuals, Q-plots and modification indices techniques were employed. Starting with the model fit evaluation, the maximum likelihood statistics χ^2 was utilized to evaluate the fitness of the hypothesised measurement model by indicating how far the model meet the unidimensionality conditions. It measured the distance (i.e. differences) between the sample and fitted covariance matrices. A small χ^2 was an indicator for the strength of the model fitting as zero χ^2 corresponds to perfect fit between the model and the observed data. χ^2 was associated with a *p*-value which represents the probability that the studied measurement model is a true reflection of reality and well confirmed by the sample data (Hughes *et al.*, 1986). Although χ^2 is considered a global variable and an appropriate measurement model for the model fit, its significant level is sensitive to the sample size which requires cautious interpretation of its value in most applications (Joreskog and Sorbom, 1989).

Other measures of model fit including the ratio of χ^2 to degree of freedom (*df*), the root of mean square error of approximation (RMSEA), the Bentler and Bonnet normed fit index (NFI), the Bentler and Bonnet non-normed fit index (NNFI) and the Bentler comparative fit index (CFI) were addressed (Bentler, 1986). The majority of these indices are independent of sample size like NNFI while CFI is affected with a small degree (Ding *et al.*, 1995). RMSEA is currently the most popular measure of model fit in the papers that use CFA and SEM. MacCallum *et al.* (1996) have used 0.01, 0.05 and 0.08 to indicate excellent, good and mediocre fit respectively. A value above 0.90 for NNFI and CFI also indicates a reasonable fit (Koufteros, 1999). In order to avoid any influence of the sample size, the study used RMSEA, NNFI and CFI indices. Using more than one index to assess the model fit is recommended to ensure the meaningful and accuracy of the resulted model and its conclusion (Tanaka, 1993, Bollen and Long, 1993). Hence, Table 4-8 demonstrates a strong evidence of good model fit and unidimensionality.

- ***Standardised Residuals***

A residual is the difference between the observed and fitted matrices of covariance where a small fitted residual < |2.58| indicates a good fit. Large residuals indicate a substantial prediction error for the correlation between two observed variables. Because residuals rely on the measurement units for the observed variables, it is necessary to calculate a standard residual by dividing the residual by its estimated standard error (Joreskog and Sorbom, 1989). Based on Table 4-9 smallest standard residual was –2.3 and the largest was 2.43 reflecting a good fit for the studied model. Two items had standardised residuals values of more than |2.58|, however based on lean distribution theoretical logic there is no need for model re-specification. It should be noted that respecification is warranted only when statistical evident and theoretical evident overwhelming converge to the same action.

- ***Q-Plots***

Standardised residuals can also be examined collectively using the Q-plots. A good fit model is characterised by the points falling approximately on a straight line (Jreskog and Srbom, 1996). The deviation from the straight line pattern is considered an indication of error specification in the model, non-normality in the variable or non-linear relationship between variables. Q-plot in Figure 4-4 was developed based on the standardised residuals of the modified model with approximately linear slope which adds another evident for model fit and no apparent misspecification.

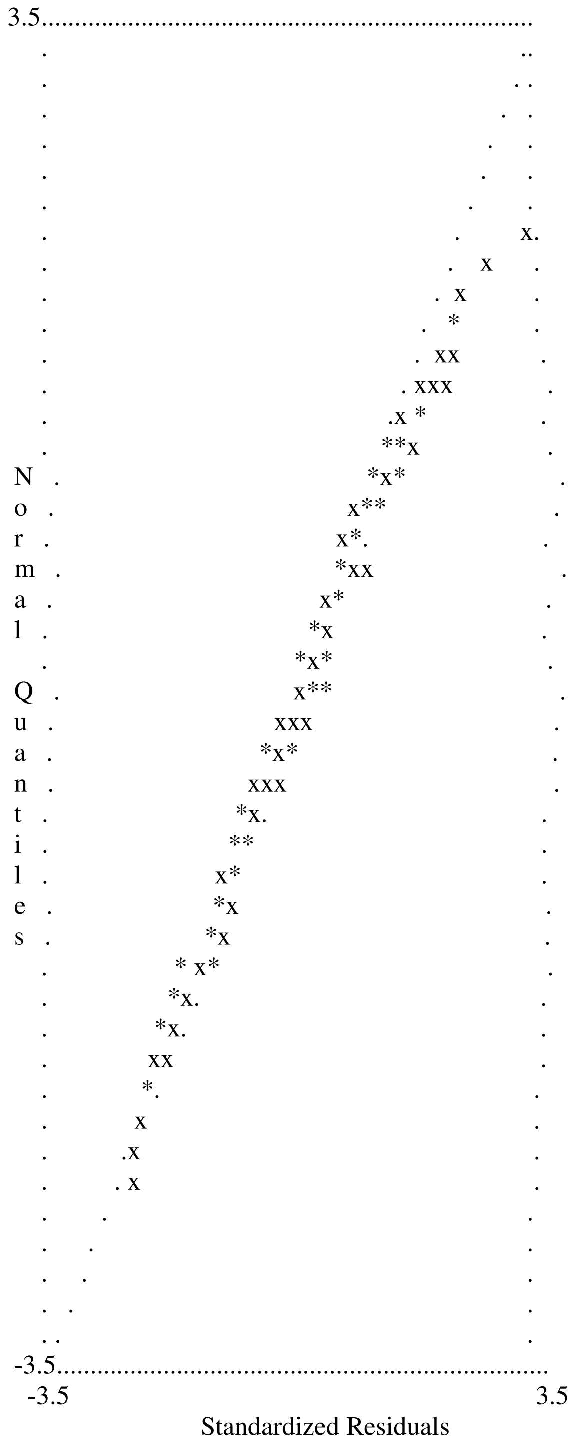


Figure 4-4 Scree plot for lean distribution measurement model.

Table 4-9 Standard Residuals (Modified Model).

Item	Cust1	Cust2	Cust4	Rep2	Rep4	Rep5	Rep7	Buff5	Flow1	Flow2	Staf1	Staf2	Staf5	Staf7	Qu1	Qu3	Qu5	Qu7	Qu8	Qu9
Cust_1	-																			
Cust_2	-0.79	-																		
Cust_4	2.83	-1.79	-																	
Rep_2	0.91	2.05	0.68	-																
Rep_4	-1.90	1.89	-0.74	0.60	-															
Rep_5	-.08	0.83	-0.39	-0.26	1.59	-														
Rep_7	0.24	0.42	1.78	0.43	1.58	0.82	-													
Buff_5	-1.85	-2.20	-1.92	0.27	-1.14	0.34	-1.65													
Flow_1	-2.24	2.19	-0.15	0.08	-0.76	1.04	-1.05	-1.03	-											
Flow_2	-0.22	0.17	-0.59	-0.68	-0.19	-0.16	-0.14	-0.11	0.81	-										
Staf_1	-2.01	0.81	-0.62	-1.55	0.71	-0.69	-1.54	-0.04	2.35	0.47	-									
Staf_2	-1.68	0.18	-0.90	-0.19	-0.62	0.60	0.70	1.41	-0.81	0.38	1.05	-								
Staf_5	-.63	1.42	0.96	-0.17	0.70	-0.15	-0.83	0.48	0.56	-0.02	3.43	-0.53	-							
Staf_7	-2.01	-1.19	0.45	-0.60	-1.09	-1.13	0.62	0.98	0.57	0.45	2.23	0.97	0.73	-						
Qu_1	0.31	1.53	-0.29	-1.02	0.37	0.32	-0.29	-1.20	2.39	1.09	-0.42	-1.04	-0.67	-1.21	-					
Qu_3	-0.47	1.20	0.55	0.29	-1.40	-2.30	-0.99	0.16	-0.48	0.42	-0.14	1.99	-0.55	-1.14	-0.42	-				
Qu_5	-0.33	0.22	2.43	0.61	-0.19	-1.16	0.25	0.75	-0.12	-0.76	-0.12	-1.82	0.00	-0.48	-0.93	1.53	-			
Qu_7	-0.98	-0.87	0.12	-0.75	0.17	0.71	0.50	0.39	0.54	-0.71	0.66	-0.26	0.32	-0.63	-1.04	-1.32	1.13	-		
Qu_8	-0.39	1.14	0.16	-0.84	0.43	1.03	-0.65	0.50	-0.92	-0.76	-0.42	-1.25	1.75	-1.17	0.03	-0.99	0.51	0.34	-	
Qu_9	-0.75	-0.27	-0.46	-1.06	1.03	1.22	0.14	0.77	-1.55	-1.18	0.23	-0.05	0.42	-0.07	0.72	-0.63	0.52	0.12	-0.51	-

- ***Modification Indices***

Modification indices show the fixed relationships between two variables on the latent variable model. They are computed for the model's parameters measuring how much χ^2 is expected to decrease if this particular parameter is set free (i.e. relaxed) and the model is re-estimated (Jreskog and Srbom, 1996). Relaxing the parameters with large modification indices (i.e. above or equal 4.0), by establishing a path between the observed indictor and the construct, is the best way of increasing the model fit. Setting this path leads to a decrease in the value of χ^2 by the amount of the parameter's modification index. Nevertheless, relaxing the parameters has to be cautiously done since it has to make sense from the theoretical point of view.

For the modification indices in Table 4-10, seven variables parameters recorded values of more than 4.0. By testing lean distribution conceptual theory, it was obvious that relaxing 'Cust_1' to 'Workforce & Planning', 'Rep_4' to 'Customer' and 'Flow_1' to 'Replenishment' fits the logic of lean distribution rather than other parameters. For 'Cust_1' (i.e. Clear customer service agreements are issued) positively influences the planning process for the internal and external distribution functions. Applying this practice helps to plan for suppliers delivery, transportation activity as well as capacity planning for labours and equipments. 'Rep_4' (i.e. Take steps to simplify the distribution network in order to decrease shipments lead time and cost) will result a significant improvement for customer service level being reducing the total orders cycle time and cost. Finally, applying 'Flow_1' practice (i.e. the quality of the transportation activity is frequently reviewed, aiming to increase its efficiency) is crucial for adopting the pull replenishment strategy. Having relied on actual customer demand to trigger the replenishment process, an efficient and flexible transportation channels are necessary to reduce the orders lead time and avoid stock-out situations.

Table 4-10 Modification indices of lean distribution practices.

Items	Quality	Customer	Replenishment	Workforce& planning	Transportation
Cust_1	1.68	-	0.51	**7.10**	2.13
Cust_2	2.54	-	0.54	0.18	**6.10**
Cust_4	0.01	-	0.04	1.73	0.01
Rep_2	2.06	1.57	-	0.00	0.61
Rep_4	3.98	**6.75**	3.81	0.01	-
Rep_5	0.31	0.04	-	2.70	0.00
Rep_7	0.24	3.01	-	1.01	**4.05**
Buff_5	0.03	**7.45**	-	1.21	2.41
Flow_1	0.59	0.09	**6.36**	0.01	-
Flow_2	1.10	0.10	1.62	0.08	-
Staf_1	-	0.35	2.00	1.22	2.82
Staf_2	0.31	1.70	1.02	-	0.10
Staf_5	2.03	0.19	0.00	-	0.44
Staf_7	0.15	3.09	0.02	-	0.29
Qu_1	-	0.75	0.51	2.03	3.76
Qu_3	1.45	0.00	1.22	-	0.14
Qu_5	0.48	0.28	0.25	-	0.00
Qu_7	-	0.60	0.85	**6.29**	0.45
Qu_8	-	1.43	0.01	1.76	1.56
Qu_9	-	0.07	0.12	0.47	3.06

Model Fit

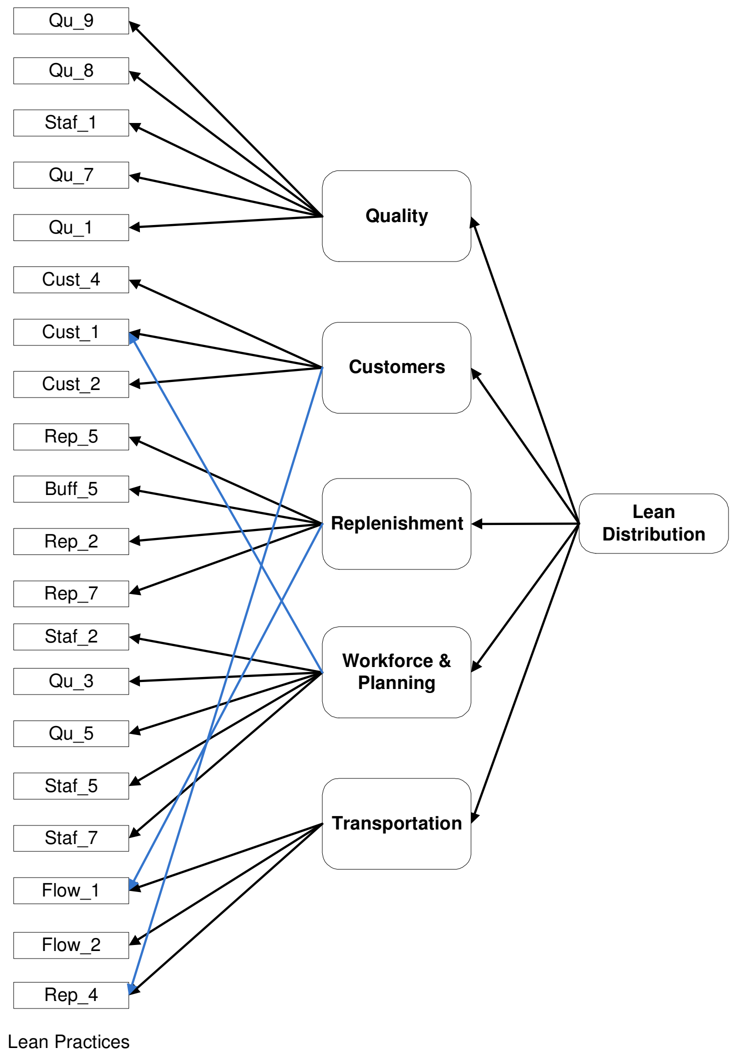
χ^2 = *221.20, df = 165, P-value = 0.00229 and RMSEA = 0.076*

Relaxing the three parameters 'Cust_1', 'Rep_4' and 'Flow_1' have been conducted in three iterations – one for each parameter – and the enhancement trend of the model fit was monitored for each iteration as illustrated in Table 4-11. By the end of third iteration, an obvious improvement was achieved for the values of χ^2, P-Value and RMSEA compared with Table 4-10 indicating a more robust fit of lean distribution measurement model to the observed data.

Table 4-11 The iterations of model fit improving.

Iterations			χ^2	*df*	**P-Value**	**RMSEA**
Cust_1	→	Workforce	214.54	164	0.0049	0.072
Rep_4	→	Customer	207.34	163	0.01075	0.068
Flow_1	→	Replenishment	198.78	162	0.0260	0.06

Hence, it can be concluded that the fitting and unidimensionality assessment of the lean distribution measurement model was performed through three different techniques; standard residuals assessment, Q-plot and modification index. All employed techniques and indices were recorded proper values indicating strong fit and unidimensional scale for the lean distribution measurement model. Figure 4.5 illustrates the final model of lean distribution. After developing the measurement model, a structural model is adopted to assess the relationship between the lean distribution (i.e. latent variable) and its identified constructs.



Chi-Square = 198.87 *df* = 162 *P*-Value = 0.026 RMSEA = 0.062

Figure 4-5 Lean Distribution measurement model.

4.4.1.3 Lean Distribution Structure Model

After accepting lean distribution measurement model, a second order factor analysis model was evaluated and interpreted. Five constructs Quality, Customer. Replenishment, Workforce & Planning and Transportation are counted as exogenous ζ (i.e. independent) variables, whereas Lean Distribution has identified as an endogenous η (i.e. dependent) variable. The path diagram in Figure 4-6 shows the relationships between the exogenous and endogenous variables with their standardised solution (SS) and *t*-values. With significant SS and *t*-values for all exogenous variables, strong relationships between lean distribution and its constructs were concluded. 'Quality' recorded the strongest relationship to the lean distribution endogenous variable with higher SS value = 0.8 and *t*-value = 4.19, followed by Customers, Transportation, Workforce and Planning and finally the Replenishment. With χ^2 = 198.78, P-value = 0.026) and RMSEA = 0.062, the structure model showed an excellent fit to the observed data.

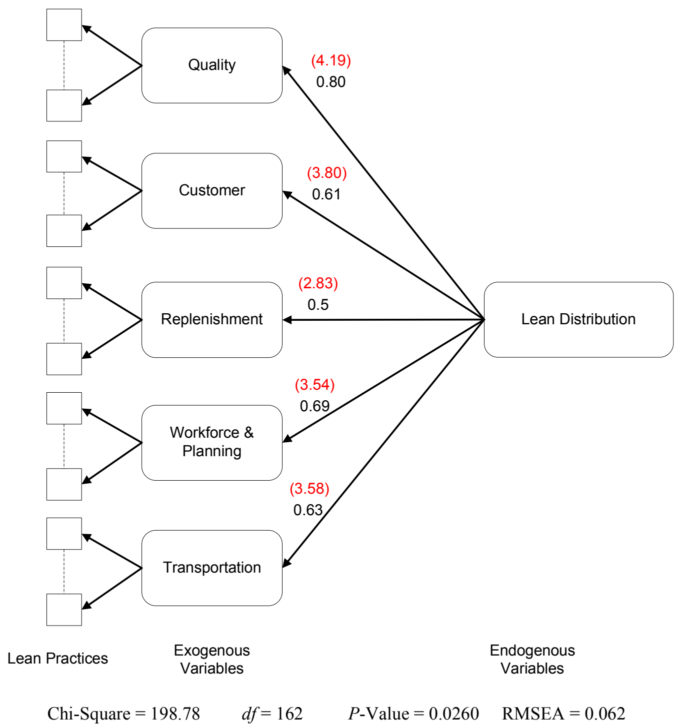


Figure 4-6 Path diagram of Lean Distribution.

The findings of this analysis have highlighted many interesting issues of the relation between lean distribution concept and its correspondent factors. The results reflect the importance of the Quality practices (i.e. corrective actions, processes standardisation, continuous improvement and performance measurement) for lean distribution paradigm. Enhancing processes quality is one of the common characteristics of lean paradigm regardless the application domain; manufacturing or distribution. The main focus of lean is to improve operations reliability in order to reduce waste and non-value added activities. Establishing robust communication channels with customers and determining clear customer service agreements are also significant requirement for lean distribution environment. This is emphasised as Customer construct records the second significant factor in the lean distribution model. to achieve a high customer service level, it is necessary to support the link between customer demand and other supply chain sources (i.e. suppliers and manufacturers) in order to efficiently meet customer requirements. With faster replenishment process, inventories can be reduced and responses to change in demand are improved. Fast replenishment can be achieved by employing effective transportation strategy in order to deliver outstanding service while maintaining low inventory and cost. Simplifying distribution networks and utilising flexible transportation means are necessary for decreasing the transportation time and cost (i.e. main waste elements).

Motivating people by involving them in setting firm's strategic objectives and creating problem solving procedures as well as continuous improvement initiatives are necessary elements in the lean distribution context. The significant influence of the workforce on the entire system performance is one of the unique characteristics of lean distribution. The majority of lean manufacturing practices, for instance, focus more on improving the operations efficiency and processes reliability and provide lower attention to the human factor.

Finally, it was concluded that a successful implementation of lean distribution can only be obtained by means of a proper balance between the different lean distribution dimensions and practices. This chapter addressed the key dimensions and practices that construct the lean distribution measurement and structure model based on various and rigorous statistical validation techniques as illustrated in Table 4-12. Given an appreciation of the five significant dimensions (i.e. Quality, Customer, Transportation, Workforce Management and Replenishment), the likelihood of the success in lean distribution implementation is vastly increased.

Table 4-12 Final lean distribution constructs and practices.

Lean Construct	Lean Practices	Description
Quality	Qu_1	Standard operating procedures are provided to the company's operators, aiming to standardise operations steps
	Qu_7	Quality verification and inspection procedures are created for each distribution function
	Qu_8	Develop corrective action procedures in order to rectify quality problems
	Qu_9	Clear goals and key performance indicators (KPIs) are identified
	Staf_1	Sort-out, organises and visually represents the equipments and tools that are needed in the workplace to maximise workers utilisation
Customer	Cust_1	Clear customer service agreements are issued containing (e.g. service lead time, buffer strategy, replenishment strategy)
	Cust_2	Comprehensive identification of customer needs and expectations is done.
	Cust_4	Customer feedbacks are used to enhance operations performance
Replenishment	Rep_2	Access to actual customer consumption and uses it as a trigger to the replenishment process
	Rep_5	Line balancing approach is used to reduce bottleneck in product flow
	Rep_7	Customer demands are levelled to reduce variability and enhance the planning process
	Buff_5	Products buffer between the internal operations (i.e. Work in Process) are minimised
Transportation	Flow_1	The quality of the transportation activity is frequently reviewed, aiming to increase the efficiency
	Flow_2	Select freight companies that offer flexible capacities for the shipment process
	Rep_4	Take steps to simplify its distribution network in order to decrease shipments lead time and cost
Workforce & Planning	Qu_3	Apply statistical process control procedures (e.g. six sigma) to insure the reliability of the distribution operations
	Qu_5	Develop continuous improvement plans to sustain and improve distribution performance
	Staf_2	Employs layout design solutions in order to minimise the internal travel distance and time for both products and workers
	Staf_5	Managers, supervisors and employees are involved in determining facility goals and their achievement feasibility
	Staf_7	Employees participate, initiate and lead problem-solving activities autonomously

Chapter 5: LEAN ASSESSMENT PHASE

5.1 Introduction

'Leanness' has been defined from different perspectives in the literature, however the majority of authors agreed that it measures whether the company is lean or not and also assesses how lean the system is. When compared with the extant literature the questions of 'how to become leaner' and the measurement of 'how lean the system is' have received less attention (Bhasin and Burcher, 2006, Soriano-Meier and Forrester, 2002). As illustrated in Figure 5-1, three main steps are followed to accomplish the lean assessment phase in the lean distribution framework include:

1. **Identifying Lean Distribution Metrics**: that represent all underlying dimensions of lean distribution and their performance.
2. **Developing tactical Leanness Index:** to evaluate the non-operational lean practices and create a tactical leanness index.
3. **Developing operational Leanness Index:** evaluate the lean practices associated with distribution operations and calculate operational leanness index.

5.2 Leanness Distribution Metrics

Distribution literature has reported different performance metrics that objectively evaluated and compared the distribution companies' performance. The metrics were changed according to the scope of the study, level of decisions and the utilised improvement practices. Some of them are used to gauge the performance of the entire firm from a strategic vision while others only focus on the operational distribution performance. Many quantitative metrics were also employed to measure the distribution leanness including inventory turnover, the ratio of total inventory to sales, operations cycle efficiency and an index of time reduction.

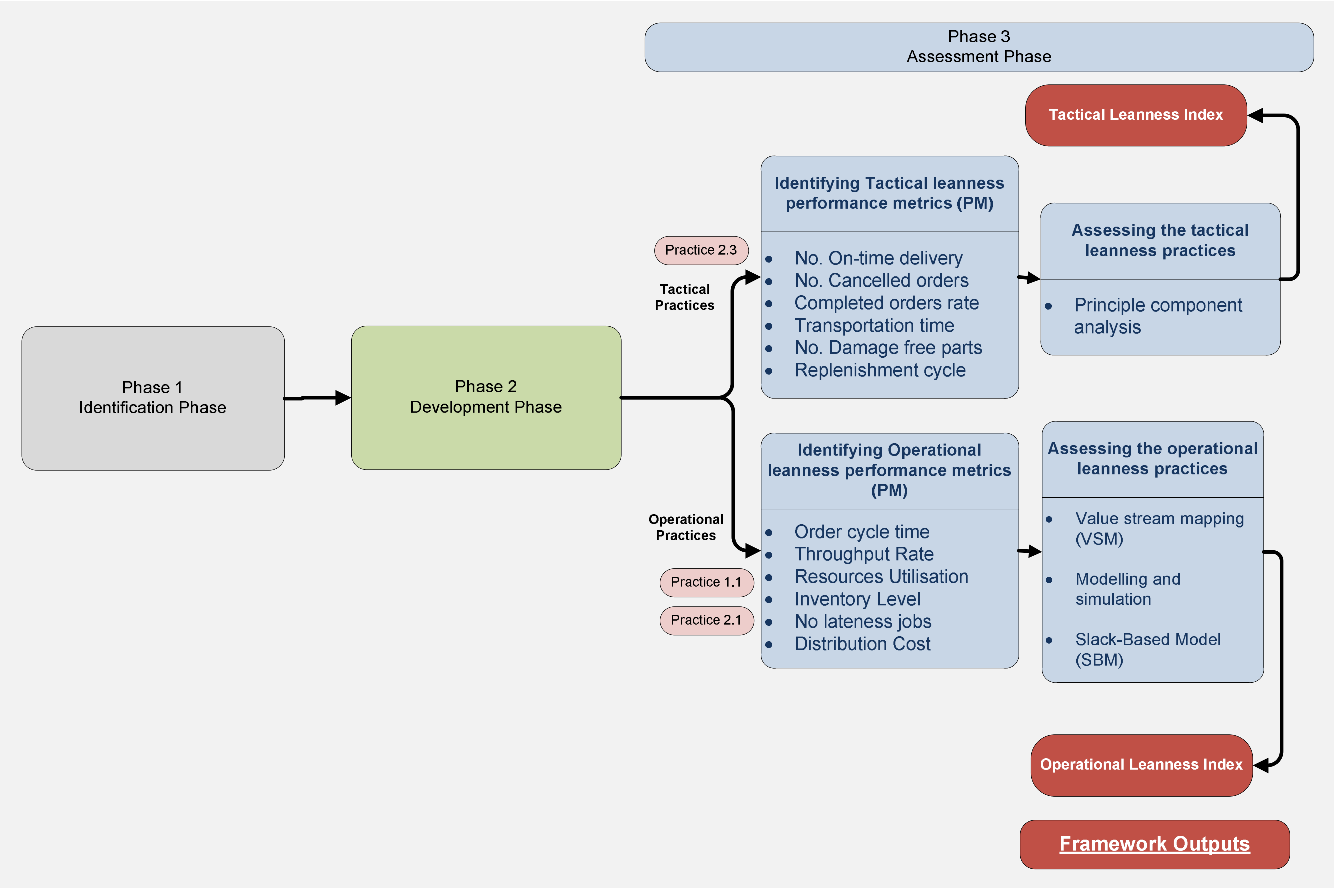


Figure 5-1 Assessment phase in Lean Distribution framework.

Since lean distribution is a multidimensional philosophy, a single or specific group of metrics will contribute partially in measuring the leanness level. Based on the conducted literature review and several meetings with distribution and supply chain academics, a standard set of lean distribution performance metrics was developed as presented in Table 5-1. They were then validated through different meetings with the distribution managers who confirmed their validity and importance for the lean assessment process. As shown in Table 5.1, the metrics are divided into two key categories – tactical and operational – based on the lean practices category.

Table 5-1 Lean Distribution metrics (Source: Author).

Practice Category	Lean Distribution Factors	Practices	Practices Description	Performance Metrics
Tactical Practices	**Workforce & Planning**	Staf_5	Managers, supervisors and employees are involved in determining facility goals and their achievement feasibility	1- Number of on-time delivery orders 2- Number of-cancelled orders 3- Percentage of completed orders. 4- Transportation Time 5- No. of damage free items 6- Replenishment Cycle Time
		Qu_5	Develop continuous improvement plans to sustain and improve distribution performance	
		Staf_7	Employees participate, initiate and lead problem-solving activities autonomously	
	Item Replenishment	Rep_2	Get an access to actual customer consumption and uses it as a trigger to the replenishment process	
	Customers	Cust_1	Clear customer service agreements are issued containing (e.g. service lead time, buffer strategy, replenishment strategy)	
		Cust_2	Comprehensive identification of customer needs and expectations is done.	
		Cust_4	Customer feedbacks are used to enhance operations performance.	
	Quality	Qu8	Develop corrective action procedures in order to rectify quality problems	
	Transportation	Flow_1	The quality of the transportation activity is frequently reviewed, aiming to increase the efficiency	
		Flow_2	Select freight companies that offer flexible capacities for the shipment process	
		Rep_4	Take steps to simplify its distribution network in order to decrease shipments lead time and cost	
Operational Practices	**Workforce Management**	Staf_2	Employs layout design solutions in order to minimise the internal travel distance and time for both products and workers.	1-Total order cycle time 2- Throughput rate 3- Resource utilisation (labours, Equipments) 4-Inventory level 5- No. of lateness jobs 6- Distribution cost
		Qu_3	Apply statistical process control procedures (e.g. six sigma) to insure the reliability of the distribution operations	
	Item Replenishment	Rep_5	Line balancing approach is used to reduce bottleneck in product flow	
		Rep_7	Customer demands are levelled to reduce variability and enhance the planning process	
		Buff_5	Products buffer between the internal operations (i.e. Work in Process) are minimised	
	Quality	Qu_1	Standard operating procedures are provided to the company's operators, aiming to standardise operations steps	
		Qu_9	Clear goals and key performance indicators (KPIs) are identified	
		Staf_1	Sort-out, organises and visually represents the equipments and tools that are needed in the workplace to maximise workers utilisation	
		Qu_7	Quality verification and inspection procedures are created for each distribution function.	

The lean distribution practices were correlated to different distribution levels (i.e. external integration, internal performance, distribution network and distribution operations) based on their functions and scope of improvement. They were divided into two main categories – tactical and operational practices – where the tactical practices were associated mainly to the non-operational levels (i.e. external integration, internal performance and distribution network) with a primary focus on improving the performance of some tactical activities such as customer-supplier relationships, distribution network structure, and transportation efficiency. Operational practices on the other hand, employ improvement efforts to the distribution operations aiming to create reliable and efficient distribution operations (e.g. inbound or outbound). The operational metrics contained:

- Orders cycle time: measure the elapsed time between the arrival of customer orders and its delivery – lower is leaner.
- Orders throughput rate: an indicator for the order's average rate of flow through distribution process steps over a given time period – higher is leaner.
- Resources utilisation (i.e. labours and equipments): measure the efficiency of using the distribution resources – higher is leaner.
- Inventory level: assess the number of Stock keeping units (SKUs) stored in the warehouse – lower is leaner.
- Distribution cost: encompasses of inventory holding cost, ordering cost and stock-out cost to measure the cost-effectiveness of the studied distribution system – lower is leaner.
- Number of lateness jobs: to measure the efficiency of distribution operations based on customer view – lower is leaner.

On the other hand, the tactical performance metrics gauge the performance of the lean practices corresponded to the tactical lean distribution dimensions such as customer, transportation, workforce management and quality. number of on-time delivery orders, number of damage free items, percentage of orders that are delivered with a complete quantities and the number of cancelled orders which were used to assess 'Customer' practices (i.e. cust1, cust4 and cust5). Replenishment cycle time and transportation lead time were employed for the 'Transportation' and 'Item Replenishment' practices (i.e. flow1, rep2 and rep4). The six metrics can also be used to assess the 'Workforce Management' and 'Quality' dimensions given that their practices are related to the continuous improvement, problem solving, corrective action and leadership issues which have direct impacts on the defined metrics.

While the operational metrics can be calculated numerically using simulation or mathematical models, tactical matrices cannot due to the subjectivity nature of its practices. Therefore, it is required to develop different lean assessment models depend on the specific natures of the lean practices. The next section represent the tactical lean assessment model while the section after will highlight the operational model.

5.3 Tactical Lean-Assessment Model

An indicator metric can be modelled for any set of variables, and calculated to present the current state of an operation's leanness (Ray *et al.*, 2006). Based on this hypothesis and using the principle component method, a leanness index will be developed based on the identified tactical performance metrics in order to assess the tactical distribution leanness level.

5.3.1.1 Model Development

Principle component method starts with deriving common factors by merging a number of independent variables into a smaller number of principle components. Identifying these factors allow the correlations between them and the dependent variable to be determined and analysed *via* correlation analysis. To ensure the significance of each variable it has to have a loading (i.e. correlation coefficient) greater than 0.40 with at least one of the identified leanness factors (i.e. general rule of thumb). Following that, a regression model is developed to identify the factor score (i.e. weight) of each independent variable relative to the selected leanness factors. Finally, the coefficient of each independent variable with its most correlated leanness factor form the final "factor score" which makes up the "lean index". Figure 5-2 shows an illustrative figure for the steps of the principle component analysis.

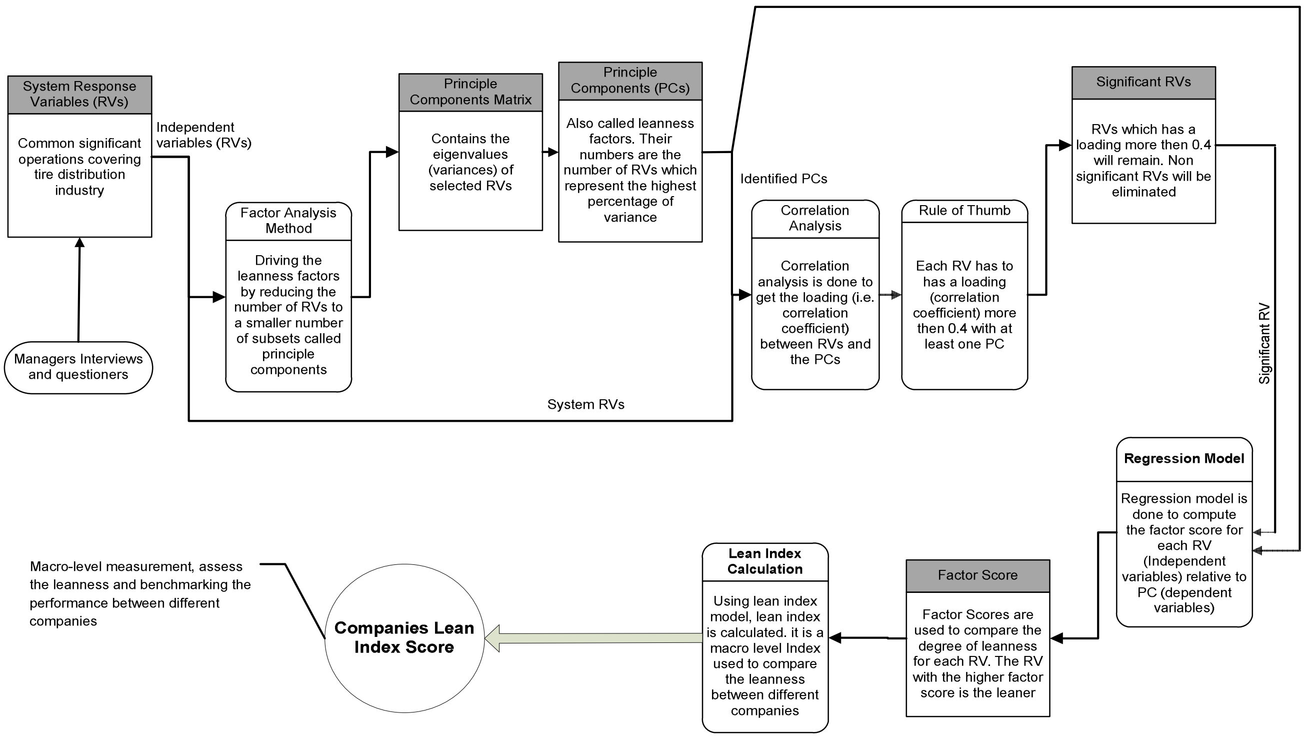


Figure 5-2 The factor analysis method for Lean Distribution assessment (Source: Author).

Quantitative data sets for the leanness metrics were collected from five companies in Ireland and UK. To get a wider picture of the distribution systems, the five selected companies had different warehouse sizes, throughput rates and annual sales volumes. Various meetings and group discussion were held with warehouse and operation managers to insure the primary selection of the tactical performance metrics and to investigate which techniques they used to monitor the values of these metrics. All managers confirmed that the selected performance metrics are used to control their company's tactical performance. By the end of this phase, these metrics were accepted as the standard independent variables on which the proposed lean index model could be based.

A dataset of one year for metrics values was collected with a specific aim of quantifying companies' leanness level. This was a straightforward process in most companies, as all required data were held on the company's operational databases and ERP systems, and it was continuously verified *via* many meetings and phone discussions with company's managers. Due to the diverse of the metrics measurement units, see Table 5.2, data standardisation was required to eliminate the data bias before the application of principle components analyses. Data standardisation is a statistical approach that changes all data to an equal range in order to ensure consistency and comparability of the data and to minimize the analysis variation.

Table 5-2 The independent variables of principle component method.

Variable	Replenishment Cycle time	No. of on-time delivery orders	No of cancelled orders	% of delivered orders in complete quantities	No of damage free items	Transportation lead time
Measure Unit	Hours	Quantity/Month	Quantity/Month	Percentage	Quantity/Month	Hours

The standardized variables are divided by the sample's standard deviation. More statistical manipulations have to be introduced to obtain meaningful results from disparate data sets, involving three steps:

- A common unit of measure representing selected variables should be derived;
- All model variables are transformed to a function of a selected common variable in order to minimize potential data bias;
- Transformed variable data is normalised for the purpose of comparison.

Labour hours were chosen as a common variable for all distribution practices and operations, regardless of their size. All variables could therefore be standardized in order to make equivalent comparison and to avoid statistical bias, Table 5-3.

Table 5-3 Standardisation formulas.

Operation	**Standardisation Formula**
Replenishment cycle time	Replenishment cycle time ÷ Total monthly labour hours
No. of On-time delivery orders	No of on-time delivery orders ÷ Total monthly labour hours
No. of Damage free items	No of damage free parts ÷ Total monthly labour hours
No. of cancelled orders	No of cancelled orders ÷ Total monthly labour hours
Percentage of completed orders	Percentage of completed orders ÷ Total monthly labour hours
Transportation lead time	Transportation lead time ÷ Total monthly labour hours

After variable conversion, they were again transformed to a standard score so that data from different operational processes, with different orders of magnitude, could be normalized and thus compared on an equivalent basis, as proposed by several authors (Spasth, 1980, Dubes and Jain, 1980). Standard scores (i.e. Z score) for each variable are computed using the formula:

$$Z = \frac{x - \mu}{\sigma} \qquad (5.1)$$

where Z is Standardized Independent Variable, x is Original Data Value, μ is Sample Mean and σ is Standard Deviation. The normalized data sets for the five companies (i.e. Z value) and six variables were then statistically examined to determine the best model for the Lean Index.

5.3.1.2 Principle Component Analysis

Factor Analysis was basically used to reduce the number of the original independent variables (i.e. tactical leanness metrics) into smaller groups of principle components (i.e. Factors), and insignificant factors – where variances were too small – are then removed before further modelling steps. The Component Matrix in Table 5-4 shows that 2-factor model accounted for 73.8 % of total data variance.

Table 5-4 Variances of the 6 independent variables data set.

Factors	Initial Eigen value			Extraction Sums of Squared Loadings		
	Variance	% of Variance	Cumulative	Total	% of Variance	Cumulative
1	2.941	49.018	49.018	2.941	49.018	49.018
2	1.492	24.86	73.878	1.492	24.86	73.878
3	0.943	15.709	89.586			
4	0.369	6.148	95.735			
5	0.16	2.662	98.397			
6	0.096	1.603	100			
Total	8					

Extraction Method: Principal Component Analysis

In order to examine the importance of the independent variables, correlation analysis was applied in conjunction with a 'rule of thumb' which stipulates that any variable loading less than 0.4 on all factors should be eliminated, Table 5-5. Given that all loadings are more than 0.4 with at least one of the two selected factors, all leanness metrics are considered significant and are therefore retained for the next step in the analysis. To obtain reasonable definitions for the leanness factors, the leanness metrics are grouped according to their loadings. Once the two factors have been defined, regression model is developed to find the factor scores of the six independent variables as presented in Table 5-6.

Table 5-5 Correlation coefficient of the independent variables with selected factors.

Component Matrix		
Independent Variables	Principle Component (i.e. Factors)	
	1	2
Replenishment cycle time	0.436	0.36
No. of On-time delivery orders		0.874
No. of damage free items	0.933	
No. of cancelled orders	0.671	0.685
Percentage of completed orders	0.843	
Transportation lead time	0.837	-0.350

The regression model is used to create weights or scores for each metric relative to the leanness factor scores being defined. The selection of variable's factor score in Table 5-6 is related to its correlation coefficient as represented in Table 5-5. The coefficients of 'on-time delivery orders' and 'cancelled orders' are highly correlated to the second factor in Table 5-5, with values 0.874 and 0.671 respectively. So the factor scores of the two metrics are obtained from the second factor in Table 5-6. The same procedure is applied for the 'replenishment orders cycle time', 'number of damage free items', 'percentage of completed orders' and 'orders lead time' metrics which are highly correlated with the first factor in Table 5.6.

Table 5-6 Linear regression results of factor scoring.

Component Score Coefficient Matrix		
Independent Variables	Principle Component (i.e. Factors)	
	Factor 1	Factor 2
Replenishment cycle time	-0.192	0.158
No. of On-time delivery orders	0.185	0.552
No of damage free items	0.323	-0.25
No of cancelled orders	0.114	-0.498
Percentage of completed orders	0.244	-0.216
Transportation lead time	-0.332	-0.149

Using Equation (5.2), a leanness index score can be calculated by multiplying the leanness factor scores by the normalised values of the studied leanness metrics.

$$\begin{aligned}\text{Lean Index} = & -0.192 * \text{Replenishment cycle time} \\ & + 0.552 * \text{Number of on-time delivery orders} \\ & + 0.323 * \text{Number of damage free items} \\ & - 0.498 * \text{Number of cancelled orders} \\ & + 0.244 * \text{Percentage of completed orders} \\ & - 0.332 * \text{Transportation lead time}\end{aligned} \tag{5.2}$$

The signs and variable coefficients are reasonable and interesting. Since the interpretation of the lean index is "the higher the more leaner", then increasing the number of on-time delivery orders, damage free items and percentage of completed orders contribute positively in companies' leanness level. On the other hand, the large number of cancelled orders and the long replenishment cycle time detract from the leanness values. Having the largest positive and negative coefficients in lean index equation, increasing the on-time deliveries and decreasing the cancelled orders were counted as the most important objectives that companies should focus on in its lean journey. This reflects the importance of customer satisfaction issue in the lean distribution context. Increasing the number of damage free items and the percentage of completed orders have also important weights indicating that continuous improvement initiatives and problem solving procedures – associated to quality dimension – play key roles in improving the whole leanness score.

Although some practices may contribute in enhancing a particular lean metric, the relationships between lean practices and performance metrics are not mutually exclusive as all practices are complementary correlating to improve the overall leanness level. For instance, despite that the practices related to the 'quality' and 'workforce management' basically contribute in enhancing 'number of damage free items' and 'percentage of completed orders' metrics, they also have a critical role in decreasing the number of cancelled orders and the cycle time of replenishment orders. The correlations between lean practices emphasise the multi-dimensional nature of the lean distribution paradigm.

5.3.1.3 Measuring Companies Leanness Level

According to Ray *et al.* (2006), another data manipulation equation (i.e. Final Leanness Index (FLI)), Equation 5.3, was developed to improve the generated leanness score in equation 5.2 by providing a clear and comparable scale. The critical limitation of this equation as Ray stated was the lack of a proper validation processes for its mathematical terms due to the limitations in the data set in his study. Personal contact with Ray in 2010 suggested use three values in FLI equation: 1, 1.5 and 2.5. Hence, a Monte-Carlo simulation model was developed in this research based on 100 data sets in order to validate the FLI equation. Figure 5-3 shows the simulation experiments indicating that FLI equation provides a reasonable scale, compared to the small scale values yielded by the first formula and the very large scale resulting from the third.

$$FLI = \exp\,(1.5 + \text{Lean Index}) \qquad (5.3)$$

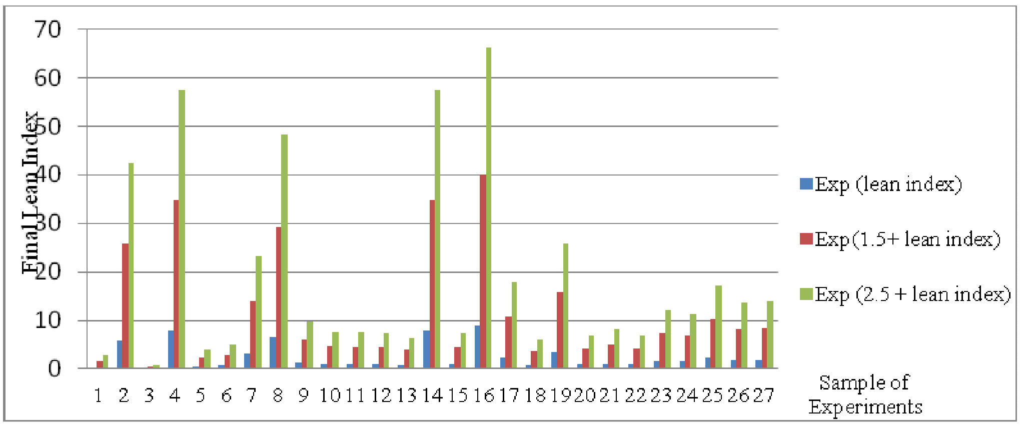


Figure 5-3 Validation chart for final lean index equation.

After validating the FLI equation, it was used to establish a comparison between the five studied distribution companies – whose names were set to companies A,B,C,D and E – and ranked them based on their leanness level. The results showed that the leanest company is E with an overall lean index score 12.66 the next companies are C, B and D with a lean index of 7.18, 4.11 and 2.77 respectively, while the poorest leanness performer is company A, with a LI = 1.75. Figure 5-4 shows the rank of the companies based on their leanness level.

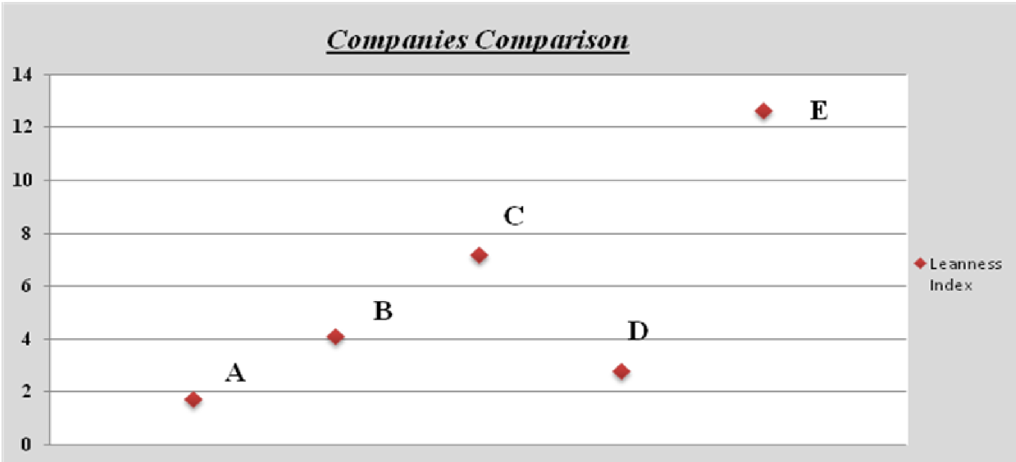


Figure 5-4 Comparison between the companies based on their leanness level.

A combination of good metric values contributed to achieve the high leanness score for company 'E' including the high values of 'On-time delivery orders', 'Damage free items' and the small numbers of 'Cancelled orders'. These positive indications are resulted due to the robust and long term relationship that the company has with its customers as well as the efficiency of its ordering process. However, the company still has room for improvement especially for the supplying process since the company records high value for the 'Transportation lead time'. This is explained due to the complex structure of its distribution network and the distance from its suppliers.

Recording the lowest leanness index, company 'A' is a small distribution company with a low distribution volume and high fluctuation in customer orders in terms of product types, quantities and delivery locations. The absence of an advanced information system that can effectively manage the information flow in the company has negatively impacted on the value of 'Replenishment cycle time'. The company also requires more efficient and reliable customer service policies to be applied in a manner which improve its customer service level and reduce the customers demand variations.

In the case of company 'C', since the company has standard agreements in place with its suppliers and issuing replenishment orders in frequent basis, a small value for 'Replenishment cycle time' was achieved. In addition, a large value for the 'Damage-free items' was recorded due to the high quality of the delivery process that the suppliers provide to the company. The company has its own delivery fleet which facilitates the delivery process and increases the value of the 'On-time delivery orders'.

Different improvement steps are required to enhance the leanness score of company's B and D. Although the small values of 'Replenishment cycle time' and the high values of 'Damage-free items' in company B, a high number of 'Cancelled orders' is observed. This is due to the imposed restrictions on supplying specific items to the company. Because the company is a distributor for a big brand name in tire industry, the supplying process is controlled by restrict logistics policies that sometimes contradict with company's needs. Company B needs to deal with alternative suppliers to avoid these restrictions and achieve high customer service level.

In company D, the long negotiations and the far distance of some suppliers cause long 'Replenishment cycle time' and 'Transportation lead time' respectively. An increasing in the number of cancelled and delayed orders are also experienced as a result of the absence of an advanced orders management system (e.g. ERP).

5.3.2 The Limitation of the Tactical Lean Assessment Model

The basic limitation of the developed model is that it cannot forecast the effects of the proposed lean practices on the system performance prior to their actual implementation (i.e. leanness future state). It also results a static leanness score due to its relying on static metrics – recording the performance at a point in time or over a period of time – that do not accurately represent the dynamics and variations in the system. Due to its powerful prediction capabilities, a neural network could be integrated with the developed model to help in creating a leanness future state for the distribution systems. Modelling and simulation can also be used to model the system's dynamics and variation towards creating an accurate leanness index that support decision making process in the distribution industry.

5.4 Operational Lean-Assessment Models

Upon the calculation of the tactical leanness scores, operational lean assessment model is proposed to help in calculating an operational leanness index and exploring the improvement opportunities in distribution operational level. As illustrated in Figure 5-5, the model encompasses of three main techniques; VSM, modelling and simulation and the SBM model (i.e. VS2 model). The detailed structure of the VS2 model and the characteristics of its components were elaborated in Chapter 3.

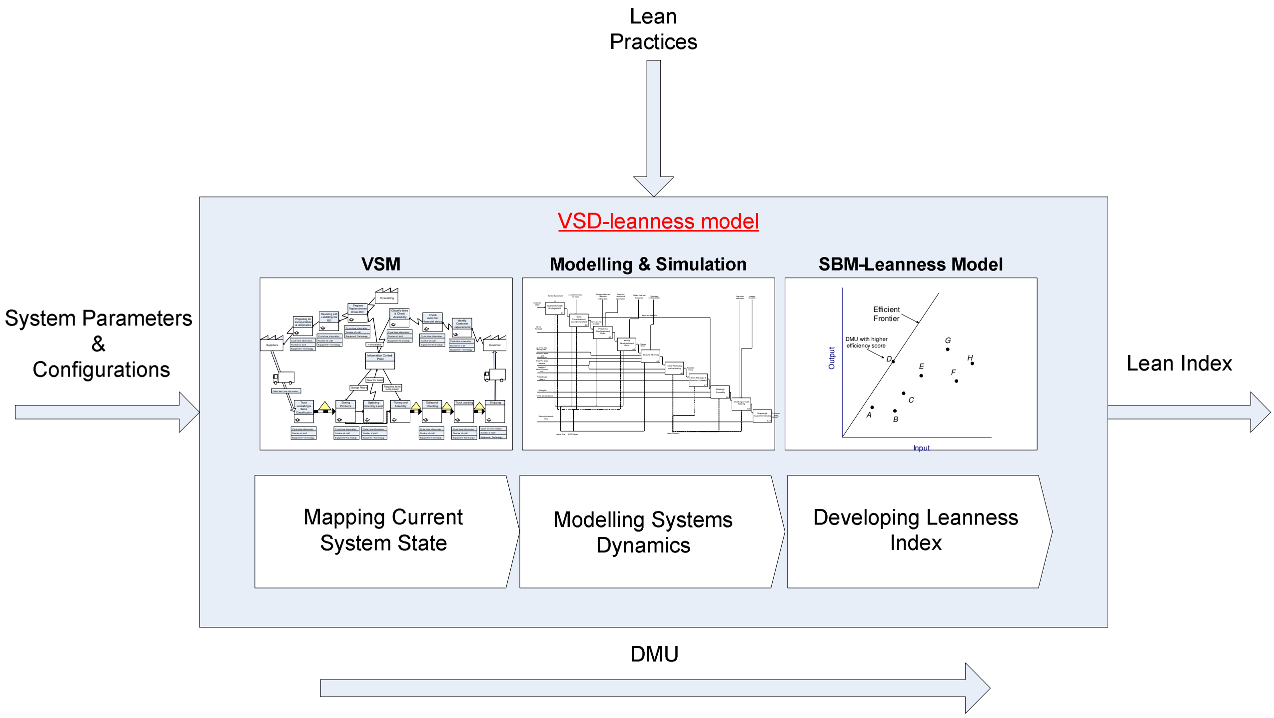


Figure 5-5 The structure of VS2-lean assessment model (Source: Author).

5.4.1 VS2 Model Structure

VSM, one of the commonly used lean tools, is originally based on lean philosophy and emphasises streamlining systems value streams (e.g. production lines, logistics cycles and others). It was used in the VS2 model to visually display the current state of the studied companies by modelling their flow of activities together with time-based performance. Modelling company's value stream and highlighting their operations and waiting times help to distinguish the value-added and non-value added portions of the distribution activities and identify the wastes visually and systematically.

A Simulation modelling approach was used in the proposed VS2 model as a complementary tool for the VSM. It models system's uncertainty and creates a dynamic view of the distribution operational parameters such as inventory level, operations times, lead times and resource utilisation. It also quantifies the gains of the lean practices on the system's current state and enables decision makers to accurately estimate the expected performance of the leanness future state as well as system's waste and slacks (i.e. output shortfall or input excesses)

Slack-Based Measure of efficiency, the third technique in VS2 model, was proposed by Tone (2001) as a DEA model that directly deals with the system's parameters slacks. Using the distance (i.e. slack) between the Decision Making Unit (DMU) and its benchmark (i.e. leanness frontier), SBM creates an efficiency score that is unit invariant between 0 and 1 and monotone decreasing to the increasing of variables slacks. Matching the lean philosophy, decreasing variable's slacks – namely waste in the lean terminologies – contributes in increasing the efficiency score which is equivalent to the leanness score in the lean assessment process.

5.4.1.1 Developing Leanness Index using SBM Model

SBM model calculates the efficiency score ρ (i.e. leanness score) through a fractional program using the input/output variables' slacks as follows:

$$(SBM) \qquad \min \quad \rho = \frac{1 - \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{io}}{1 + \frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{ro}} \tag{5.4}$$

$$\text{Subject to} \qquad x_0 = X\lambda + s^- \tag{5.5}$$

$$y_0 = Y\lambda - s^+ \tag{5.6}$$

Where $\lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0$

ρ: Efficiency score (i.e. leanness score)
x_0: Input variable of DMU_0
y_0: Output Variable of DMU_0
m and s: Number of input/output variables
λ: Weight for DMUs
s^- and s^+: Slacks associated with inputs/outputs variables

Ideally a lean distribution system runs without any sources of waste or non-value added activities (i.e. ideal system configurations). Using the ideal case as a benchmark, the leanness level of a distribution system under the current or leanness state can be measured. In the VS2 model, the distribution system under the current state (i.e. before applying any lean practices) is defined as Actual DMU (ADMU), while the ideal system state (i.e. no waste or non-value added activities) is labelled IDMU (i.e. ideal DMU). When one or more lean practices are adopted the system state is changed from ADMU (i.e. current state) to LDMU (i.e. leanness state).

To evaluate the leanness level of different system states, input/output variables of each DMU need to be defined, see Figure 5-6. The input variables are quantitative representation of the resources and efforts required to operate the distribution systems. Time, resources, storage space and operations cost are good representations for the required elements to commence distribution activities and hence used as input variables. On the other hand, the outcomes of the distribution operations including customer satisfaction, operations efficiency, resources and space utilisations are counted as the major output variables. In order to quantify the output values and make them comparable, a simulation model is used to derive the output values under different system states and input values.

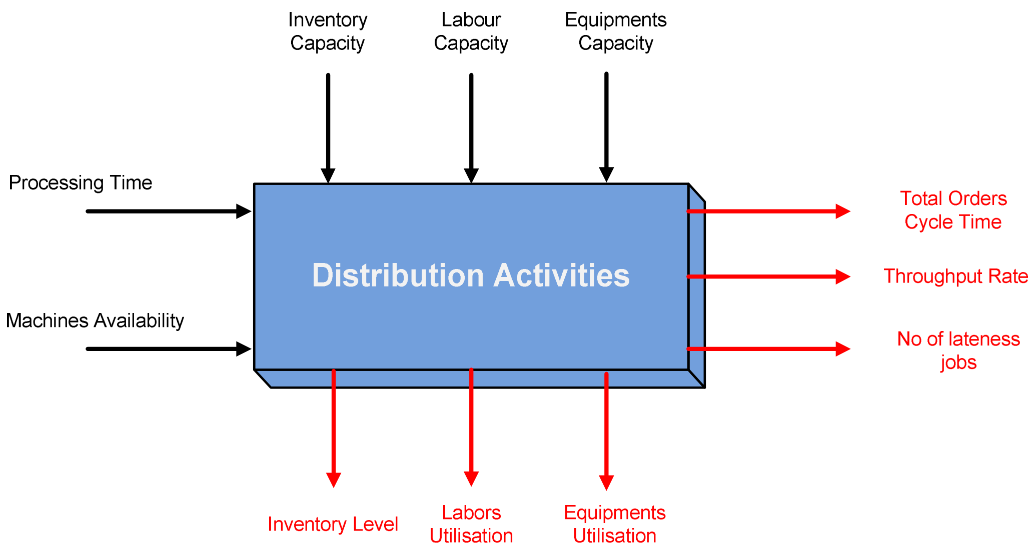


Figure 5-6 The input/output variables of distribution system (Source: Author).

The system current state (i.e. ADMU) faces various sources of waste and non-value added activities (i.e. inefficiencies). In order to create an ideal system state (i.e. IDMU) with 100% leanness, only the value added portions of the input variables has to be used – slacks equal zero. In the distribution environments, some wastes can be easily identified (e.g. waiting time, WIP levels, Inventory levels and labours underutilisation), while others could not be recognised such as the wastes result from systems variation (e.g. customer demand variation, suppliers delivery variation and others).

To increase the IDMU leanness level to the maximum and push the leanness frontier further, system's variation and uncertainties have to be considered and continuous update on system state have to be applied when distribution technology or management skills improve. Therefore, it was necessary to integrate a simulation modelling approach with the SBM-leanness model to provide dynamic representation for system's parameters and outcomes.

Because of various techniques are involved in the VS2-model with a number of correlation links, sequential steps are represented to guide its implementation process.

Deeper understanding of VS2 model characteristics and its component as well as their relationships is gained by following these implementation steps.

5.4.2 Steps in Measuring Leanness using VS2-Lean Assessment Model

Step1: Determine study scope. In distribution systems the scope could be focused on the internal distribution operations only, the external relationships with customers and suppliers, the ordering process or the whole system starting from receiving customer orders and ending with item delivery. The accurate identification of the study scope allows efficient implementation of the lean assessment process.

Step 2: Mapping system's current state using VSM. System parameters, operations, activities and buffer areas have to be highlighted in the selected scope of the value stream. The map should also illustrate the system time performance as well as the logical flow of the items and information.

Step3: Data collection and analysis. Each technique in VS2-model requires a specific kind of data. For example, the value stream mapping needs detailed information about system structure, processing time, resources capacities, waste and non-value added activities. The simulation model on the other hand requires historical data for specific system parameters (e.g. customer orders frequency, items quantity, operation time and equipment breakdown intervals) to model the stochastic nature of the studied system.

Step4: Develop simulation models for ADMU and IDMU. The model will mimic the system's configuration under the current and ideal state for the ADMU and IDMU respectively. To ensure model validity and reliability, comprehensive validation and verification process is held with the participation of system managers.

Step 5: Identify the value-added and non-value added portions in the input variables. Based on the customer defined value and managers' experience, the value added and non-value added portions for each input variable is distinguished. While the current input variables will be used in the ADMU simulation model, only the value-added input variables are used for the IDMU simulation model.

Step 6: Calculate ADMU's output values. By running the ADMU simulation model under the current input variables.

Step 7: Calculate IDMU's output values. By running the IDMU simulation model under the value-added input variables.

Step 8: Calculate the leanness level of ADMU based on the IDMU. The SBM model is applied to calculate the leanness level of the ADMU based on the leanness benchmark (i.e. IDMU) using SBM fractional model, equations (3.4).

Step 9: Evaluate the proposed lean practices (i.e. LDMU). By creating a new simulation model for LDMU mimics the new system's configuration and input variables under the proposed lean practices, the output values of LDMU can be calculated. SBM model can then be adopted to calculate the leanness level of LDMU based on the leanness benchmark (i.e. IDMU).

The nine steps are illustrated in Figure 5-7 and applied on two distribution companies to increase the understanding level of VS2 model structure and illustrate its capability in quantifying leanness level.

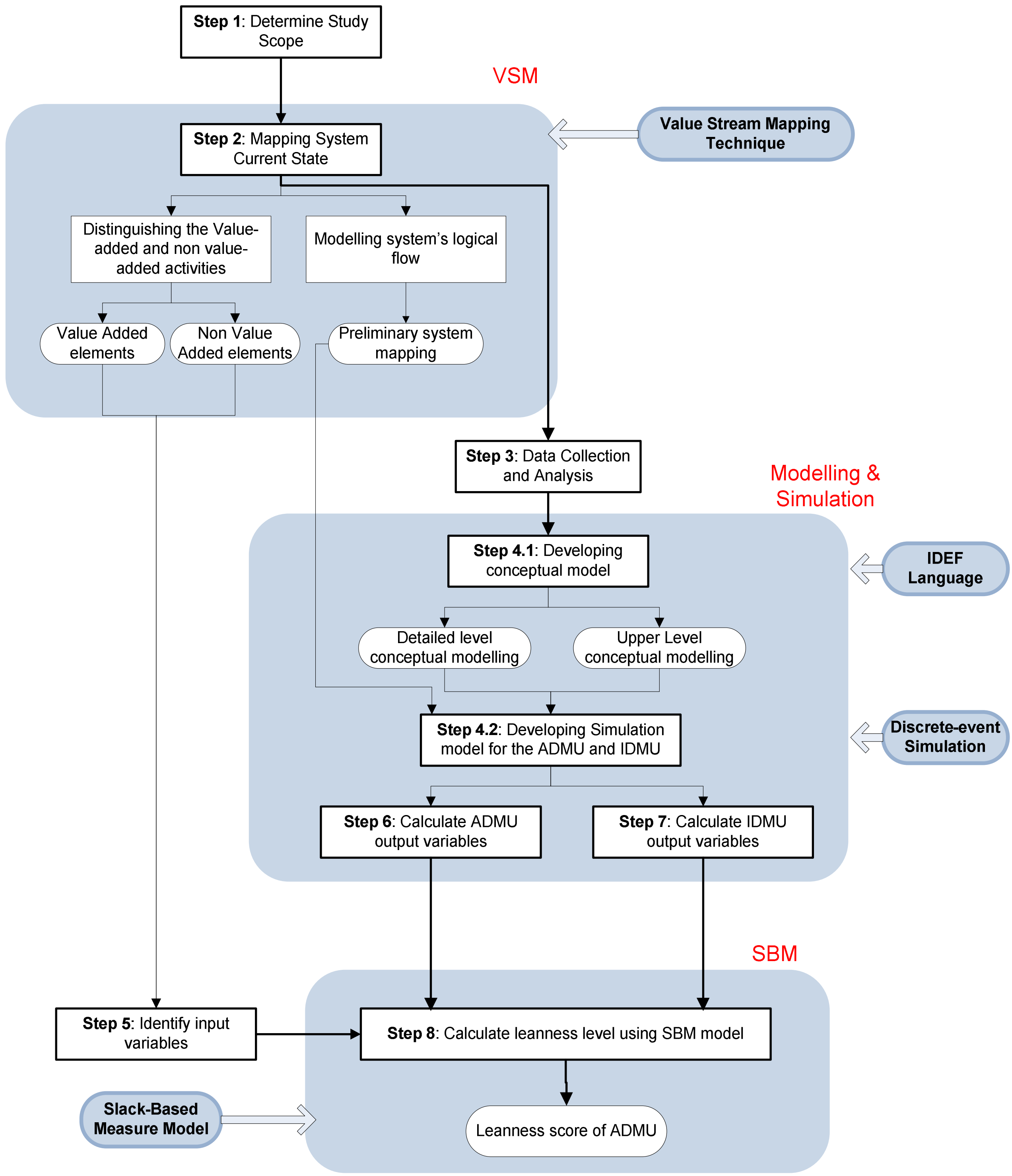


Figure 5-7 VS2 Lean assessment model steps (Source: Author).

5.5 Case Studies

In the tactical lean assessment stage, five distribution companies (A, B, C, D and E) were compared and ranked based on their tactical leanness level. The generated leanness indices helped to explore and priorities the improvement opportunities for each company on its tactical level. To extend the benefits of the lean assessment process to the distribution operational level, the VS2 model was adopted for two distribution companies – Companies B and D.

Companies B and D represented two different distribution sectors: Tyres and Plumbing & Heating items respectively. An overview on both companies along with their special market conditions, characteristics and features are illustrated in the following sections. Based on the challenges facing the two companies, various lean initiatives are proposed and examined by applying the VS2 lean assessment model. Finally, comparisons of the companies' current and leanness future state are held to calculate their operational leanness level.

5.6 Case Study 1 – Tyre Distribution Industry (Company B)

Tyre manufacturing is one of the ten most important industries in the world that service a number of distinct markets such as automotive, aerospace, agriculture and bicycle (Hur *et al.*, 2004). The variety of markets creates a high demand on several categories of tires which vary in size and type (e.g. racing tyres demand more engineering technology than consumer tyres). Tyre supply and manufacturing is a much easier processes than many other automotive components as it needs a relatively small number of commodity raw materials (natural and synthetic rubbers and other chemicals). Nevertheless, its distribution network is considered complex as a direct result of globalisation. Many foreign distribution centres have been established to support increasing tyre export activities. Transportation strategies have all been revised in order to provide short transport time with a minimum of incurred cost.

The effective management of the internal distribution operations is a critical requirement for the tire distribution industry to respond to the challenges of item flow and productivity. In addition, the focus should also turn to decreasing tyre prices and offering good sales discounts and promotions by eliminating the waste and non-value added operations as a key to achieve a minimum of operating cost.

5.6.1 An Overview of Company B

Company B is a distribution centre for one of the biggest brand names in the tyre market. It supplies tyres for a wide variety of customers ranging from large scale companies to individual buyers. The diversity in customer types causes a wide variation in the customer demand regarding to tyre quantities and types. To maintain customer loyalty, the company aims to respond speedily to customer's demand in an accurate manner with the least possible cost.

The company faces two challenges in the ordering and inbound/outbound activities, in particular, storage and picking operations. Monthly forecasting plans are generated based on extensive analysis of the market conditions, competitors' positions, future customer contracts and SKU consumption rates. Applying such a process for more than 200 different SKUs requires considerable time and effort. Forecasting inaccuracy hold another critical challenge for the company's operations. In order to cope with these challenges, the company has decided to increase the lot sizes of its replenishment orders and regularly schedules them in long intervals. Although this policy has prevented stock-out situations and reduced item unavailability rates, it has resulted in considerable long order cycle time as well as high inventory costs.

Pull replenishment – one of the key lean distribution practices – is suggested to overcome the forecast challenges since it relies on the actual customer demand to derive the replenishment process. It showed dramatic benefits to improve customer service whereas at the same time maintain low inventories and cost. For the pull replenishment approach to work, a robust relationship with company's suppliers should be established to mitigate the risk of item stock-out and reduce lead time of items.

The long processing time of the storing and picking operations is another challenge the company faces. This challenge was emerged due to the special characteristics of the tyre storage racks, the absence of items tracking technology and the inefficient storage policy that is currently applied (i.e. random storage). Since tyres require special kinds of storage racks due to their size and shape, special storing and picking instructions are needed that cause longer processing time. Moreover, the applied storage policy – random storage – contributes in increasing the challenge since pickers often visit several storage locations to pick one type of tyres. Locating the similar tyre types close together and applying advanced tracking system linked with ERP are suggested to increase the efficiency of storing and picking operations. According to the company's manager, it is expected that the storing and picking times are reduced by 20% by applying these practices.

Several interviews with company's planning and operational managers were held to identify the implications of the suggested practices on system parameters, logical flow and input variables. Table 5.7 summarises the two challenges facing Company B and the proposed lean initiatives to resolve them.

Table 5-7 Operations challenges facing Company B.

Challenges	Lean Initiative	Initiative Type
• High inventory level due to the large replenishment lot sizes. • Long orders waiting time as a result of long intervals between replenishment orders	Decreasing the reliance on the orders forecasting policy and applying pull replenishment strategy instead.	Replenishment order
• Long operations time for storing and picking operations.	Storing the similar SKUs near together and applying advanced tracking systems	Distribution operation

5.6.2 VS2-Lean Assessment Model (Company B)

- ***Determine Study Scope***

Various processes are involved in the value stream of the company such as marketing, sales, finance, orders management, inbound, outbound and shipment processes. In addition, different supply chain partners are engaged in company's activities and significantly impact on its performance including customers, suppliers, government bodies and competitors. The operational lean assessment process has included three different processes; order management, inbound and outbound operations. Pull replenishment approach was proposed for improving the order management process, while a new storage policy (i.e. class-based storage) was suggested to improve the storing and picking operations performance. The financial dimension was out of the scope of the study due to the confidentiality that the company imposed on its financial data.

- ***Mapping system's current state using VSM***

The company receives the customer orders through two key sources either by its sales team or online purchasing. Ordered items are then identified and checked for availability. For the available SKUs, a picking document is directly passed to the warehouse facility triggering the outbound operations (i.e. picking, assembly, checking, loading and delivery), while the unavailable SKUs are directed to the replenishment process to form a full truck load replenishment order. As illustrated in Figure 5-8, only a short time is needed to process customer orders – the upper path – thanks to the ERP system which facilitates the orders' information flow and reduces the probability of the transaction errors.

Inbound planning operation is commenced prior to the arrival of suppliers' trucks. It aims to determine the storage places for the incoming items, printing the labels and storing documents. The unloading process is triggered once the suppliers' trucks arrive where one handling equipment unit and three staff are assigned for each truck. After that, one staff member with a handling equipment unit is then assigned to store the unloaded tyres (i.e. put away). This process followed by updating the inventory level and storage location records in the applied ERP system. Although the efficiency that the ERP provided in customer orders processing, it caused inefficient performance for the warehouse operations due to its sophistication and inconsistency with the data of the real system parameters, in particular warehouse storage locations.

The long processing time for the storing and picking operations, 300 and 275 minutes/order respectively (Figure 5-8), emphasises the need for applying improvement initiatives in both areas. Value stream mapping has also provided a value for the actual processing time against the value added (VA) processing time. Actual processing time was calculated by adding the value stream operations and waiting times from the point of order to delivery, while VA processing time is calculated by excluding the waiting times and 20% of the company's operations times – representing other operations wastes according to company B's manager. Both values are employed in the lean assessment model as will be shown in the next sections.

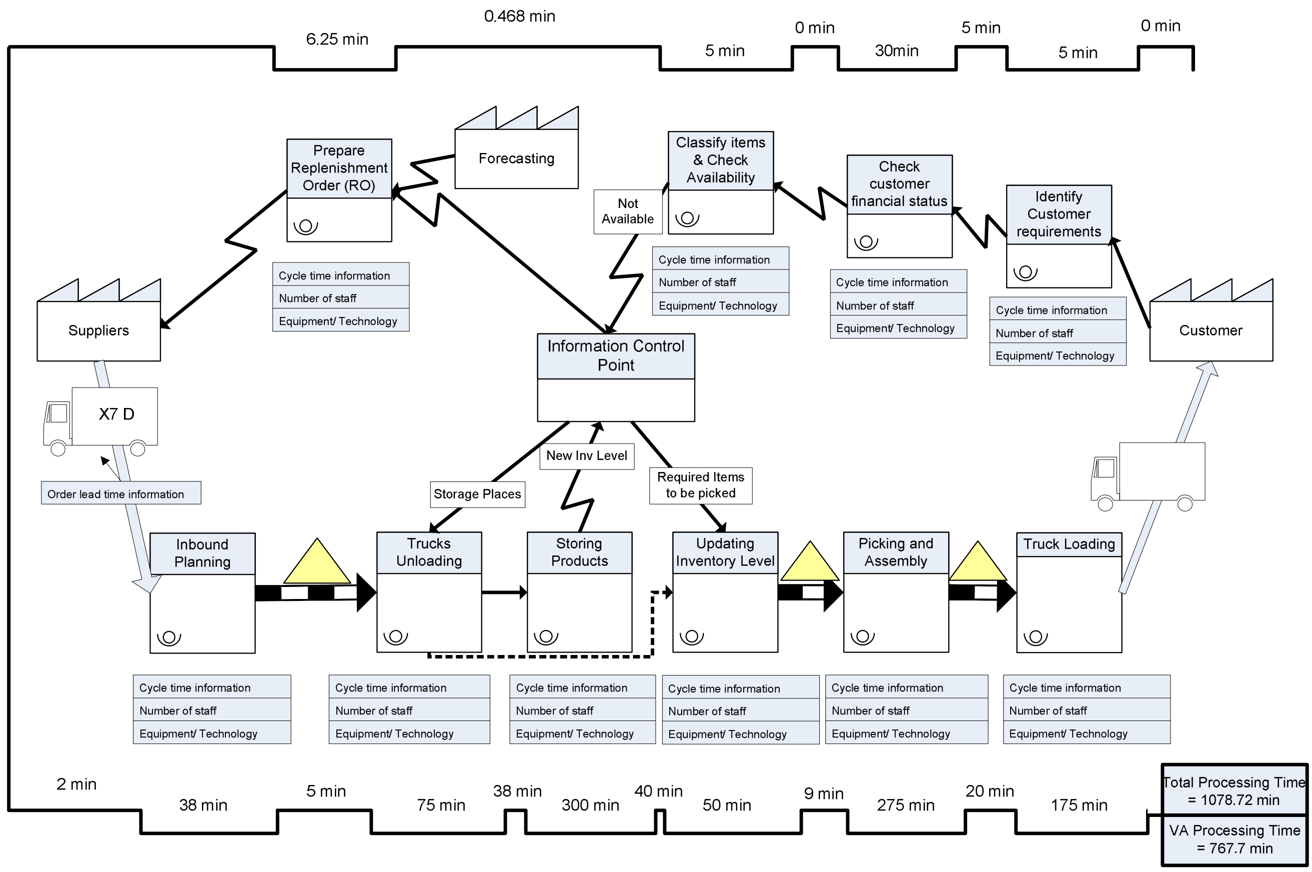


Figure 5-8 Value stream mapping for Company B.

- ***Data collection and analysis***

Time, resources and space are clearly the required input variables to commence any distribution operation. In company B, the three variables are translated into five input variables including (1) processing times, (2) machine availability, (3) available inventory space (i.e. inventory capacity), (4) labour capacity and (5) equipment capacity. VSM is used to calculate company's processing time (Figure 5-8) recording 2.24 days. A high rate of equipment availability is essential to achieve a high efficient distribution operation. 100% availability could not be achieved in real world due to the frequent equipment breakdowns and maintenance activities, however maximising equipment availability rate is always a target for the operational and maintenance managers. In the studied company, the current availability rate is estimated as 70%, based on the maintenance records. It was explained due to the absence of regular equipment maintenance plans which increased the rate of breakdowns occurrence.

Inventory capacity, the third input variable, has a significant impact on the performance of item flow, order cycle time and distribution costs. Small inventory on-hand facilitates flow of items within the warehouse and reduces the inventory holding cost. However, it increases the dependency on suppliers delivery which often increases order cycle time and transportation cost. The total inventory capacity of company B is 60,000 tyres with an approximate capacity of 300 tyres for each type – all tyre types use the same storage space. Finally, the company uses 13 staff, excluding top managerial staff and 6 handling equipment units with different sizes. These estimations resulted from several interviews with planning and operational managers and a number of site visits. All input variables and their values are shown in Table 5-8.

Table 5-8 Input variables of company B and their estimated values.

Input Variables	**Measurement Units**	**Actual Values**
Processing Time	Days/order	2.24
Machine Availability	Percentage	70%
Inventory Capacity	SKUs	300
Labour Capacity	Number	13
Equipment Capacity	Number	6

- ***Develop Simulation model for ADMU and IDMU***

Being the first step in developing a simulation model, a detailed conceptual model is developed which highlights the main functions and decision points involved in company's distribution process (Mahfouz *et al.*, 2010, Arisha *et al.*, 2004). Given its ability for modelling the complex systems and its hierarchical nature that provides a comprehensive understanding for system's details, IDEF language is selected to conceptually model the ADMU and IDMU.

Each function in company B was modelled in two different levels of details. The upper level, using IDEF0 language, showed the sequence of the main functions as well as their inputs, outputs, controls and mechanisms (i.e. utilised resources). Figure 5-9 shows the IDEF0 model for company B which contains nine key functions, six types of controls and three kinds of resources; labours, handling equipment units and ERP. Each function is then broken down into-smaller sub functions illustrating the detailed objects flow and the decision points, using IDEF3. The put-away function (i.e. storing function) is used as an example to show the IDEF3 capabilities in exploring function's details and showing operations logical flow, as seen in Figure 5-10.

Based on the IDEF models, a Discrete-event simulation models was then developed for the actual and ideal state of company B. While the actual simulation model (i.e. ADMU model) was based on the current system parameters and configurations, the ideal simulation model (i.e. IDMU model) used the ideal system state and the add-value portions of system's variables. Some model assumptions were made such as (i) no supplier disruptions are considered (ii) all received items from suppliers are accepted (no return for item damage or wrong quantities). Simulation software based on Java and XML technology was used to build the proposed model providing object-oriented hierarchical and event-driven simulation capabilities (Mahfouz and Arisha, 2010). It also uses breakthrough activity-based modelling paradigms (e.g. real world activities such as assembly, batching, and branching) for modelling the large-scale applications.

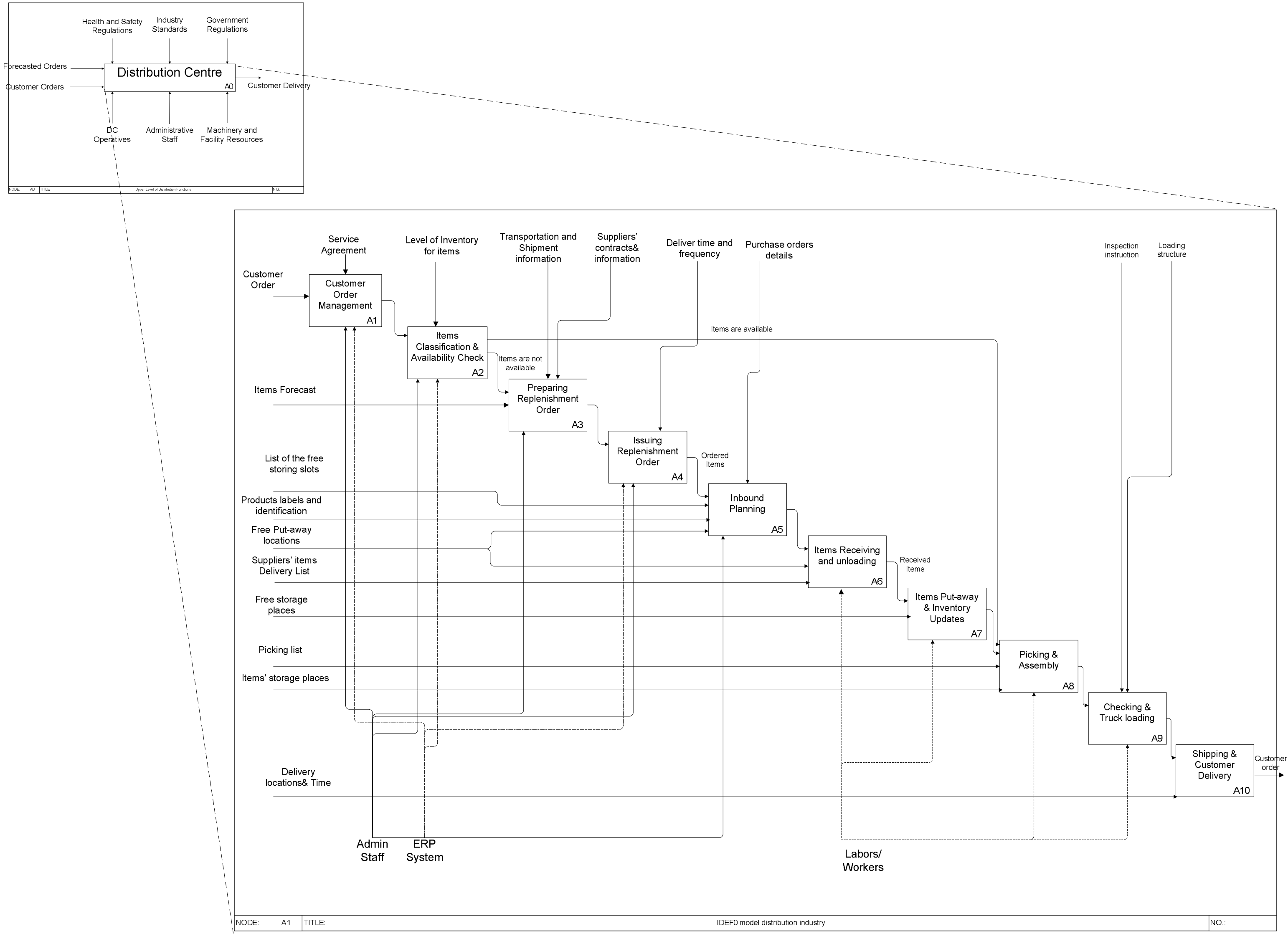


Figure 5-9 A sample of higher level conceptual model for company B.

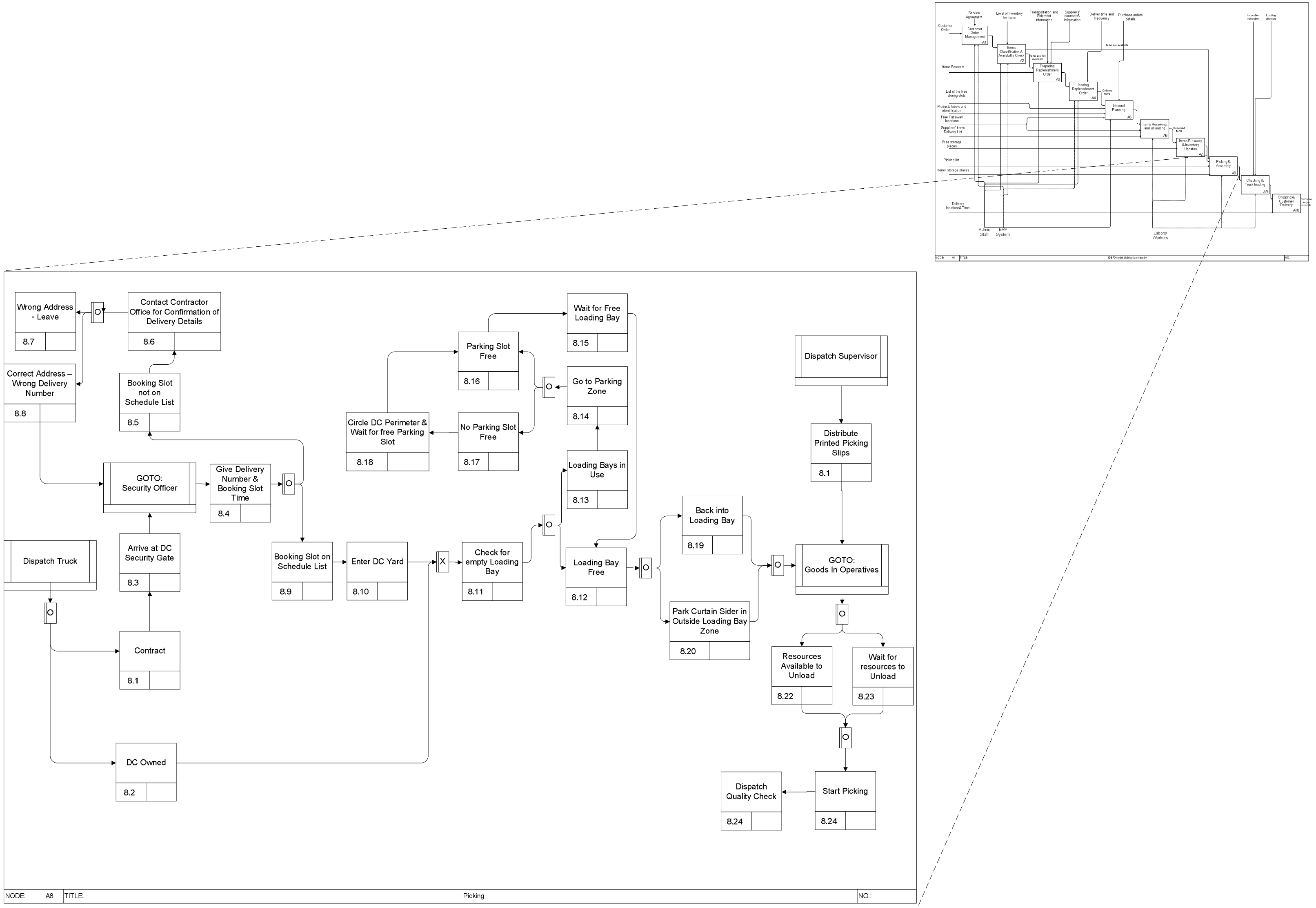


Figure 5-10 A sample of lower layer conceptual model for Company B.

Resources were characterised by their availability and breakdown frequency, whereas the product enteritis were attributed by arrival time, processing time, and products characteristics (e.g. processing routing and products type). Logical entities make decisions for creating, joining, splitting, buffering, and branching product entities. 150 blocks in a hierarchical form representing; queues, activities, and branching points have encompassed the simulation model. Figure 5-11 outlines the logical structure of the simulation models and illustrates the inputs and output entities as well as the relationships between them.

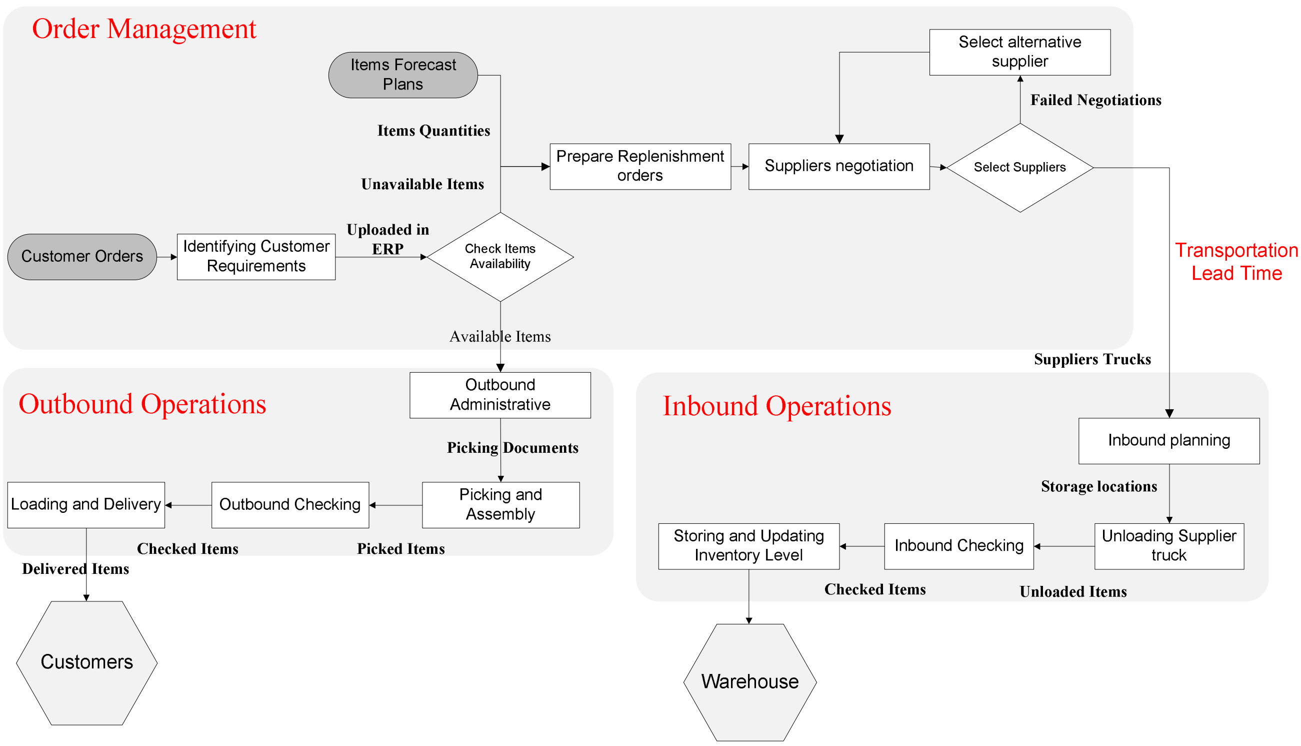


Figure 5-11 Flow chart for the simulation blocks and their relationships (Source: Author).

In order to represent the stochastic nature of the system's parameters such as customer orders arrival time, number of SKUs in an order, handling equipment unit breakdown rate and repair time, a theoretical statistical distribution was employed. The analysis of customer orders arrival rate resulted in exponential distribution with a mean of 8 orders a day based on sales historical records. Service time was proportional to the required SKUs quantities and followed a normal distribution. Suppliers lead times were constant based on supplier's locations and conditions of delivery. Finally, the frequency of equipment maintenance plans was also taken into consideration as well as the rates of breakdown and repair time. A snapshot of the ADMU simulation model is illustrated in Figure 5-12.

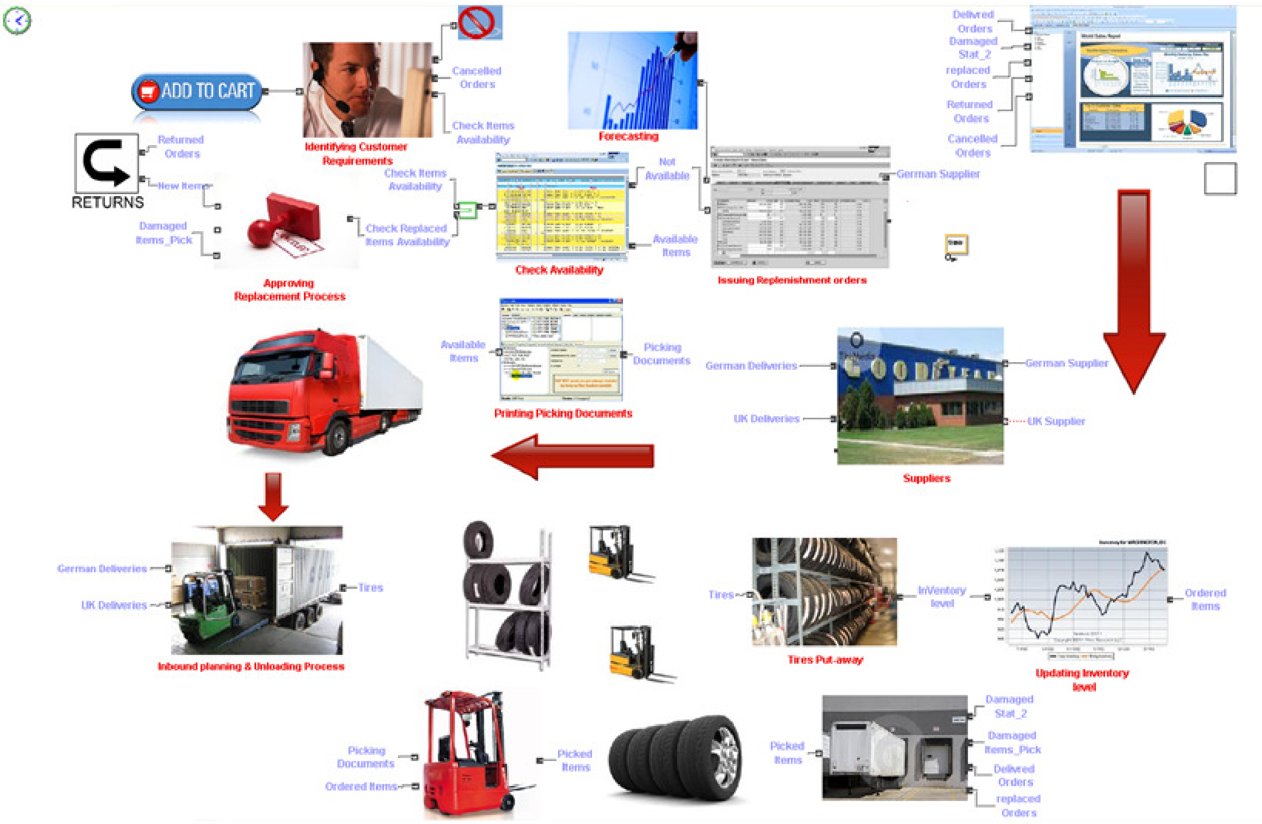


Figure 5-12 A snapshot for company B's simulation model.

In an effort to create an accurate representation for company B, various verification and validation methods were employed. For the verification phase, the decomposition method (i.e. verify every group of blocks) was used to ensure that every block functions as expected. A built-in simulation debugger was also used to avoid any coding bugs. Out of ten validation methods that had been stated in Rabe (2009), three validation methods have been applied on the simulation models; (1) data collection phase, (2) conceptual modelling phase and finally (3) simulation results phase.

The validation process of the data collection phase was as follows; (1) no measurement errors in data collection process, (2) generated data have to match the pattern of historical data and (3) set attribute values within specified range. To achieve that, a detailed examination of data documentation quality and consistency was done with the cooperation of company B staff. After that, the conceptual model was validated based on interviews with company's managers to ensure that all specified processes, structures, system elements, inputs and outputs are considered correctly. The modelling team also examined the accuracy and consistency of the conceptual model to the problem definition. Finally, "Face validation" approach was used to validate the final simulation results.

- ***Identify value added and non-value added input values***

As aforementioned in section 5.4.1, DMUs represent the system state either under the current state, leanness state or under any of the proposed lean practices. In contrast of ADMU, IDMU was performed only under the value-added portions of the input values representing the ideal system state. In Figure 5-13 an example of two-distribution operations with four buffer areas is illustrated to differentiate the value-added and non-value added portions of distribution activities.

Several group meetings and brainstorming sessions were held with the company's distribution planners and operations managers to identify the percentage of waste and non-value added portions of the current input variables as presented in Table 5-9. The value stream mapping in Figure 5-8 was used to calculate the ideal processing time – representing around 70% of the total processing time. The equipment availability rate was set by 100% in the ideal state, while the labours and equipment capacities are advised to be decreased by 60% and 70% respectively. Despite the fact that zero inventory level is the standard practice in lean philosophy, it was stated that it will be unrealistic to run the distribution model with zero inventory level. Instead, the company's managers have suggested that 50 SKUs can be used as the minimum capacity that the company can apply in its warehouse.

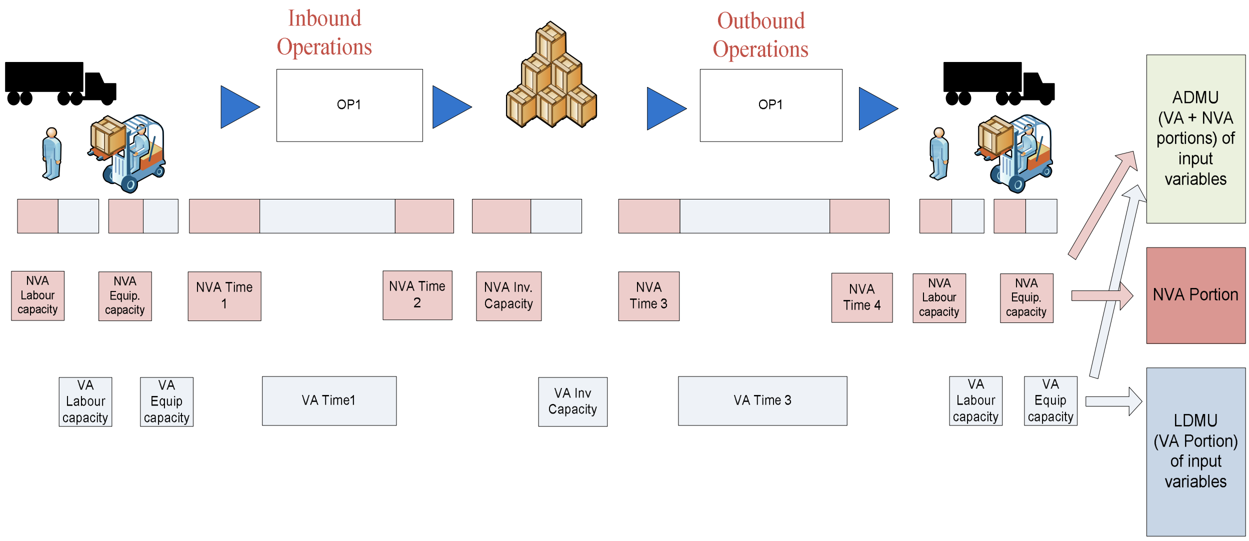


Figure 5-13 Input variables analyses for creating ADMU and IDMUU (Source: Author).

Table 5-9 Actual and leanness values of the identified input variables.

Input Variables	Measurement Units	Actual Values	Leanness values	Percentage of non-value added
Processing Time	Days/order	2.24	1.5	33%
Machine Availability	Percentage	70%	1	30%
Inventory Capacity	SKUs	300	50	83%
Labour Capacity	Number	13	5	61%
Equipment Capacity	Number	6	2	70%

After identifying the input variables of both system states (i.e. ADMU and IDMU), it became necessary to identify their output variables to accomplish the assessment process. Since operational performance metrics (Table 5.1) are described as appropriate representatives of the operational leanness level, they are used to represent the output variables for company B. The distribution cost metric was excluded in this case as the financial dimension is out of the study scope.

- ***Calculate ADMU's output variables***

By running the ADMU simulation model under the actual input values, showed in the third column in Table 5.9, ADMU's output values are resulted in Table 5.10. Ten simulation runs were replicated to mitigate against the stochastic influence of the model.

Table 5-10 The actual input/output values of ADMU.

Types of DMU	Actual Input Variables	Actual Output variables
ADMU	Processing Time = 2.24 Days/order Machine Availability = 0.7 Inventory Capacity = 300 SKU/Tyre Type Labour Capacity = 13 labours Equipment Capacity = 6 Labours	Total Order Cycle Time = 30 days Throughput Rate = 2.46 orders/day Labour Utilisation = 30% Equipment Utilisation = 40% No of lateness jobs = 301 Orders Total Inventory Level = 13304Tyre

The results of the ADMU simulation models showed an overall poor performance of the studied metrics due some problems facing the company including the supplying restrictions on some items, the long processing time of the storing and picking operations, the frequent breakdown of the handling equipment units and the large capacity of resources especially in the low demand periods. Items supplying restriction is the most critical challenge given its direct impact on customer satisfaction and items availability. Operationally, the long storing and picking operations times negatively influenced order cycle time, the number of late jobs and the throughput rate. Equipment utilisation is affected by the frequent breakdowns and the lack of maintenance plans while the large inventory level is rising due the reliance on item forecasting and long replenishment frequent.

- ***Calculate IDMU's Output Variables***

In this stage, the leanness frontier is calculated using the IDMU simulation model using the ideal input values in Table 5.9. All wastes and non-value added activities are removed from the simulation model and the input values. Large differences in order cycle time, resources utilisation, number of lateness jobs and total inventory level were noted compared to the ADMU output values, Table 5-11. The Throughput rate was also increased in IDMU indicating the smooth flow of tyres within the ideal distribution facility. This indicated the urgent need for adopting various improvement initiatives on the current system state to reduce the big inefficiency gap with the benchmark.

Table 5-11 Input/output values of IDMU.

Types of DMU	Ideal Input Variables	Ideal Output variables
IDMU	Processing Time = 1.5 day/order Machine Availability = 1 Inventory Capacity = 50 SKUs / Tyre Type Labour Capacity = 5 labours Equipment Capacity = 2 Labours	Total Order Cycle Time = 2.64 days Throughput Rate = 3.3 orders/day Labour Utilisation = 60% Equipment Utilisation = 50% No of lateness jobs = 1 Order Inventory Level = 5500 Tyre

It can be argued that the resulted IDMU does not represent the ideal leanness precisely since it is based only on the value-added portions of the input variables which are not representative of all distribution parameters. Nevertheless, the simulation modelling approach helps to formulate the other distribution hidden wastes and evaluate their impacts on the output variables (i.e. performance metrics). However, there are still some sources of waste which could not be quantified but they would not represent the majority. Therefore, it can be concluded that the calculated IDMU's output variables were close enough to the ideal leanness and can be used efficiently as a leanness benchmark in the SBM model.

- ***Calculate the leanness level of the ADMU based on the IDMU***

Using the slacks of the inputs/outputs variables directly in SBM's objective function identically fits the lean concept – focuses on decreasing the non-value added activities and sources of waste towards achieving the optimal leanness level. Because the comparison was held between only two DMUs, ADMU leanness score can be calculated using Equation 5.6 with no need for solving the whole SBM mathematical model. In SBM, slacks are the distance from the ADMU to its benchmark, IDMU, and can be reformulated as follows where X and Y are the IDMU's input/output variables, respectively

$$s_i^- = x_i - X \qquad (5.7)$$

$$s_r^- = y_r - Y \qquad (5.8)$$

Consequently, leanness score equation, where only ADMU/IDMU pair is considered, can be driven from equation (3.1) by substituting (s^-_i and s^+_r) in Equations (5.7 and 5.8):

$$Leanness\ Score = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{x_{iA} - x_{il}}{x_{iA}}}{1 + \frac{1}{s} \sum_{r=1}^{s} \frac{y_{sA} - y_{sl}}{y_{sA}}} \qquad (5.9)$$

where

x_{iA}: Actual input variable i | x_{il}: Leanness input variable i

y_{sA}: Actual output variable s | y_{sl}: Leanness actual output variable s

m and s: Number of input/output variables

Given that $S_i^- = x_{iA} - x_{iI}$ and $S_r^+ = y_{sA} - y_{sI}$

Table 5-12 shows the input/output values of ADMU and IDMU which are represented by using the symbols of Equation 5.9 to directly calculate the leanness index of company B.

Table 5-12 Input/output values for both ADMU and IDMU.

Variables types		ADMU		IDMU	
Input Variables	Processing Time	x_{1A}	2.24	x_{1I}	1.5
	Machine Availability	x_{2A}	0.7	x_{2I}	1
	Inventory Capacity	x_{3A}	300	x_{3I}	50
	Labour Capacity	x_{4A}	13	x_{4I}	5
	Equipment Capacity	x_{5A}	6	x_{5I}	2
Output Variables	Total Order Cycle time	y_{1A}	30	y_{1I}	2.64
	Throughput Rate	y_{2A}	2.46	y_{2I}	3.3
	Labour Utilisation	y_{3A}	0.3	y_{3I}	0.6
	Equipment Utilisation	y_{4A}	0.4	y_{4I}	0.5
	No of Lateness Jobs	y_{5A}	301	y_{5I}	1
	Inventory Level	y_{6A}	13304	y_{6I}	5500

By substituting in Equation 5.9, ADMU leanness score was calculated as follows:

$$Leanness\ Score = \frac{1 - \frac{1}{5}\left(\frac{2.24-1.5}{2.24} + \frac{1-0.7}{0.7} + \frac{300-50}{300} + \frac{13-5}{13} + \frac{6-2}{6}\right)}{1 + \frac{1}{6}\left(\frac{30-2.64}{30} + \frac{2.46-3.3}{2.46} + \frac{0.6-0.3}{0.6} + \frac{0.5-0.4}{0.5} + \frac{301-1}{301} + \frac{13304-5500}{13304}\right)}$$

= 0.2601

ADMU's leanness score displayed a moderate difference from the leanness frontier, 73%, indicating high degree of inefficiency, Figure 5-14. The leanness score highlights the need for applying different lean practices to reduce the gap between both ADMUs and IDMUs leanness scores.

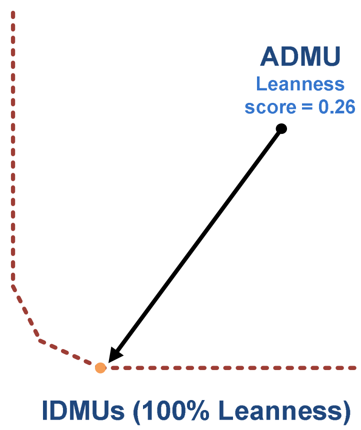


Figure 5-14 The distance between ADMU and IDMU's leanness score.

- ***Evaluate the proposed lean practices (LDMU)***

Two lean practices were proposed, pull replenishment approach (i.e. LDMU1) and class-based storing policies (i.e. LDMU2) to improve the performance of company B and increase its leanness score. The parameters and configurations of ADMU simulation model are changed as well new input/output values are re-estimated based on the special characteristics of each practice.

- **Applying pull replenishment (Rep 6)**

Establishing 200 monthly forecast plans for all company's SKUs is a laborious and time consuming activity, in particular when 100% accuracy is difficult to be obtained. In addition, forecast plans change in a continuous manner which results in various types of waste including high level of inventory, bullwhip effect and loses of sales. In the current competitive market, distribution planers cannot totally replace the forecasting-based replenishment with the pull replenishment especially in the global supply chain network. Therefore, integration between pull replenishment and items forecast strategy is proposed. This integration aims to decrease the items inventory levels and cost while at the same time keeps the customer satisfaction levels high.

Some changes were applied on the ADMU simulation model to fit the characteristics of LDMU1. Reducing supplier's lead time, increasing replenishment orders frequency and decreasing order lot sizes were the key changes on the ADMU model. Being reliant upon customer demand as a trigger for the replenishment process, pull replenishment practice requires a fast response from suppliers with accurate supplying schedule. In addition, a high frequency of replenishment orders with small lot sizes are necessary to decrease orders cycle time, eliminate inventory excess and keep company's flexibility level. It also needs a reliable ordering management process by decreasing the processing time of some activities such as customer requirement identification, item check availability and ordering administrative processes.

Under pull replenishment configuration the reliance on item's replenishment is increased due to the low inventory level. Therefore, the customer orders flow in LDMU1 simulation model is changed as most of customer orders are fulfilled through the replenishment process instead of the direct picking from warehouses. Some input values were also modified to fit the characteristics of the LDMU1. For instance, the inventory capacity was decreased from 300 in the ADMU to 50 items representing the proposed reduction in the inventory level – one of the pull replenishment features. According to company's manager the capacity of resource has to be decreased to reflect the expected staff reduction in the pull replenishment environment. Finally, LDMU1 output values are calculated under the new system configurations and input values as shown in Table 5-13.

Table 5-13 Input/output values for LDMU1 against IDMU

Variables Types		ADMU		LDMU1		IDMU	
Input Variables	Processing Time	x_{1A}	2.24	x_{1L}	2.24	x_{1I}	1.5
	Machine Availability	x_{2A}	0.7	x_{2L}	0.7	x_{2I}	1
	Inventory Capacity	x_{3A}	300	x_{3L}	50	x_{3I}	50
	Labour Capacity	x_{4A}	13	x_{4L}	5	x_{4I}	5
	Equipment Capacity	x_{5A}	6	x_{5L}	2	x_{5I}	2
Output Variables	Total Order Cycle time	y_{1A}	30	y_{1L}	22	y_{1I}	2.64
	Throughput Rate	y_{2A}	2.46	y_{2L}	3	y_{2I}	3.3
	Labour Utilisation	y_{3A}	0.3	y_{3L}	0.68	y_{3I}	0.6
	Equipment Utilisation	y_{4A}	0.4	y_{4L}	0.63	y_{4I}	0.45
	No of Lateness Jobs	y_{5A}	301	y_{5L}	240	y_{5I}	1
	Total Inventory Level	y_{6A}	13304	y_{6L}	7500	y_{6I}	5500

In general, LDMU1 achieved better performance than ADMU since the orders cycle time, number of lateness jobs and inventory levels were decreased while the throughput is slightly increased. This performance improvement reduced the gap between the ADMU and the leanness benchmark recording 0.65 leanness score – calculated using the SBM equation (Equation 5.9) as illustrated in Figure 5-15.

The result indicates that pull replenishment approach has an advantage over the forecast-based replenishment under two conditions; (1) providing a short orders lead time by establishing a robust collaboration with company's suppliers and (2) efficient replenishment process with short replenishment cycle time. Without realising these conditions, pull replenishment cannot cope with the fluctuation in customer demand causing huge loss in customer service level as well as the distribution cost.

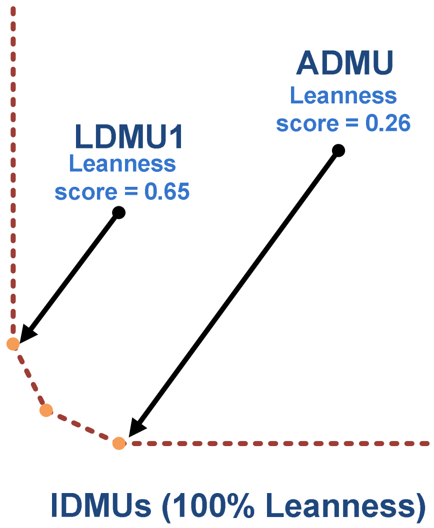


Figure 5-15 The positions of ADMU and LDMU1 regarding IDMU.

- **Storing similar SKUs near each other (Buff4)**

Storing and picking operations are key distribution activities since both constitute 50-75% of the total distribution operation cost (Coyle, 2003). Three process decisions are most often considered in the both operations: (1) how to store SKUs, (2) how to pick SKUs and (3) what is the best route for the picker in the warehouse. The first decision significantly impacts on the other two as the efficient storage policy results effective picking operation.

Company B uses the random storage policy where storage locations are selected according to the free locations. It is simple to follow and often require less space than other policies, however it increases the distance travelled by the picker and in turn increases picking operations time. It also requires continuous follow up and updates for the storage places record which adds more time before and after storing operations. On the other hand, Class-based storage (CBS) policy provides easy tracking for the SKUs, accelerates the storing process and increases the efficiency of picking operations. All SKUs in the CBS policy are ranked according to their type and then partitioned into different storage classes where warehouse locations are assigned for each class (Petersen and Aase, 2004).

According to company's operations manager, applying CBS strategy results enhancement in storing and picking performance. Some modifications were applied on LDMU2 simulation model and its input variables to represent the consequences of applying the CBS strategy – processing time is decreased by 20%. Table 5-14 shows a dramatic decrease in order cycle time and the number of lateness jobs indicating the great influence of the storing and picking operations on the system's time performance. The leanness score of LDMU2 recorded 0.5 which located between the leanness level of ADMU and LDMU1, Figure 5-16. The high inventory level in the warehouse and the drop in the resource utilisation and throughput rate decreased LDMU2 leanness score compared to LDMU1.

Table 5-14 Input/output values of LDMU2 against IDMU

Variables Types		ADMU		LDMU2		IDMU	
Input Variables	Processing Time	x_{1A}	2.24	x_{1A}	1.8	x_{1I}	1.5
	Machine Availability	x_{2A}	0.7	x_{2A}	0.7	x_{2I}	1
	Inventory Capacity	x_{3A}	300	x_{3A}	300	x_{3I}	50
	Labour Capacity	x_{4A}	13	x_{4A}	5	x_{4I}	5
	Equipment Capacity	x_{5A}	6	x_{5A}	2	x_{5I}	2
Output Variables	Total Order Cycle time	y_{1A}	30	y_{1A}	17.82	y_{1I}	2.64
	Throughput Rate	y_{2A}	2.46	y_{2A}	2.8	y_{2I}	3.3
	Labour Utilisation	y_{3A}	0.3	y_{3A}	0.55	y_{3I}	0.6
	Equipment Utilisation	y_{4A}	0.4	y_{4A}	0.5	y_{4I}	0.45
	No of Lateness Jobs	y_{5A}	301	y_{5A}	101	y_{5I}	1
	Total Inventory Level	y_{6A}	13304	y_{6A}	10000	y_{6I}	5500

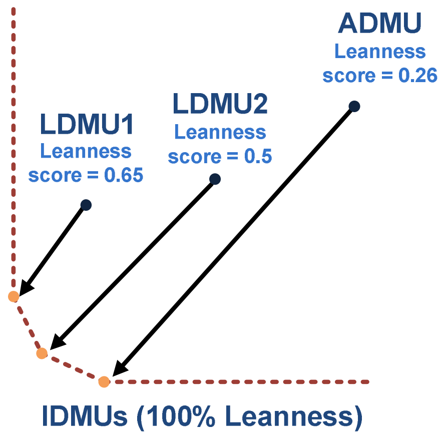


Figure 5-16 The positions of ADMU, LDMU1and LDMU2 regarding the leanness frontier.

It could be argued that by applying the aforementioned practices the leanness score does not significantly increase. This argument is accepted owing to the fact that the complete lean implementation requires a collection of practices to be applied together in order to cover all distribution dimensions. A lot of trade-offs occur between the distribution parameters which make the improvement in one dimension may negatively impact on the other dimension and in turn the overall leanness level.

5.6.3 Company B Leanness Level – Summary

For company's current sate, low tactical leanness score has been recorded, 4.11, relative to the highest leanness company (i.e. Company E LI = 12.66) as illustrated in Table 5-15. This indicates the need for applying various tactical improvement initiatives on the company. As aforementioned, the company suffers from supplying restriction on specific items which negatively impact on its customer satisfaction level. The complex structure of the company's distribution network also plays a role in decreasing its tactical leanness level. It is necessary for the company to enhance its leanness level by applying various tactical improvement initiatives on different dimensions. For instance, it requires flexible customer service policies (e.g. Cust1 or Cust4) along with establishing alternative suppliers list (Qu5 and Qu8) to mitigate the negative impacts of items supplying restrictions. Moreover, applying (Flow1, Flow2 and Rep4) practices is important to simplify the distribution network and increase the transportation efficiency as shown in Table 4.10.

Table 5-15 The tactical and operational leanness level of Company B.

Company	Tactical leanness level	Operational Leanness level		
		Current State	Pull Replenishment	Class-based Storing
Company B	4.11	26%	65%	50%

For the operational level, the leanness level of system's current state has recorded low value, 26%. By applying pull replenishment policies ad class-based storing, the leanness level has dramatically increased recording 65% and 50% respectively. Pull replenishment policy eliminated two waste elements; high inventory level and long items lead time. Applying class-based storing policy has also improved the efficiency of the storing and picking operations by reducing the travelling distance of labours and equipments in both operations.

5.7 Case Study 2 – Plumbing and Heating Distribution Industry (Company D)

Company D is a leading construction merchant in the Irish market. It has reported a turnover of €370 million for the fiscal year 2010. Approximately €160 million of this figure was generated by the company's plumbing and heating (P&H) distribution division. The company is a wholesaler for P&H retailers involved in a wide range of products with different brands from European and worldwide manufacturers, in particular China.

Two main strategic objectives were targeted by the company to retain its customers' loyalty in the current competitive market; (1) avoid item stock-out and (ii) minimise order cycle time. The replenishment process represents one of the critical challenges for the company. Some SKUs – branded items – are replenished in a short lead time from graphically close outlets in UK or Ireland, however the real challenge exists with the manufactured products that are supplied from China. Their lead time takes around 12-14 weeks and extra two weeks are required for price and delivery negotiations with the supplier. To cope with such long delay, the company has decided to keep a high level of inventory from the all types of SKUs. Although this policy acted positively regarding customer satisfaction level, it results in huge inventory holding cost. A pull replenishment practice (i.e. LDMU) is suggested in aiming to balance between the two contradictory objectives – the customer satisfaction and distribution cost.

Similar to company B, pull replenishment requires some changes to the company's configurations. In addition to the normal pull replenishment features (e.g. reducing replenishment orders frequency, decreasing order lot sizes, reducing inventory level and decreasing suppliers lead times), it is necessary to deal with alternative suppliers to the suppliers with long lead time. The cost dimensions will also be taken into consideration to create a deeper understanding for the relation between the pull replenishment approach and the inventory cost.

5.7.1 VS2-Lean Assessment Model (Company D)

- ***Determine study scope***

Similar to company B, the assessment process will include three key areas in the distribution company; order management, inbound and outbound operations. The cost dimension was also covered including three cost elements; holding inventory, ordering and stock-out costs and provide a new analysis perspective for the pull replenishment approach.

- ***Mapping system's current state using VSM***

The distribution operations in company D are triggered either by receiving a customer order or developing items forecast plans. After items availability check, the suppliers are contacted with a long process of negotiations. Given the long negotiation and replenishment lead time, the company's planner sometimes places replenishment orders for more items than what in the forecast plan to mitigate the risk of order delay and to cope with the fluctuated customer demand.

Because failures of plumbing and heating products always cause significant damage, an extensive checking process is performed after receiving and unloading suppliers' trucks (i.e. inbound operations). This process focuses on ensuring items reliability as well as to confirm their quantities. It is considered one of the longest operations in the warehouse which often builds up a large WIP in the site. Updating inventory level is performed daily after the storing process however it is a relatively long process due to the inefficiency of the applied information system. The company's value stream mapping,

Figure 5.17, shows that around 50% of the processing time is considered waste due to the long time of the supplier negotiation and inbound checking take.

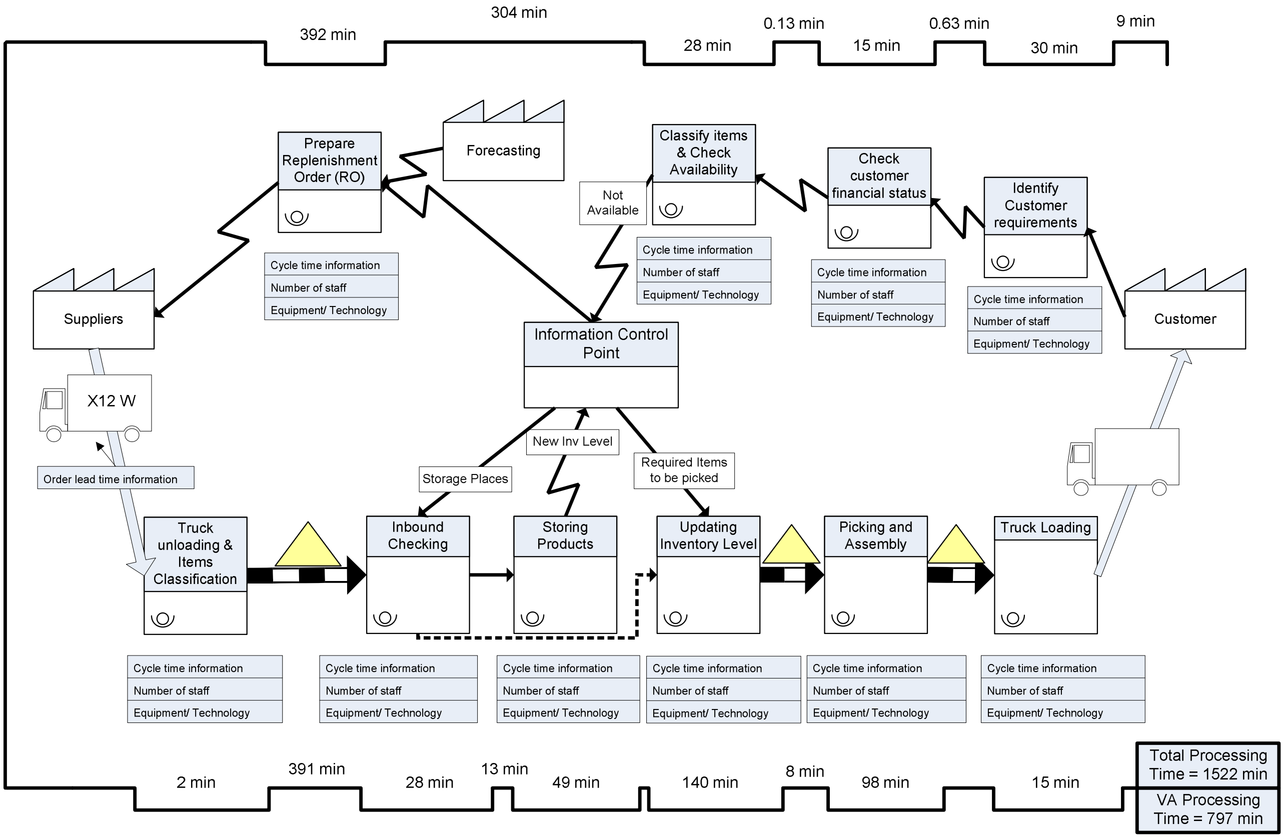


Figure 5-17 VSM for the processes of company D.

- ***Data collection and analysis***

The data collection phase was started by identifying company's input variables and their estimated values. Similar to the previous case, total processing time, equipment availability, inventory and resources capacities (labours and equipment units were used as input variables. Actual and ideal (i.e. leanness) processing times were estimated based on the value stream map in Figure 5.17. The other variables were evaluated based on several meeting with the company's planning manager. Equipment availability is estimated at 70% based on the records of equipment breakdowns and maintenance plans. High inventory capacity is estimated at 500 SKUs for each type, while resource capacities of 10 labours and 3 handling equipment units are set. Table 5-16, summarises the identified input variables and their estimated values.

Table 5-16 Input variables of Company D.

Input Variables	Measurement Units	Actual Values
Processing Time	Days/order	3.17
Machine Availability	Percentage	70%
Inventory Capacity	SKUs	500
Labour Capacity	Number	10
Equipment Capacity	Number	3

- ***Develop Simulation models for ADMU and IDMU***

IDEF0 and IDEF3 were integrated to conceptually model the upper and detailed levels of companies operations. The models are approximately the same as the model in company B, yet two functions are added to the company's IDEF0 model, supplier negotiation and inbound checking while outbound checking has been removed as presented in Figure 5.18. Both functions affected on the items flow as the replenishment orders can be redirected to the alternative suppliers based on the negotiations results with the basic supplier while the inbound checking stage comes up with various decisions either to accept or reject the received items.

Figure 5.19 shows an example for a lower layer model using IDEF3 – Items receiving and unloading function (A6 and A7). For each function in Figure 5.18, IDEF3 model was developed to describe all system's details and bridge the gap between the real system and the proposed simulation model those can be found in Appendix 2.

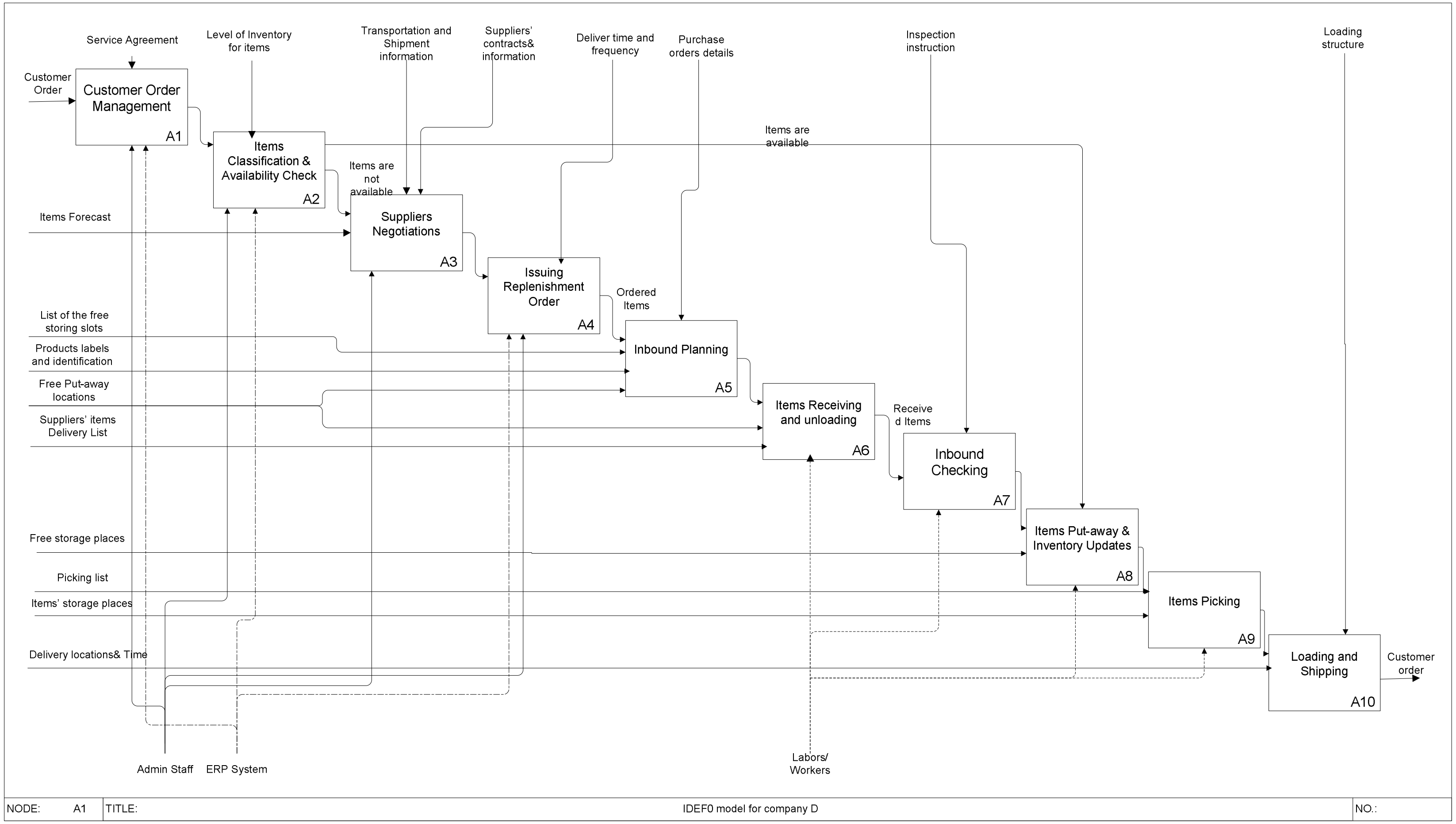


Figure 5-18 A sample of the Upper level conceptual model for Company D.

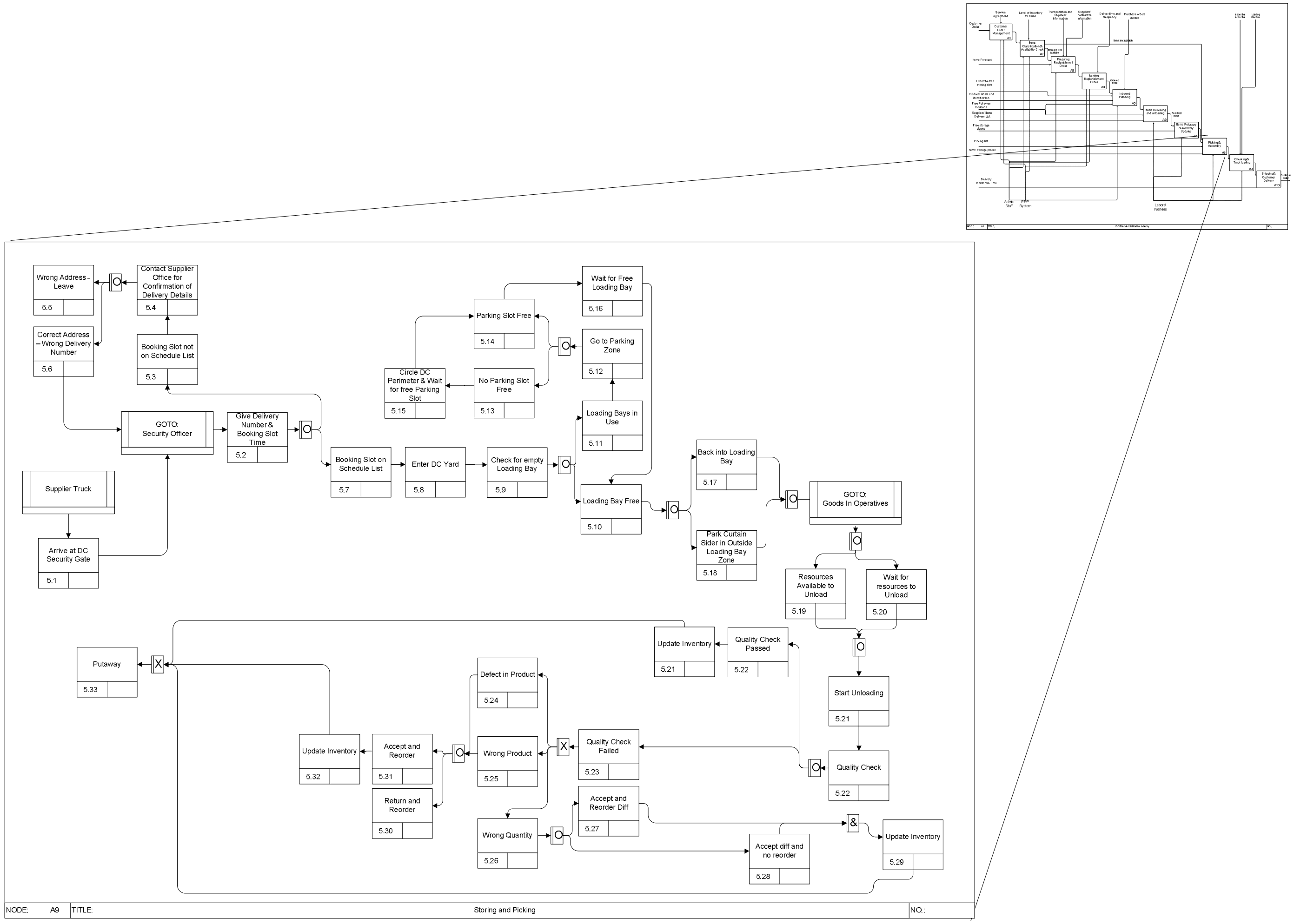


Figure 5-19 A sample of lower level conceptual model for company D.

The ADMU simulation model was developed based on two layers of details – the upper layer for the general system's structure and lower layer for more detailed activities using IDEF0 and IDEF3 models respectively. Various interviews and site visits were held to gain a better understanding of the system's current configuration, operation rules and variables. Historical data for order arrival time, order size, average operations times, machines breakdown rates and repair time were provided and statistically analysed based on one year historical data as a necessary input to the simulation model. Cost data (i.e. average holding cost of items, the cost of placing replenishment orders and the stock-out cost (opportunity or penalty cost if applied)) were also collected using the company's financial records and the experience of the participating manager.

Given the large volume of SKUs that the company deals with, a database was integrated with the simulation model to facilitate the storing and retrieving of SKUs data. Various types of data are stored including data about customers, suppliers, product and order information. The same verification and validation methods were applied as presented in the previous case – company B.

- ***Identify value added and non-value added portions in the input variables***

The value-added and non-value added portions of the input values were distinguished as shown in Table 5-17. Based on the value stream mapping, the actual and ideal processing times were identified where a substantial difference between both states were observed – almost 50%. It was also indicated that the handling equipment unit works to 70% of its capacity due to breakdowns and maintenance activities, but ideally, equipment units have to be available all the time. The operations manager has added that 10 labours and 3 equipment units are the current capacity of the company's resources which can be decreased to 7 labours and 2 handling equipment units. Finally, the high fluctuation of customers demands and long supplier's lead time obliges the company to keep high stock levels for all SKUs, as high as 500 SKUs for each item type, which can be decreased to 50 SKUs in the ideal conditions, according to the inventory manager.

Table 5-17 Input values of ADMU and IDMU.

Input Variables	ADMU	IDMU
Processing Time per Order	3.17 day	1.51 day
Machine Availability	0.7	1
Inventory Capacity	500	50
Labour Capacity	10	7
Equipment Capacity	3	2

- ***Calculate the ADMU's output values***

Seven performance metrics were used to assess the company's leanness level representing various lean distribution dimensions including customer satisfaction, distribution operations efficiency, resources utilisation, distribution cost and inventory level, see Table 5-18. The used metrics were evaluated under the current company's configurations using the ADMU simulation model.

The order cycle time, throughput rate and number of lateness jobs have recorded a good level of performance due to the high availability rate of the storing items. This has decreased the reliance on the replenishment process and suppliers delivery which in turn mitigated the risk of the long replenishment lead time and its impact on the fulfilment rate for the customer orders. Nevertheless, this policy caused dramatic increasing in the distribution total cost given the high figures of inventory holding costs. The low frequency of the replenishment process also decreased the workload for the inbound activities which contributed in the under-utilisation performance of the inbound staff and in turn the average resource utilisation.

Table 5-18 Input/output values of ADMU.

Types of DMU	Actual Input Variables	Actual Output variables
ADMU	Processing Time = 3.17 hr/order Machine Availability = 0.7 Inventory Capacity = 500 tyres/type Labour Capacity = 10 labours Equipment Capacity = 3 Equipments	Total Order Cycle Time = 2 days Throughput Rate = 9.5 Orders/day Labour Utilisation = 53% Equipment Utilisation = 50% No of Lateness Jobs = 22 orders Total Inventory Level = 25230 SKU Distribution Cost = 1,930,887€

- ***Calculate IDMU's output values***

All waste elements were eliminated from IDMU's simulation model and input values including suppliers lead time (one of the seven waste types), the WIP in the distribution facility, supplier negotiation time and others. Operation roles and logical processes sequence were kept the same as the current system configurations. Table 5-19 illustrates the values of IDMU's input/output variables after finishing the simulation runs.

Table 5-19 Input/output values of IDMU.

Types of DMU	Ideal Input Variables	Ideal Output variables
IDMU	Processing Time = 1.51 days/order Machine Availability = 1 Inventory Capacity = 50 tyres/type Labour Capacity = 7 labours Equipment Capacity = 2 Equipments	Total Order Cycle Time = 1.2 days Throughput Rate = 10 Orders/Day Labour Utilisation = 0.56% Equipment Utilisation = 0.6% No of lateness jobs = 1 Orders Total Inventory Level = 2500 SKU Distribution Cost = 242,998 €

Order cycle time, number of lateness orders, total inventory level and distribution cost dropped to their lowest levels while throughput rate increased. The low values of resource utilisation resulted due to the short processing time for the distribution operations in the ideal state (i.e. value-added portions) which further resulted in long idle time for labours and equipment units.

- ***Calculate the leanness level of ADMU based on the IDMU***

By evaluating company's input/output values as presented in Table 5-20, leanness score were calculated using SBM model as follows;

Table 5-20 Input/output values of ADMU and IDMU.

Variables types		ADMU		IDMU	
Input Variables	Processing Time	x_{1A}	3.17	x_{1I}	1.51
	Machine Availability	x_{2A}	0.7	x_{2I}	1
	Inventory Capacity	x_{3A}	500	x_{3I}	50
	Labour Capacity	x_{4A}	10	x_{4I}	7
	Equipment Capacity	x_{5A}	3	x_{5I}	2
Output Variables	Total Order Cycle time	y_{1A}	2	y_{1I}	1.2
	Throughput Rate	y_{2A}	9.5	y_{2I}	10
	Labour Utilisation	y_{3A}	0.53	y_{3I}	0.56
	Equipment Utilisation	y_{4A}	0.5	y_{4I}	0.6
	No of Lateness Jobs	y_{5A}	22	y_{5I}	1
	Total Inventory Level	y_{6A}	25230	y_{6I}	2500
	Distribution Cost	y_{7A}	2930887	y_{7I}	242998

$$Leanness\ Score = \frac{1-\frac{1}{5}\left(\frac{3.17-1.51}{3.17}+\frac{1-0.7}{0.7}+\frac{500-50}{500}+\frac{10-7}{10}+\frac{3-2}{3}\right)}{1+\frac{1}{6}\left(\frac{2-1.2}{2}+\frac{10-9.5}{9.5}+\frac{0.56-0.53}{0.53}+\frac{0.6-0.5}{0.5}+\frac{22-1}{22}+\frac{25230-2500}{25230}+\frac{2930887-242998}{2930887}\right)}$$

= 0.32

ADMU's leanness score depicted that keeping high inventory level to increase the customer satisfaction is inefficient regarding to the leanness level. Although the policy increased the system's throughput rate and decreased order's cycle time and the number of lateness jobs, it caused huge inventory holding costs which resulted in low leanness score away from leanness frontier by 68%, see Figure 5.20.

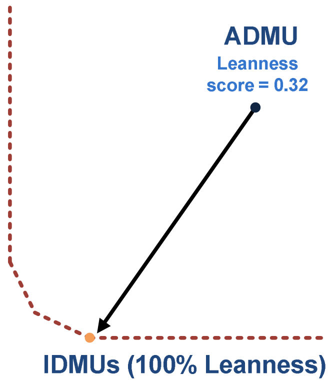


Figure 5-20 Positions of ADMU regarding to leanness frontier.

Aiming to improve the ADMU performance and decrease the gap with the leanness benchmark (i.e. IDMU), a pull replenishment policy (i.e. LDMU) is suggested.

- ***Evaluating Lean Distribution Practices***

Pull replenishment strategy (LDMU)

Various sources of waste are observed in the system's current state including the long negotiation process with the suppliers, long transportation lead time as well as the high inventory cost. Keeping high inventory levels also results in inefficient performance for the inbound and outbound activities, in particular the storing and picking operations because of the unorganised status of the warehouse floor that it causes. Therefore, pull replenishment approach was suggested to improve company's performance given its capability in balancing the trade-off between customer satisfaction and distribution cost as well as reducing inventory. To apply pull replenishment, various changes were applied on current system's state including:

- Decreasing supplier negotiation time: by developing long term agreements with clear supplying conditions regarding to the items prices and delivery procedures.

- Establishing new collaboration with alternative suppliers: aiming to decrease the transportation lead time and hence respond efficiently to the rush orders and demand peaks.
- Increasing the frequency of replenishment orders: to facilitate the items flow across the distribution network and reduce the replenishment lead time.
- Reducing replenishment orders' lot sizes: aiming to decrease the inventory level and in turn the holding cost.

An LDMU simulation model was developed to calculate the output values as represented in Table 5-21.

Dramatic reduction in the inventory level and distribution cost was observed comparing to ADMU. These were resulted due to decreasing replenishment orders lot sizes and inventory capacity. However, the low inventory capacity caused bad performance for orders cycle time and throughput rate. Having said that, pull replenishment has resulted significant improvement in company's leanness score, 0.62, compared to ADMU's leanness score, Figure 5.21. The results emphasised the significant impact of reducing distribution cost on company's operational leanness level.

Table 5-21 Input/output values for ADMU and IDMU.

Variables Types		ADMU		LDMU		IDMU	
Input Variables	Processing Time	x_{1A}	3.17	x_{1A}	3.17	x_{1I}	1.51
	Equipment Availability	x_{2A}	0.7	x_{2A}	0.7	x_{2I}	1
	Inventory Capacity	x_{3A}	500	x_{3A}	200	x_{3I}	50
	Labour Capacity	x_{4A}	10	x_{4A}	10	x_{4I}	7
	Equipment Capacity	x_{5A}	3	x_{5A}	3	x_{5I}	2
Output Variables	Total Order Cycle time	y_{1A}	2	y_{1A}	6.21	y_{1I}	1.2
	Throughput Rate	y_{2A}	9.5	y_{2A}	2.76	y_{2I}	10
	Labour Utilisation	y_{3A}	0.53	y_{3A}	0.58	y_{3I}	0.56
	Equipment Utilisation	y_{4A}	0.5	y_{4A}	0.58	y_{4I}	0.6
	No of Lateness Jobs	y_{5A}	22	y_{5A}	12	y_{5I}	1
	Total Inventory Level	y_{6A}	25230	y_{6A}	505	y_{6I}	2500
	Distribution Cost	y_{7A}	2930887	y_{7A}	106129	y_{7I}	242998

nness Score

$$\frac{1-\frac{1}{5}\left(\frac{3.17-1.51}{3.17}+\frac{1-0.7}{0.7}+\frac{200-50}{200}+\frac{10-7}{10}+\frac{3-2}{3}\right)}{1+\frac{1}{6}\left(\frac{6.21-1.2}{6.21}+\frac{10-2.76}{2.76}+\frac{0.56-0.58}{0.58}+\frac{0.6-0.58}{0.58}+\frac{12-1}{12}+\frac{505-2500}{505}+\frac{106129-242998}{106129}\right)}$$

$= 0.62$

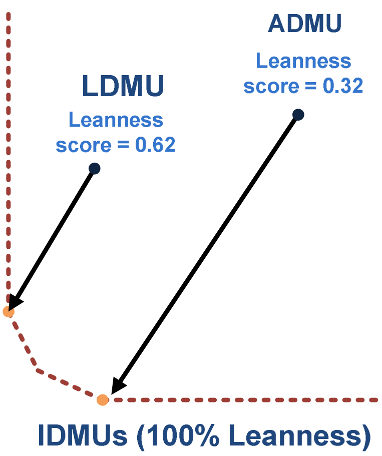


Figure 5-21 Positions of ADMU and LDMU regarding leanness frontier.

5.7.2 ***Company D Leanness Level – Summary***

Low tactical and operational leanness scores of company D resulted indicating the low leanness values of system's current state as shown in Table 5-22. The high fluctuation in customer demand, long replenishment and transportation lead times and the inefficient information flow within the company were the main reasons behind the low tactical leanness level. Various lean distribution practices such as Cust1, Cust2, Cust4, Flow1, Rep4, Qu7, Rep5 and Rep7 are important for enhancing the tactical leanness performance as presented in Table 4.10.

Table 5-22 Tactical and operational leanness score for company D.

Company	**Tactical leanness level**	**Operational Leanness level**	
		Current State	Pull Replenishment
Company D	2.77	32%	62%

Applying pull replenishment strategy increased the operational leanness score by 30% given its contribution in reducing the inventory level and distribution cost despite the negative changes in orders' cycle time and throughput rate.

Chapter 6: CONCLUSION

6.1 Summary

Inefficient distribution performance is considered a serious challenge against developing a streamlined and waste free supply chain network. Despite the critical role that the distribution industry plays in improving the supply chain performance, there are few publications which address the lean distribution concept. There appears to be no literature that reported on lean assessment in distribution environments. The main question of this research is

Can a Lean Distribution Framework be developed to assess the leanness level in the distribution industry?

Two objectives were set in order to answer this question. The first was to identify the dimensional structure of lean distribution, while the second was to quantify the overall leanness distribution level to guide the improvement process in the distribution industry. As illustrated in Figure 6-1, a comprehensive lean distribution assessment framework was proposed to achieve the study objectives – identify a lean distribution structure and quantitatively assess its overall leanness level. The framework was composed of three main phases; the identification phase, development phase, and assessment phase.

The initial phase (identification phase) of the framework was to generate a list of lean distribution factors and their corresponding practices towards developing a lean distribution structure. This phase combined extensive literature review findings as well as the outcomes of several interviews with distribution and supply chain academics. In order to validate the resulted list, four interviews was held with distribution practitioners, and concluded with a list of 7 factors and 40 practices initially representing the lean distribution concept.

Lean Distribution Framework

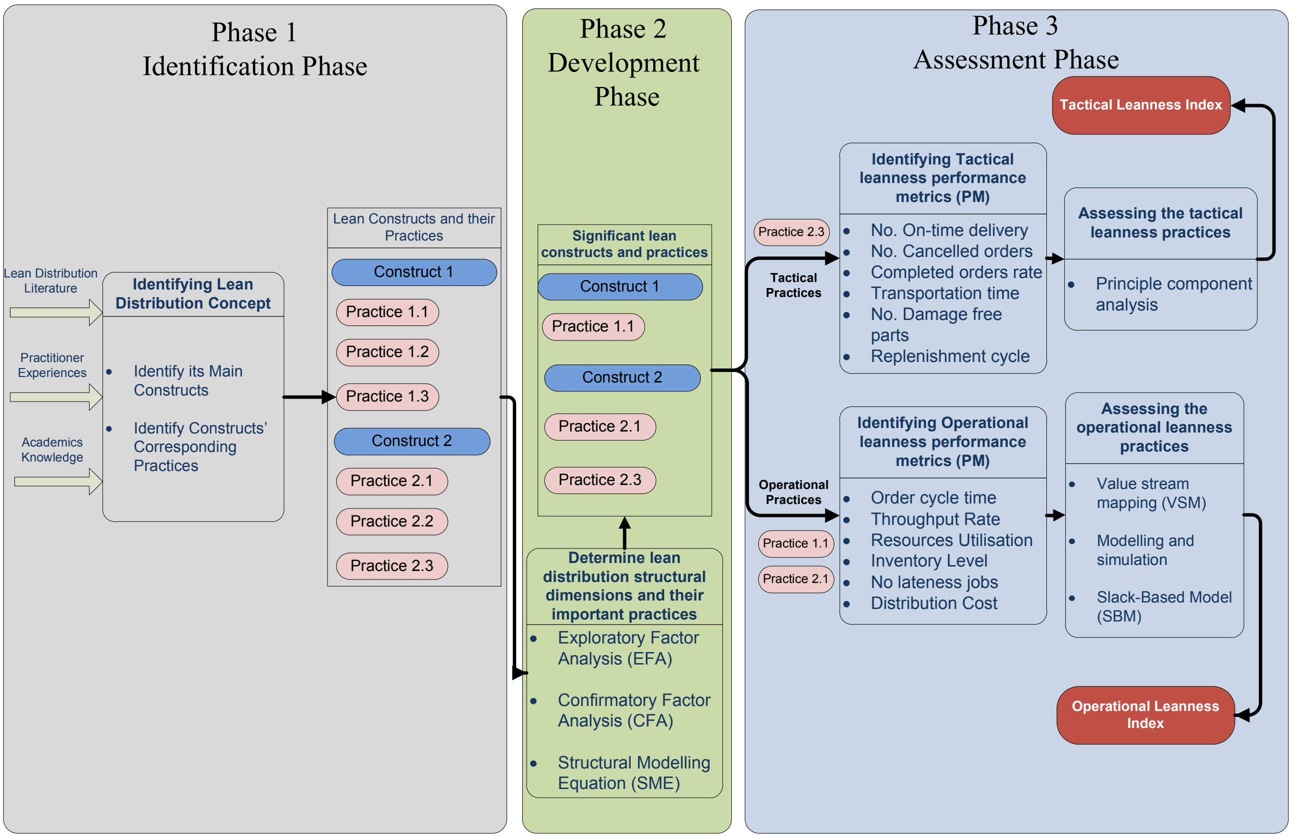


Figure 6-1 Milestones of Lean Distribution Framework

In the development phase, a rigorous validation process based on a wide scale survey was applied to validate the generated lean distribution list and eliminate the insignificant factors and practices. Various statistical techniques, including EFA, CFA, and SEM, were used to explore the interrelationships between the identified factors. Lean distribution measurement and structure models were then developed in order to illustrate the inter-correlation between the retained factors. Five dimensions (i.e. Quality, Customer, Transportation, Workforce and Replenishment) and twenty lean practices of lean distribution were composed the final structure of lean distribution. The final output of this phase has satisfied the first study objective.

Although the improvement of each individual dimension on its own achieves a better performance, companies that are able to implement the complete set of dimensions will attain a distinctive improvement in performance. Nevertheless without measuring these dimensions, it would be ineffective for companies to plan their lean implementation process. For this purpose, two lean assessment models were developed (assessment phase) to develop a leanness index score and represent the leanness level in the distribution companies. The models evaluated distribution businesses at a tactical and an operational level. Principle Component Analysis techniques were used for the tactical lean assessment model. Five distribution companies were included in a case study analysis. Relative leanness indices were calculated and then used for a comparative exercise between the five studied companies. Two of the five companies were selected to examine their operational leanness level. An integrated lean assessment model (VS2) was successfully employed to find the operational leanness level of both companies, and evaluate the proposed lean practices ahead of their implementation. Tactical and operational leanness indices resulted for each company representing its overall leanness level and guiding its continuous improvement process. By the end of this phase the second study objective was achieved and research question was answered.

6.2 Discussion

Several important aspects were observed during the research stages and yielded important insights that need to be highlighted. The proposed framework resulted lean distribution measurement and structure models to provide robust insights for the lean practitioners and distribution decision makers. A lean distribution structure model was developed based on five key dimensions: Quality, Customer, Transportation, Workforce & Planning and Replenishment. Quality recorded the most significant factor followed by Customers, Transportation, Workforce & Planning and finally Replenishment. The supplier construct was removed from the lean distribution exploratory model since its associated practices could not pass the reliability test based on the survey responses. Despite the important role of supplier collaboration on the lean distribution paradigm – according to lean distribution literature – the situation looks different in practice. Since most of distribution companies tend to hold a considerable high level of inventory, supplier collaboration seems to be a less significant factor where lean distribution is concerned. If pull replenishment practice is to take place, the issue of supplier collaboration might need more attention from the distribution managers due to its critical role in this policy. This might indicate that more effort from lean practitioners is needed in order to explain the benefits of a pull replenishment policy to the distribution managers.

The developed lean assessment framework can help in supporting this initiative. As shown in Table 5-15 and Table 5-22, the impact of applying the pull replenishment policy were quantitatively measured based on the leanness level of two different distribution companies. These figures provide a clear vision of the positive consequences of applying the pull replenishment policy which critically support the decision making process. In addition to its ability in evaluating the proposed lean practices before implementation phase, the developed lean assessment framework provided an assessment of the overall leanness level by assessing the tactical and operational leanness levels. The study has defined two groups of leanness metrics: tactical and operational. These groups included customers, quality, workforce, transportation, buffering, cost, and operational dimensions. The list was validated through various discussion workshops and focus group meetings with different distribution and operations managers, and then used as a representative of the overall leanness level.

The assessment models used within the framework focused on establishing statistical and mathematical relationships between the leanness index (i.e. dependent variable) and the identified leanness performance metrics (i.e. independent variable). A principle component approach was used for the tactical lean assessment model, while integration between VSM, modelling and simulation, and SBM models was developed for the operational lean assessment. Based on the tactical lean assessment model, the five studied companies were arranged in a descending order regarding to their leanness level as follows; E (Li = 12.66), C (Li = 7.18), B (Li = 4.22), D (Li = 2.77), and A (Li = 1.75). Several tactical improvement initiatives were suggested for the studied companies to increase their leanness level. Special attention is required to simplify the distribution network and also enhance supplier performances in companies E and C. For companies B and D, improving customer satisfaction and the replenishment process were recommended. Finally, more robust quality and ordering processes are important for company A.

The integration of simulation modelling approach, value stream mapping (VSM) and slack-based model (SBM) in the operational lean assessment model provided a robust approach to dynamically evaluate the leanness level. Previous publications used static offline approaches to evaluate system's leanness level (Ray *et al.*, 2006; Wan and Chen, 2008). Simulation modelling created an edge by predicting the impact of lean practices on system performance. The stochastic nature of the system was considered in the modelling phase. The use of VSM allows the decision makers to have a better understanding of the value-added and non-value added activities. SBM model formulated mathematically the relationship between the input/output variables and the proposed leanness index. The current status of Company B recorded a low operational leanness index of 26%. By applying two lean initiatives, pull replenishment and class-based storage (i.e. similar SKUs stored physically near each other), the leanness level has significantly improved to reach 65% and 51%, respectively. The implementation of pull replenishment strategy has also recorded a significant impact on the leanness level of Company D, improving it from 32% to 62%.

Generally, it was concluded that increasing customer satisfaction, reducing operation times, and distribution costs are the most significant objectives for the lean distribution paradigm. Optimising the trade-off between customer satisfaction and operations cost can be achieved by eliminating elements of waste and isolating sources of variations.

6.3 Contribution

The study has provided various contributions in the knowledge and application domains. The first contribution was in presenting a comprehensive and complete lean distribution framework that can be employed to identify, implement and assess the lean paradigm in any other application domain rather than distribution (e.g. health-care, transportation or retailing). Applying this framework helps the lean implementation process as well as supports the continuous improvement initiatives.

A number of other contributions were also achieved in each phase of the framework (i.e. identification, development and assessment). The previous publications have presented lean distribution as a collection of individual dimensions and practices (Christensen, 1996; Kiff, 2000; Reichhart and Holweg, 2007). Identifying lean paradigm based on multi-dimensional perspective was addressed only in lean manufacturing literature (Shah and Ward, 2003 and 2007), but no apparent research has used the same perspective in describing lean distribution. In identification phase, lean distribution concept has been initially identified based on several dimensions and constructs – seven lean factors with 40 correspondent lean practices – that present the overall lean concept of the distribution industry.

Relying on rigorous statistical reliability and validity tests using EFA, CFA and SEM, the development phase has yielded another contribution for this study – lean distribution measurement and structure models. The literature contained several publications that employed those techniques in order to identify different concepts including supply chain agility, lean manufacturing and other macro level strategic applications (Bush and Sinclair, 1991; Swafford *et al.*, 2006; Nahm *et al.*, 2003). The outcome of this phase is considered a complement of these research efforts in a new application domain – distribution industry.

In assessment phase, two main contributions have been resulted. The first is the identification of a comprehensive leanness metrics that represent the overall distribution leanness level. The metrics list has considered both lean distribution tactical and operational levels. The authors in lean distribution literature usually focus on one level when evaluating distribution performance; either tactical (e.g. Kiff, 2000; Hines, 1999; Jones, 1997) or operational (Reichhart and Holweg, 2007; Chua and Katayama, 2009; Diseny *et al.*, 1997).

The majority of lean assessment tools in the last decade were based on subjective questionnaires that explore different areas of the studied systems (Ray *et al.*, 2006). According to Wan and Chen (2008), an objective, quantitative and integrated measure of overall leanness has not been established yet to measure how lean a system is. Filling this gap was the second contribution of the assessment phase. It developed two quantitative lean assessment models in order to evaluate the overall distribution leanness level. The first model further developed the work of Ray *et al. (*2006) and employed different statistical techniques (i.e. standardisation, normalisation and principle component analysis) to generate a tactical leanness index of the distribution industry. On the other hand, VSM, Modelling and Simulation and SBM were integrated to calculate a quantitative leanness index in order to indicate the operational leanness level, evaluate the proposed lean initiatives ahead of their implementation and set an internal operational benchmark for the studied companies. It is a novel model regarding the integration of the three techniques since this integration was not addressed before in the lean assessment context.

6.4 Research limitations

The dissertation introduced an important step towards a deeper understanding of the lean distribution philosophy and lean implementation. Nevertheless, some research limitations are observed:

1) The study is directed to the Irish distribution sector in both identification and development phases.
2) The tactical lean assessment model is not able to evaluate the impact of lean practices on system's performance ahead of their implementation.
3) The research did not include any direct financial performance in the lean distribution paradigm.

6.5 Recommendations for Future Research

Based on the findings and outcomes of this research, there are opportunities for future research. Internationalising the study to include distribution companies in other countries will create an opportunity to generalise the research, and to explore the impact of other geographical and economic factors, along with culture differences in understanding lean distribution.

In the tactical lean assessment model, more research effort can be done to develop a prediction tool for the values of tactical metrics using neural networks or any robust forecasting technique. Developing such models can enhance the proposed framework.

Setting a global standard (benchmark) for assessing leanness is a potential for research opportunity. Finally, combine tactical and operational leanness index in one single index to represent the distribution business overall performance is worth investigating.

REFERENCES

ACHANGA, P., SHEHAB, E., ROY, R. & NELDER, G. (2006) Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management,* 17**,** 460-471.

ACKERMAN, K. B. & BREWER, A. M. (2001) Warehousing: a key link in the supply chain. *Handbook of logistics and supply-chain management***,** 225-237.

AFIFI, A. A., CLARK, V. & MAY, S. (2004) *Computer-aided multivariate analysis,* New York, NY, CRC Press.

ANDERSON, J. C. & GERBING, D. W. (1982) Some methods for respecifying measurement models to obtain unidimensional construct measurement. *Journal of Marketing Research,* 19**,** 453-460.

ANDERSON, J. C. & GERBING, D. W. (1988) Structural equation modeling in practice: A review and recommended two-step approach. *Psychological bulletin,* 103**,** 411.

ANDREWS, F. (2000) Dell, it turns out has a better idea than Ford. *The New York Times,* 26**,** C12.

APTE, U. M. & VISWANATHAN, S. (2000) Effective cross docking for improving distribution efficiencies. *International Journal of Logistics Research and Applications,* 3**,** 291-302.

ARISHA, A., YOUNG, P. & EL BARADIE, M. (2004) A simulation model to characterize the photolithography process of a semiconductor wafer fabrication. *Journal of Materials Processing Tech.,* 155**,** 2071-2079.

ARMISTEAD, C. (1999) Knowledge management and process performance. *Journal of Knowledge Management,* 3**,** 143-157.

BAKER, P. (2004) Aligning distribution center operations to supply chain strategy. *International Journal of Logistics Management, The,* 15**,** 111-123.

BAKER, P. (2007) An exploratory framework of the role of inventory and warehousing in international supply chains. *International Journal of Logistics Management, The,* 18**,** 64-80.

BAKER, P. (2008a) The design and operation of distribution centres within agile supply chains. *International Journal of Production Economics,* 111**,** 27-41.

BAKER, P. (2008b) The Role, Design and Operation of Distribution Centres in Agile Supply Chains. *School of Management.* CRANFIELD, CRANFIELD UNIVERSITY.

BAKER, P. & HALIM, Z. (2007) An exploration of warehouse automation implementations: cost, service and flexibility issues. *Supply Chain Management: An International Journal,* 12**,** 129-138.

BALLÉ, M. (2005) Lean attitude. *IEE Manufacturing Engineer,* 84**,** 14-19.

BALLOU, B., EARLEY, C. E. & RICH, J. S. (2004) The impact of strategic-positioning information on auditor judgments about business-process performance. *AUDITING,* 23**,** 71-88.

BALLOU, R. H. (1987) *Basic business logistics: transportation, materials management, physical distribution*, Prentice-Hall Englewood Cliffs.

BANCROFT, T. (1993) Strategic role of the distribution centre: How to turn your warehouse into a DC. *International Journal of Physical Distribution & Logistics Management,* 21**,** 45-47.

BAYOU, M. E. & DE KORVIN, A. (2008) Measuring the leanness of manufacturing systems--A case study of Ford Motor Company and General Motors. *Journal of Engineering and Technology Management,* 25**,** 287-304.

BELL, J. (2005) *Doing your research project: a guide for first-time researchers in education, health and social science*, Open Univ Pr.

BEUTHE, M., JOURQUIN, B., GEERTS, J. F. & KOUL À NDJANG'HA, C. (2001) Freight transportation demand elasticities: a geographic multimodal transportation network

analysis. *Transportation Research Part E: Logistics and Transportation Review,* 37**,** 253-266.
BHASIN, S. & BURCHER, P. (2006) Lean viewed as a philosophy. *Journal of Manufacturing Technology Management,* 17**,** 56-72.
BOLLEN, K. A. & BOLLEN, K. A. (1989) *Structural equations with latent variables*, Wiley New York.
BOLLEN, K. A. & LONG, J. (1993) *Testing structural equation models*, Sage Publications, Inc.
BRAH, S. A. & LIM, H. Y. (2006) The effects of technology and TQM on the performance of logistics companies. *International Journal of Physical Distribution & Logistics Management,* 36**,** 192-209.
BRANDIMARTE, P. & ZOTTERI, G. (2007) *Introduction to distribution logistics*, LibreDigital.
BRUNT, D., HINES, P. & SULLIVAN, J. (2001) The Value Analysis Time Profile-an approach to value stream costing. *Manufacturing operations and supply chain management: the lean approach***,** 97.
BUSH, R. J. & SINCLAIR, S. A. (1991) A multivariate model and analysis of competitive strategy in the US hardwood lumber industry. *Forest Science,* 37**,** 481-499.
CAGLIANO, R., CANIATO, F. & SPINA, G. (2006) The linkage between supply chain integration and manufacturing improvement programmes. *International Journal of Operations & Production Management,* 26**,** 282-299.
CHAN, J. S., SAMSON, D. A. & SOHAL, A. S. (1993) An integrative model of Japanese manufacturing techniques. *International Journal of Operations & Production Management,* 10**,** 37-56.
CHAPMAN, C. D. (2005) Clean house with lean 5S. *Quality progress,* 38**,** 27-32.
CHARNES, W. W. (1978) Measuring the efficiency of decision making units* 1. *European journal of operational research,* 2**,** 429-444.
CHEN, M. C., HUANG, C. L., CHEN, K. Y. & WU, H. P. (2005) Aggregation of orders in distribution centers using data mining. *Expert Systems with Applications,* 28**,** 453-460.
CHEN, Y. C. (2002) An application of fuzzy set theory to the external performance evaluation of distribution centers in logistics. *Soft Computing-A Fusion of Foundations, Methodologies and Applications,* 6**,** 64-70.
CHOPRA, S. (2003) Designing the distribution network in a supply chain. *Transportation Research Part E: Logistics and Transportation Review,* 39**,** 123-140.
CHRISTENSEN, L. (1996) JIT sensitive distribution-cutting waste and serving the customer. *Logistics Information Management,* 9**,** 7-9.
CHRISTOPHER, M. (1992) *Logistics and supply chain management: strategies for reducing costs and improving services*, Financial Times.
CHRISTOPHER, M. (2004) Supply chains: a marketing perspective. *Understanding supply chains: concepts, critiques, and futures***,** 23-42.
CHUA, C. W. & KATAYAMA, H. (2009) Lean Approaches in Warehousing Design and Management for Automotive Parts Supply Operation. *APIEMS.*
COMM, C. L. & MATHAISEL, D. F. X. (2000) A paradigm for benchmarking lean initiatives for quality improvement. *Benchmarking: An International Journal,* 7**,** 118-128.
COOPER, W. W., SEIFORD, L. M. & ZHU, J. (2004) Data envelopment analysis. *Handbook on data envelopment analysis***,** 1-39.
COTTRILL, K. (1997) The supply chain of the future. *Distribution,* 96**,** 52-54.
COYLE, J. J., BARDI, E.J., AND LANGLEY, C.J., (2003) *The management of business logistics: A supply chain perspective*, South-Western, Mason, OH.
CRESWELL, J. W. (1999) Mixed-method research: Introduction and application. *Handbook of educational policy***,** 455-472.
CRESWELL, J. W. (2003) *Research design*, Sage Publications.
CROTTY, M. (1998) *The foundations of social research: Meaning and perspective in the research process*, Sage Publications Ltd.
CROWE, J., MAHFOUZ, A., ARISHA, A. & BARRETT, F. (2010) Customer Management Analysis of Irish Plumbing & Heating Distribution System: A Simulation Study. IEEE.

DAGANZO, C. (2005) *Logistics systems analysis*, Springer Verlag, Hidelberg.
DALE, A. (1988) *Dale, Arber and Procter (1988) Doing secondary analysis*, Unwin Hyman (London and Boston).
DAUGHERTY, P. J. & PITTMAN, P. H. (1995) Utilization of time-based strategies: creating distribution flexibility/responsiveness. *International Journal of Operations & Production Management,* 15**,** 54-60.
DAVY, J. A., WHITE, R. E., MERRITT, N. J. & GRITZMACHER, K. (1992) A derivation of the underlying constructs of just-in-time management systems. *Academy of Management Journal***,** 653-670.
DETTY, R. B. & YINGLING, J. C. (2000) Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *International Journal of Production Research,* 38**,** 429-446.
DEVELLIS, R. F. (2011) *Scale development: Theory and applications*, Sage Publications, Inc.
DILLMAN, D. A. (2000) *Mail and Internet Surveys: The Tailored Design Method,* New York, Wiley.
DING, L., VELICER, W. F. & HARLOW, L. L. (1995) Effects of estimation methods, number of indicators per factor, and improper solutions on structural equation modeling fit indices. *Structural Equation Modeling: A Multidisciplinary Journal,* 2**,** 119-143.
DREJER, A., BLACKMON, K. & VOSS, C. (2000) Worlds apart?--a look at the operations management area in the US, UK and Scandinavia. *Scandinavian Journal of Management,* 16**,** 45-66.
DUBES, R. & JAIN, A. K. (1980) Clustering methodologies in exploratory data analysis. *Advances in Computers,* 19**,** 113-228.
DUGGAN, K. J. (2002) *Creating mixed model value streams: practical lean techniques for building to demand*, Productivity Pr.
EASTERBY-SMITH, M., THORPE, R. & LOWE, A. (2002) *Management research: An introduction*, Sage Publications Ltd.
EISELT, H. A. & LAPORTE, G. (1989) Integrated planning in distribution systems. *International Journal of Physical Distribution & Logistics Management,* 19**,** 14-19.
ELLRAM, L. M. (1995) Partnering pitfalls and success factors. *Journal of Supply Chain Management,* 31**,** 35-44.
ENNS, S. T. (2007) Pull replenishment performance as a function of demand rates and setup times under optimal settings. IEEE Press.
FISHER, M. L., HAMMOND, J. H., OBERMEYER, W. R. & RAMAN, A. (1994) Making supply meet demand in an uncertain world. *Harvard Business Review,* 72**,** 83-83.
FLYNN, B. B., SCHROEDER, R. G. & FLYNN, E. J. (1999) World class manufacturing: an investigation of Hayes and Wheelwright's foundation. *Journal of Operations Management,* 17**,** 249-269.
FOGARTY, D. W. (1992) Work in process: performance measures. *International Journal of Production Economics,* 26**,** 169-172.
FUJIMOTO, T. (1999) *The evolution of a manufacturing system at Toyota*, Oxford University Press, USA.
FULLER, J. B., O'CONOR, J. & RAWLINSON, R. (1993) Tailored logistics: the next advantage. *Harvard Business Review,* 71**,** 87-87.
FYNES, B. & ENNIS, S. (1994) From lean production to lean logistics: The case of Microsoft Ireland. *European Management Journal,* 12**,** 322-331.
GAGLIARDI, J. P., RUIZ, A. & RENAUD, J. (2008) Space allocation and stock replenishment synchronization in a distribution center. *International Journal of Production Economics,* 115**,** 19-27.
GEBENNINI, E., GAMBERINI, R. & MANZINI, R. (2009) An integrated production-distribution model for the dynamic location and allocation problem with safety stock optimization. *International Journal of Production Economics,* 122**,** 286-304.
GENTRY, J. J. (1996) The role of carriers in buyer-supplier strategic partnerships: a supply chain management approach. *Journal of Business Logistics,* 17**,** 35-56.
GOODSON R., A. E. (2002) Read a Plant-Fast. *Harvard business review,* 80**,** 105-113.

GREEN, J. C., LEE, J. & KOZMAN, T. A. (2010) Managing lean manufacturing in material handling operations. *International Journal of Production Research,* 48**,** 2975-2993.
GURUMURTHY, A. & KODALI, R. (2009) Application of benchmarking for assessing the lean manufacturing implementation. *Benchmarking: An International Journal,* 16**,** 274-308.
HAIR, J. F., ANDERSON, R. E. AND TATHAM, R. L. (1987) *Multivariate data analysis*, MacMillan, New York.
.
HAKIM, C. (1982) Secondary analysis in social research: A guide to data sources and methods with examples.
HALL, R. W. (1987) *Attaining manufacturing excellence: just-in-time, total quality, total people involvement*, Dow Jones-Irwin.
HAMMER, M. (2004) Deep change. *Harv Bus Rev,* 82**,** 84-93.
HANCOCK, W. M. & ZAYKO, M. J. (1998) Lean production: implementation problems. *IIE solutions,* 30**,** 38-42.
HANDFIELD, R. B. & PANNESI, R. T. (1995) Antecedents of leadtime competitiveness in make-to-order manufacturing firms. *International Journal of Production Research,* 33**,** 511-537.
HARRELL, C. & GLADWIN, B. (2007) Productivity improvement in appliance manufacturing. *Simulation Conference, 2007 Winter.*
HATTIE, J. (1985) Methodology Review: Assessing Unidimensionality of Tests and ltenls. *Applied Psychological Measurement,* 9**,** 139.
HAYES, R. H. & WHEELWRIGHT, S. C. (1984) *Restoring our competitive edge: competing through manufacturing*, Wiley New York.
HELPER, S. (1991) How much has really changed between US automakers and their suppliers. *Sloan Management Review,* 32**,** 15-28.
HERTZ, S., JOHANSSON, J. K. & DE JAGER, F. (2001) Customer-oriented cost cutting: process management at Volvo. *Supply Chain Management: An International Journal,* 6**,** 128-142.
HIGGINSON, J. K. & BOOKBINDER, J. H. (2005) Distribution centres in supply chain operations. *Logistics Systems: Design and Optimization***,** 67-91.
HILL, T. (1993) *Manufacturing strategy: the strategic management of the manufacturing function*, Macmillan.
HINES, P., HOLWEG, M. & RICH, N. (2004) Learning to evolve: a review of contemporary lean thinking. *International Journal of Operations & Production Management,* 24**,** 994-1011.
HINES, P., RICH, N., BICHENO, J., BRUNT, D., TAYLOR, D., BUTTERWORTH, C. & SULLIVAN, J. (1998) Value stream management. *International Journal of Logistics Management, The,* 9**,** 25-42.
HINES, P., RICH, N. & ESAIN, A. (1999) Value stream mapping: a distribution industry application. *Benchmarking: An International Journal,* 6**,** 60-77.
HOLWEG, M. & PIL, F. K. (2004) *The second century: reconnecting customer and value chain through build-to-order,* Cambridge, MIT Press.
HOPP, W. J. & SPEARMAN, M. L. (2004) Commissioned Paper To Pull or Not to Pull: What Is the Question? *Manufacturing & Service Operations Management,* 6**,** 133-148.
HUERTAS, J. I., RAMÍREZ, J. D. & SALAZAR, F. T. (2007) Layout evaluation of large capacity warehouses. *Facilities,* 25**,** 259-270.
HUGHES, M. A., PRICE, R. L. & MARRS, D. W. (1986) Linking theory construction and theory testing: Models with multiple indicators of latent variables. *Academy of Management Review***,** 128-144.
HUMPHREYS, P., HUANG, G. & CADDEN, T. (2005) A web-based supplier evaluation tool for the product development process. *Industrial Management & Data Systems,* 105**,** 147-163.

HUNG-DA WAN, F. FRANK CHEN & RIVERA, L. (2007) Leanness Score of Value Stream Maps. *Industrial Engineering Research Conference.* G. Bayraksan, W. Lin, Y. Son, and R. Wysk, eds.
HUR, D., HARTLEY, J. L. & HAHN, C. K. (2004) An exploration of supply chain structure in Korean companies. *International Journal of Logistics Research and Applications,* 7**,** 151-164.
IGNIZIO, J. P. (2009) Optimizing factory performance. New York, McGraw-Hill.
JRESKOG, K. G. & SRBOM, D. (1996) *LISREL 8 user's reference guide*, Scientific Software.
JAYARAM, J., VICKERY, S. & DROGE, C. (2008) Relationship building, lean strategy and firm performance: an exploratory study in the automotive supplier industry. *International Journal of Production Research,* 46**,** 5633-5649.
JAYARAMAN, V. (1998) Transportation, facility location and inventory issues in distribution network design: an investigation. *International Journal of Operations & Production Management,* 18**,** 471-494.
JONES, D. T., HINES, P. & RICH, N. (1997) Lean logistics. *International Journal of Physical Distribution & Logistics Management,* 27**,** 153-173.
JORDAN, J. A. & MICHEL, F. J. (2001) *The lean company: making the right choices*, Society of Manufacturing.
JORESKOG, K. G. & SORBOM, D. (1989) LISREL 7: User's Reference Guide Mooresville, IN: Scientific Software. Inc.
KAISER, H. F. (1970) A second generation little jiffy. *Psychometrika,* 35**,** 401-415.
KAPLAN, R. S. & NORTON, D. P. (1996) *The balanced scorecard: translating strategy into action*, Harvard Business school press.
KARLSSON, C. & AHLSTROM, P. (1997) A lean and global smaller firm? *International Journal of Operations & Production Management,* 17**,** 940-952.
KATAYAMA, H. & BENNETT, D. (1999) Agility, adaptability and leanness: a comparison of concepts and a study of practice. *International Journal of Production Economics,* 60**,** 43-51.
KEEBLER, J. S. (2001) Measuring Performance in the Supply Chain. IN MENTZER, J. T. (Ed.) *Supply Chain Management.* Sage Publications, Thousands Oaks.
KIFF, J. S. (2000) The lean dealership–a vision for the future:"from hunting to farming". *Marketing Intelligence & Planning,* 18**,** 112-126.
KNOX, K. (2004) A Researcher's Dilemma-Philosophical and Methodological Pluralism. *Electronic journal of business research methods,* 2**,** 119-128.
KOJIMA, S. & KAPLINSKY, R. (2004) The use of a lean production index in explaining the transition to global competitiveness: the auto components sector in South Africa. *Technovation,* 24**,** 199-206.
KOUFTEROS, X. A. (1999) Testing a model of pull production: A paradigm for manufacturing research using structural equation modeling. *Journal of Operations Management,* 17**,** 467-488.
KOUFTEROS, X. A., VONDEREMBSE, M. A. & DOLL, W. J. (1998) Developing measures of time-based manufacturing. *Journal of Operations Management,* 16**,** 21-41.
LALWANI, C. S., DISNEY, S. M. & NAIM, M. M. (2006) On assessing the sensitivity to uncertainty in distribution network design. *International Journal of Physical Distribution & Logistics Management,* 36**,** 5-21.
LAMBERT, D. M., COOPER, M. C. & PAGH, J. D. (1998) Supply chain management: implementation issues and research opportunities. *International Journal of Logistics Management, The,* 9**,** 1-20.
LAMMING, R. (1993) *Beyond partnership: strategies for innovation and lean supply*, Prentice Hall London.
LAMMING, R. (1996) Squaring lean supply with supply chain management. *International Journal of Operations & Production Management,* 16**,** 183-196.
LANGEVIN, A. & RIOPEL, D. (2005) *Logistics systems: design and optimization*, Springer Verlag.

LEMOINE, O. W. & SKJOETT-LARSEN, T. (2004) Reconfiguration of supply chains and implications for transport: A Danish study. *International Journal of Physical Distribution & Logistics Management,* 34**,** 793-810.
LEVINSON, W. A. & RERICK, R. A. (2002) *Lean enterprise: A synergistic approach to minimizing waste*, Asq Pr.
LI, S., RAO, S. S., RAGU-NATHAN, T. S. & RAGU-NATHAN, B. (2005) Development and validation of a measurement instrument for studying supply chain management practices. *Journal of Operations Management,* 23**,** 618-641.
LIKER, J. K. (2004) *The Toyota way: 14 management principles from the world's greatest manufacturer*, McGraw-Hill Professional.
LOCKE, L., SPIRDUSO, W. & SILVERMAN, S. (1993) Preparation of proposals for qualitative research: Different assumptions. *Proposals that work: A guide for planning dissertations and grant proposals***,** 96-118.
LONG, J. S. (1983) *Covariance structure models: An introduction to LISREL,* Sage Publications, Inc.
MACCALLUM, R. C., BROWNE, M. W. & SUGAWARA, H. M. (1996) Power analysis and determination of sample size for covariance structure modeling. *Psychological methods*, 1, 130-149.
MACDUFFIE, J. P. & HELPER, S. (2002) Creating lean suppliers: diffusing lean production through the supply chain. *International Motor Vehicle Program*
MAHFOUZ, A. & ARISHA, A. (2010) The Analysis of Rush Orders Risk in Supply Chain: A Simulation Approach. *Modsim World 2010 Conference & Expo.* Hampton, Virginia.
MAHFOUZ, A., HASSAN, S. A. & ARISHA, A. (2010) Practical simulation application: Evaluation of process control parameters in Twisted-Pair Cables manufacturing system. *Simulation Modelling Practice and Theory,* 18**,** 471-482.
MALEYEFF, J. (2006) Exploration of internal service systems using lean principles. *Management Decision,* 44**,** 674-689.
MALTZ, A. & DEHORATIUS, N. (2004) Warehousing: The evolution continues. *Warehousing Education and Research Council, Oak Brook, IL.*
MANRODT, K. B., THOMPSON, R. H. & VITASEK, K. (2008) lean practices in supply chain IN LASALLE, J. L. (Ed.), The Association for Operations Management.
MASON, R. & LALWANI, C. (2008) Mass customised distribution. *International Journal of Production Economics,* 114**,** 71-83.
MAYER, R. J., MENZEL, C. P., PAINTER, M. K., BLINN, T. & DEWITTE, P. S. (1997) Information integration for concurrent engineering (IICE) IDEF3 process description capture method report. KNOWLEDGE BASED SYSTEMS INC COLLEGE STATION TX.
MCLACHLIN, R. (1997) Management initiatives and just-in-time manufacturing. *Journal of Operations Management,* 15**,** 271-292.
MEHTA, V. & SHAH, H. (2005) Characteristics of a work organization from a lean perspective. *ENGINEERING MANAGEMENT JOURNAL-ROLLA-,* 17**,** 14.
MEREDITH, J. (1998) Building operations management theory through case and field research. *Journal of operations management,* 16**,** 441-454.
MORGAN, D. L. (1998) Practical strategies for combining qualitative and quantitative methods: Applications to health research. *Qualitative health research,* 8**,** 362.
MORGAN, R. M. & HUNT, S. D. (1994) The commitment-trust theory of relationship marketing. *the journal of marketing***,** 20-38.
MORSE, J. M. (1991) Approaches to qualitative-quantitative methodological triangulation. *Nursing research,* 40**,** 120.
MOURITS, M. & EVERS, J. J. M. (1995) Distribution network design: An integrated planning support framework. *International Journal of Physical Distribution & Logistics Management,* 25**,** 43-57.
MULCAHY, D. E. (1994) *Warehouse distribution and operations handbook*, McGraw-Hill.

NABHANI, F. & SHOKRI, A. (2009) Reducing the delivery lead time in a food distribution SME through the implementation of six sigma methodology. *Journal of Manufacturing Technology Management,* 20**,** 957-974.

NAPOLITANO, M. (2004) Making the Move to Cross-Docking. *Warehousing Education and Research Council.* Oxford, OH.

NARUS, J. A. & ANDERSON, J. C. (1996) Rethinking distribution: adaptive channels. *Harvard Business Review,* 74**,** 112-122.

NEUMAN, W. L. (2003) *Social research methods: Qualitative and quantitative approaches*, Allyn and Bacon.

NIGHTINGALE, D. J. & MIZE, J. H. (2002) Development of a lean enterprise transformation maturity model. *Information-Knowledge-Systems Management,* 3**,** 15-30.

OHNO, T. (1988) *Toyota production system: beyond large-scale production,* New York, Productivity Pr.

OPPENHEIM, A. N. (2000) *Questionnaire design, interviewing and attitude measurement*, Pinter Pub Ltd.

ORMAN, L. V. (2007) Consumer support systems. *Communications of the ACM,* 50**,** 49-54.

PALLANT, J. (2005) *SPSS survival manual*, Open Univ. Press.

PETERSEN, C. G. & AASE, G. (2004) A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics,* 92**,** 11-19.

PETT, M. A., LACKEY, N. R. & SULLIVAN, J. J. (2003) *Making sense of factor analysis: The use of factor analysis for instrument development in health care research*, Sage Publications, Inc.

PFOHL, H. C., ZOLLNER, W. A. & WEBER, N. (1992) Economies of scale in customer warehouses: theoretical and empirical analysis. *Journal of Business Logistics,* 13**,** 95-124.

PIERCY, N. & RICH, N. (2009) Lean transformation in the pure service environment: the case of the call service centre. *International Journal of Operations & Production Management,* 29**,** 54-76.

PUBS, F. (1993) Integration definition for function modeling (IDEF0). *Federal Information Processing Standards Publication,* 183.

QUINN, F. (2005) The lion of lean: an interview with James Womack. *Supply Chain Management Review,* 9**,** 28-33.

RAMANATHAN, R. (2003) *An introduction to data envelopment analysis: a tool for performance measurement*, Sage Publications Pvt. Ltd.

RAY, C. D., ZUO, X., MICHAEL, J. H. & WIEDENBECK, J. K. (2006) The lean index: Operational" lean" metrics for the wood products industry. *Wood and fiber science,* 38**,** 238-255.

READ, W. F. & MILLER, M. S. (1991) The state of quality in logistics. *International Journal of Physical Distribution & Logistics Management,* 21**,** 32-47.

REICHHART, A. & HOLWEG, M. (2007) Lean distribution: concepts, contributions, conflicts. *International journal of production research,* 45**,** 3699-3722.

RINEHART, J., HUXLEY, C. & ROBERTSON, D. (1994) Worker Commitment and Labour Management Relations under Lean Production at CAMI. *Relations industrielles,* 49**,** 750-772.

ROBSON, C. (2002) *Real world research: A resource for social scientists and practitioner-researchers*, Wiley-Blackwell.

ROODBERGEN, K. J. & DE KOSTER, R. (2001) Routing methods for warehouses with multiple cross aisles. *International Journal of Production Research,* 39**,** 1865-1884.

ROONEY, S. & ROONEY, J. (2005) Lean glossary. *Qual Prog,* 38**,** 41-7.

ROSS, A. & DROGE, C. (2002) An integrated benchmarking approach to distribution center performance using DEA modeling. *Journal of Operations Management,* 20**,** 19-32.

ROSSMAN, G. B. & WILSON, B. L. (1985) Numbers and words. *Evaluation Review,* 9**,** 627.

ROTHER, M. & SHOOK, J. (1999) Learning to see: value stream mapping to add value and eliminate muda 1, Brookline, MA: The Lean Enterprise Institute. Inc.

ROUWENHORST, B., REUTER, B., STOCKRAHM, V., VAN HOUTUM, G. J., MANTEL, R. J. & ZIJM, W. H. M. (2000) Warehouse design and control: Framework and literature review. *European Journal of Operational Research,* 122**,** 515-533.

SAKAKIBARA, S., FLYNN, B. B. & SCHROEDER, R. G. (1993) A FRAMEWORK AND MEASUREMENT INSTRUMENT FOR JUST IN TIME MANUFACTURING. *Production and Operations Management,* 2**,** 177-194.

SAKAKIBARA, S., FLYNN, B. B., SCHROEDER, R. G. & MORRIS, W. T. (1997) The impact of just-in-time manufacturing and its infrastructure on manufacturing performance. *Management Science***,** 1246-1257.

SAMSON, D. & TERZIOVSKI, M. (1999) The relationship between total quality management practices and operational performance. *Journal of operations management,* 17**,** 393-409.

SANCHEZ, A. M. & PÉREZ, M. P. (2001) Lean indicators and manufacturing strategies. *International Journal of Operations & Production Management,* 21**,** 1433-1452.

SAUNDERS, M., LEWIS, P. & THORNHILL, A. (2009) *Research methods for business students*, Prentice Hall.

SAUNDERS, M. L., P, THORNHILL (2003) *Research Methods for Business Students*, Financial Times Prentice Hall Inc., London

SCHEIN, E. H. (1987) *The clinical perspective in fieldwork*, Sage Publications, Inc.

SCHWANDT, T. A. (2000) Three epistemological stances for qualitative inquiry. *Handbook of qualitative research,* 2**,** 189-213.

SEGARS, A. H. & GROVER, V. (1993) Re-examining perceived ease of use and usefulness: A confirmatory factor analysis. *MIS quarterly***,** 517-525.

SHAH, R. & WARD, P. T. (2003) Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management,* 21**,** 129-149.

SHAH, R. & WARD, P. T. (2007) Defining and developing measures of lean production. *Journal of operations management,* 25**,** 785-805.

SHINGO, S., SHING, S. & DILLON, A. P. (1989) *A study of the Toyota production system from an industrial engineering viewpoint*, Productivity Pr.

SIMCHI-LEVI, D., KAMINSKY, P. & SIMCHI-LEVI, E. (2003) *Designing and managing the supply chain: concepts, strategies, and case studies*, Irwin/McGraw-Hill.

SINGH, R. K., CHOUDHURY, A. K., TIWARI, M. K. & MAULL, R. S. (2006) An integrated fuzzy-based decision support system for the selection of lean tools: a case study from the steel industry. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 220**,** 1735.

SMITH, L. (2007) Developing a Theoretical Index Model to Assess 'Leanness'. *Management* Dublin, Dublin institute of Technology.

SORIANO-MEIER, H. & FORRESTER, P. L. (2002) A model for evaluating the degree of leanness of manufacturing firms. *Integrated Manufacturing Systems,* 13**,** 104-109.

SPASTH, H. (1980) Cluster Analysis Algorithms for data reduction and classifications of objects. *New York*.

SPEAR, S. & BOWEN, H. K. (1999) Decoding the DNA of the Toyota production system. *Harvard Business Review,* 77**,** 96-108.

SRINIVASARAGHAVAN, J. & ALLADA, V. (2006) Application of Mahalanobis distance as a lean assessment metric. *The International Journal of Advanced Manufacturing Technology,* 29**,** 1159-1168.

SRIVASTAVA, S. K. & SRIVASTAVA, R. K. (2006) Managing product returns for reverse logistics. *International Journal of Physical Distribution & Logistics Management,* 36**,** 524-546.

STALK, G. & HOUT, T. M. (1990) *Competing against time*, Free press.

STECKLER, A., MCLEROY, K. R., GOODMAN, R. M. & BIRD, S. T. (1992) Toward integrating qualitative and quantitative methods: An introduction. *Health Education Quarterly*.

STUART, I., MCCUTCHEON, D., HANDFIELD, R., MCLACHLIN, R. & SAMSON, D. (2002) Effective case research in operations management: a process perspective. *Journal of Operations Management,* 20**,** 419-433.
SUGIMORI, Y., KUSUNOKI, K., CHO, F. & UCHIKAWA, S. (1977) Toyota production system and kanban system materialization of just-in-time and respect-for-human system. *International journal of production research,* 15**,** 553-564.
SWINK, M. L. (1998) A tutorial on implementing concurrent engineering in new product development programs. *Journal of Operations Management,* 16**,** 103-116.
TAJ, S. (2005) Applying lean assessment tools in Chinese hi-tech industries. *Management Decision,* 43**,** 628-643.
TANAKA, J. S. (1993) Multifaceted conceptions of fit in structural equation models. *Testing structural equation models,* 10**,** 39.
TAPPING, D. & SHUKER, T. (2003) *Value stream management for the lean office*, Productivity Press.
TASHAKKORI, A. & TEDDLIE, C. (2003) *Handbook of mixed methods in social & behavioral research*, Sage Publications, Inc.
TAYLOR, D. H. (2006) Strategic considerations in the development of lean agri-food supply chains: a case study of the UK pork sector. *Supply Chain Management: An International Journal,* 11**,** 271-280.
TICEHURST, G. W. & VEAL, A. J. (2000) Business research methods. *Frenchs Forest, Australia: Longman*.
TOMPKINS, J. A., WHITE, J.A., BOZER, Y.A. AND TANCHOCO, J.M.A. (2003) *Facilities planning,* Hoboken, NJ, John Wiley.
TONE, K. (2001) A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research,* 130**,** 498-509.
TREVILLE, S. & ANTONAKIS, J. (2006) Could lean production job design be intrinsically motivating? Contextual, configurational, and levels-of-analysis issues. *Journal of Operations Management,* 24**,** 99-123.
VAN DEN BERG, J. P. (1999) A literature survey on planning and control of warehousing systems. *IIE transactions,* 31**,** 751-762.
VAN HOEK, R. I., HARRISON, A. & CHRISTOPHER, M. (2001) Measuring agile capabilities in the supply chain. *International Journal of Operations & Production Management,* 21**,** 126-148.
WARING, A. (1996) *Practical systems thinking*, Cengage Learning EMEA.
WATERS, C. D. J. (2003) *Global logistics and distribution planning: strategies for management*, Kogan Page Ltd.
WERC (2010) `DC Measures 2010. The Association of Distribution Professionals.
WHETTEN, D. A. (1989) What constitutes a theoretical contribution? *The Academy of Management Review,* 14**,** 490-495.
WHITE, R. E., PEARSON, J. N. & WILSON, J. R. (1999) JIT manufacturing: a survey of implementations in small and large US manufacturers. *Management Science***,** 1-15.
WILSON, L. (2010) *How to implement lean manufacturing*, McGraw-Hill.
WILSON, M. M. J. & ROY, R. N. (2009) Enabling lean procurement: a consolidation model for small-and medium-sized enterprises. *Journal of Manufacturing Technology Management,* 20**,** 817-833.
WOMACK, J. P. & JONES, D. T. (2005) Lean consumption. *Harvard Business Review,* 83**,** 58-68.
WOMACK, J. P., JONES, D. T. & ROOS, D. (1991) The machine that changed the world: The story of lean production.
WOMACK, J. P., JONES, D. T., SIMON & SCHUSTER, A. (1996) *Lean thinking*, Simon & Schuster Audio.
WORLEY, J. M. & DOOLEN, T. L. (2006) The role of communication and management support in a lean manufacturing implementation. *Management Decision,* 44**,** 228-245.
WRIGHT, C. & LUND, J. (2006) Variations on a lean theme: work restructuring in retail distribution. *New Technology, Work and Employment,* 21**,** 59-74.

WU, Y. C. J. (2002) Effective lean logistics strategy for the auto industry. *International Journal of Logistics Management, The,* 13**,** 19-38.
YATES, S. J. & YATES, S. (2004) *Doing social science research*, Sage Publications Ltd.
YIN, R. K. (2003) Case Study Research: design and methods, applied social research methods Series. *Case study research: design and methods (Applied Social Research Methods Series).*
ZHANG, J. & RAY, C. D. (1995) Modified multivariate evaluation techniques for industry-wide product surveys.
ZHOU, C. & LI, Z. (2005) An introduction to Chinese manufacturing research institutions. *International journal of production research,* 43**,** 2649-2669.
ZYLSTRA, K. D. (2006) *Lean distribution: applying lean manufacturing to distribution, logistics, and supply chain*, Wiley.

APPENDICES

Appendix 1: Lean Distribution Survey

Section 1 : Company Information

1. Please indicate under which business sector your company can be classified? *(Please tick all that apply)*

Wholesaler	☐	Manufacturing Distribution Centre	☐
Third Party Logistics (3PL)	☐	Retailing Distribution Centre	☐
Warehousing	☐	Other (Please Specify)	________

2. How many people are currently employed in your company ?

1-20 ☐ 21-50 ☐ 51-100 ☐ 101-150 ☐ 151+ ☐

3. Does your company distribute internationally ? Yes ☐ No ☐

3. Approximately, How much storage space does your company have? *(Please indicate by square meter)* ________

Section 2 : Company Practices

Customers

1. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Clear customer service agreements are issued containing (e.g. service lead time, buffer strategy, replenishment strategy)	1	2	3	4	5
Comprehensive identification of customer needs and expectations is done	1	2	3	4	5
Your company changes customer service agreement according to customer's condition, value and requirement (i.e. no standard customer service policy for all customers)	1	2	3	4	5
Customers' feedback are used to enhance operations performance	1	2	3	4	5
Your company provides its customers with the ability to follow-up the replenishment process and get information about replenishment problems	1	2	3	4	5

Replenishment Orders

2. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Your company reduces the number of customer orders that are consolidated into a single replenishment order	1	2	3	4	5
Your company has access to actual customer consumption and uses it as a trigger to the replenishment process	1	2	3	4	5
Company's replenishment strategy is flexible subject to customer requirements, conditions and values	1	2	3	4	5
Your company takes steps to simplify its distribution network in order to decrease shipments lead time and cost	1	2	3	4	5
Line balancing approach is used to reduce bottleneck in product flow	1	2	3	4	5
Your company places replenishment orders in high frequency with small lot sizes	1	2	3	4	5
Customer demands are levelled to reduce variability and enhance the planning process	1	2	3	4	5

Buffer Strategy

3. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Emergency stocks are kept near to the sources (i.e. Manufacturer or main distribution centre) in order to deal with unexpected or rush orders	1	2	3	4	5
Your company identifies the activities that add values to the customers (i.e. value-added activities) and eliminate the non-value added ones	1	2	3	4	5
Products flow are managed in consistent small batch sizes throughout the daily work activitie	1	2	3	4	5
Products with similar characteristics are stored at same location	1	2	3	4	5
Products' buffer between the internal operations (i.e. Work in Process) are minimised	1	2	3	4	5

All information is STRICTLY CONFIDENTIAL

Suppliers

4. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Your company has up to date information about suppliers' problems	1	2	3	4	5
The company's suppliers are involved in setting the replenishment policies and strategies	1	2	3	4	5
Your company has continuous cooperation with key suppliers to resolve customer issues	1	2	3	4	5

Transportation

5. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
The quality of the transportation activity is frequently reviewed, aiming to increase the efficiency	1	2	3	4	5
Your company selects freight companies that offer flexible capacities for the shipment process	1	2	3	4	5

Handling Equipments

6. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
All mechanical handling equipments are maintained regularly	1	2	3	4	5
Your company utilises operational methods and solutions to increase the efficiency of the handling equipments	1	2	3	4	5
Your company identifies optimal travelling routes for the handling equipments to decrease the travel distance and time	1	2	3	4	5

Standardised Processes

7. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Standard operating procedures are provided to the company's operators, aiming to standardise operations steps	1	2	3	4	5
Your company identifies and regularly discusses the best practices of its operations	1	2	3	4	5

People

8. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Employees feedback and concerns are encouraged and included before making changes and taking actions	1	2	3	4	5
Managers, supervisors and employees are involved in determining facility goals and their achievement feasibility	1	2	3	4	5
Daily work activities are organised into teamwork functions in order to enrich work environment and enhance problem solving activities	1	2	3	4	5
Employees participate, initiate and lead problem-solving activities autonomously	1	2	3	4	5

Workplace Organisation

9. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Your company sorts-out, organises and visually represents the equipments and tools that are needed in the workplace	1	2	3	4	5
Your company employs layout design solutions in order to minimise the internal travel distance and time for both products and workers	1	2	3	4	5
The workplace is kept clean, clear and free of debris	1	2	3	4	5

Continuous Improvement

10. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Your company applies statistical process control procedures (e.g. six sigma) to insure the reliability of the distribution operations	1	2	3	4	5

Advanced technology systems are installed to standardise and simplify the processes, and to reduce the redundancy and transaction errors (e.g. ERP)	1	2	3	4	5
Your company develops continuous improvement plans to sustain and improve distribution performance	1	2	3	4	5

Quality Assurance

11. To what extent does your company implement the following practices? *(Please circle only ONE number per line and answer all questions)*

	No Implementation				Complete Implementation
Structured problem solving methodologies (e.g. 5 whys) are utilised in order to determine the root cause of the problems	1	2	3	4	5
Quality verification and inspection procedures are created for each distribution function	1	2	3	4	5
Your company develops corrective action procedures in order to rectify quality problems	1	2	3	4	5
Clear goals and key performance indicators (KPIs) are identified	1	2	3	4	5

Thank You

Thank you for completing the survey, your participation is very much appreciated. If there are any additional comments regarding lean distribution please include them in the space provided below.

In order to receive a key findings report from this survey and if you would like to be included in the competition for a €200 One4all gift voucher, please include a business card with a contactable email. All individual details will be held with the strictest confidence.

Please Return your completed questionnaire in a stamped addressed envelope enclosed to:

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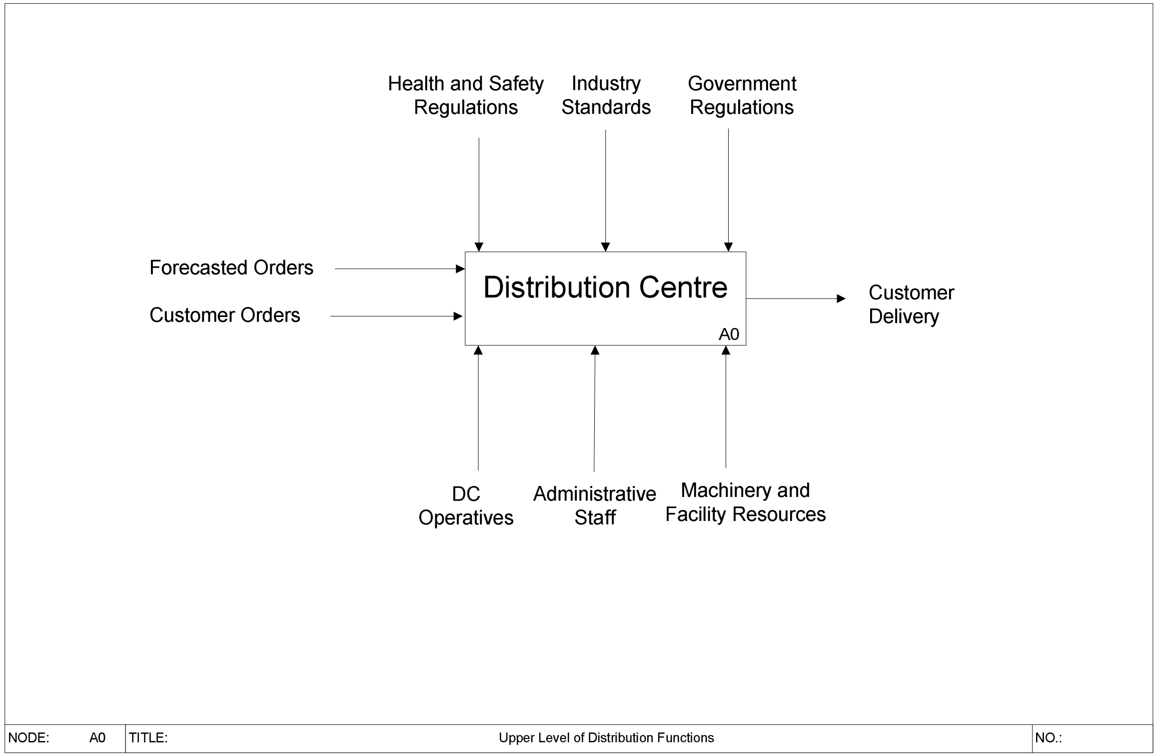
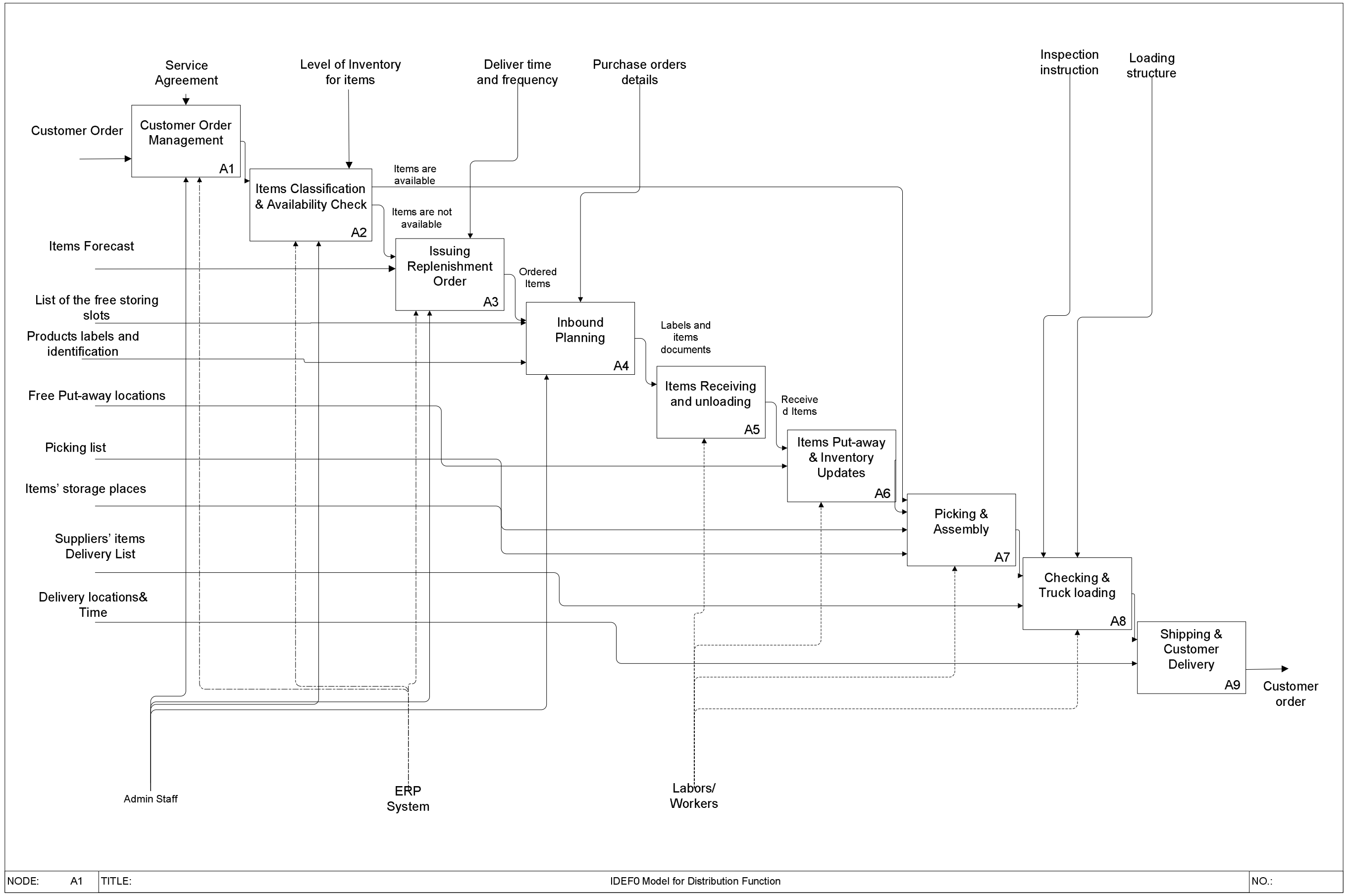
Appendix 2: Lean Distribution Conceptual Models (IDEF0, IDEF3)

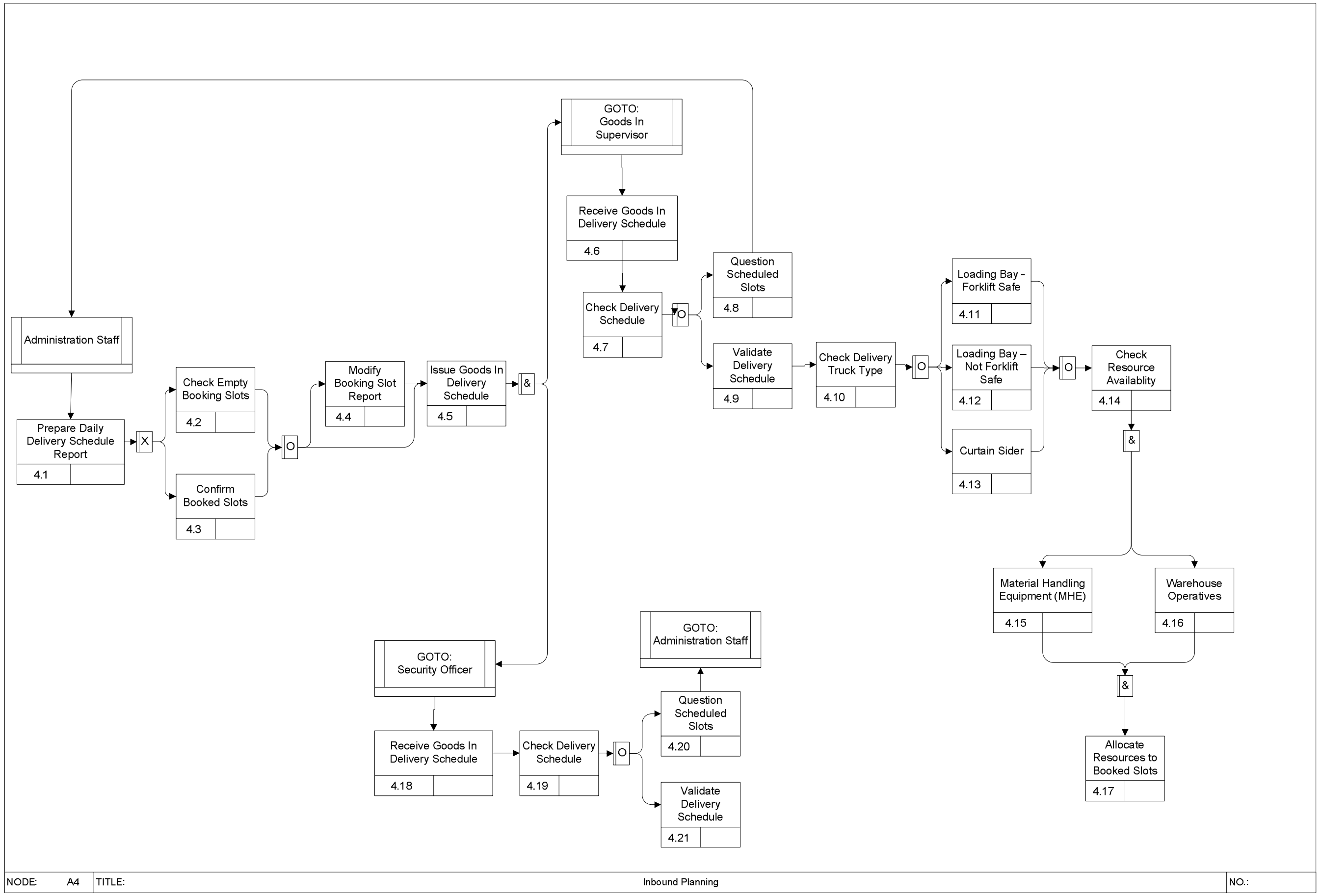
A0 : Upper modelling level of distribution function



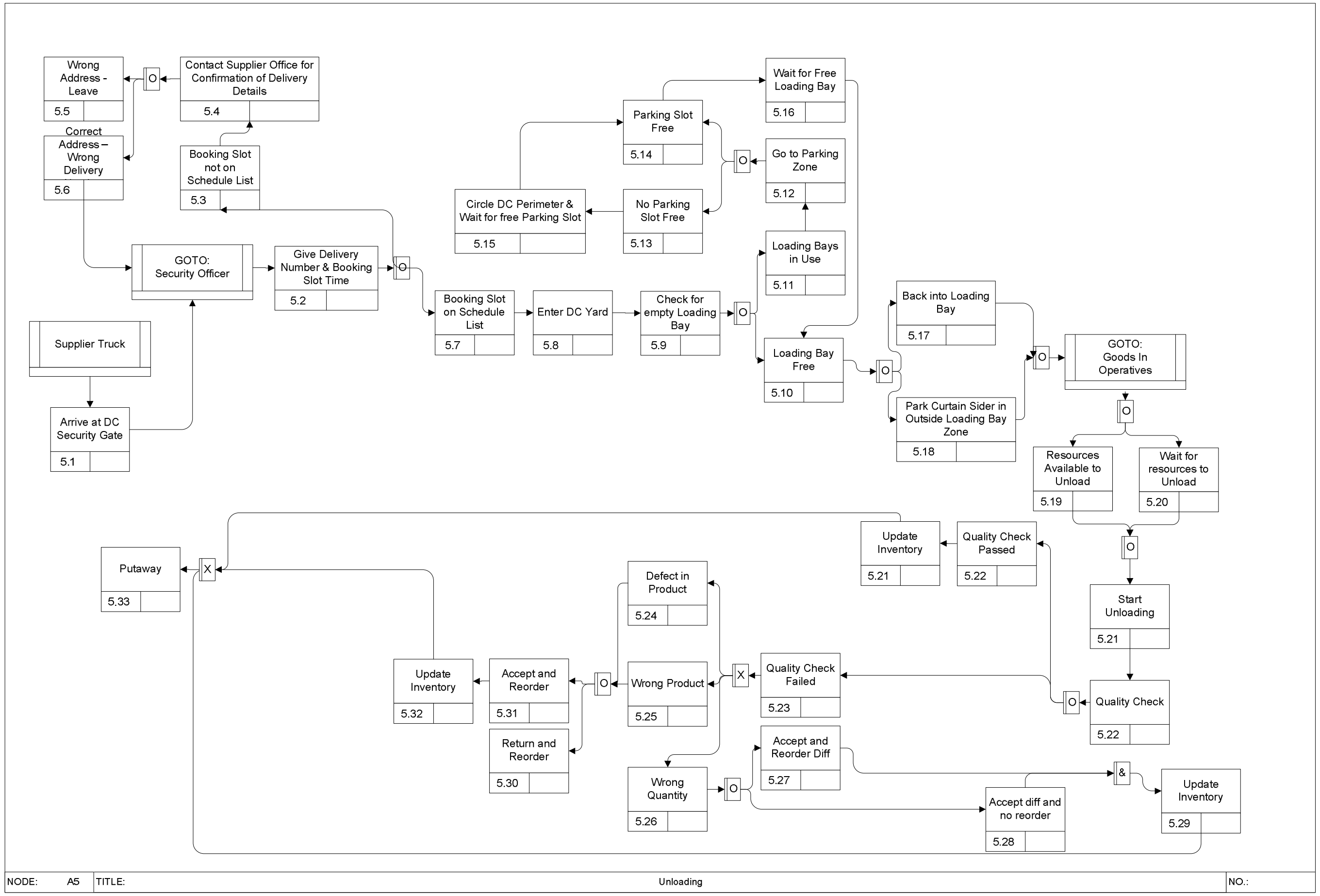
A1: IDEF0 model for the distribution main function



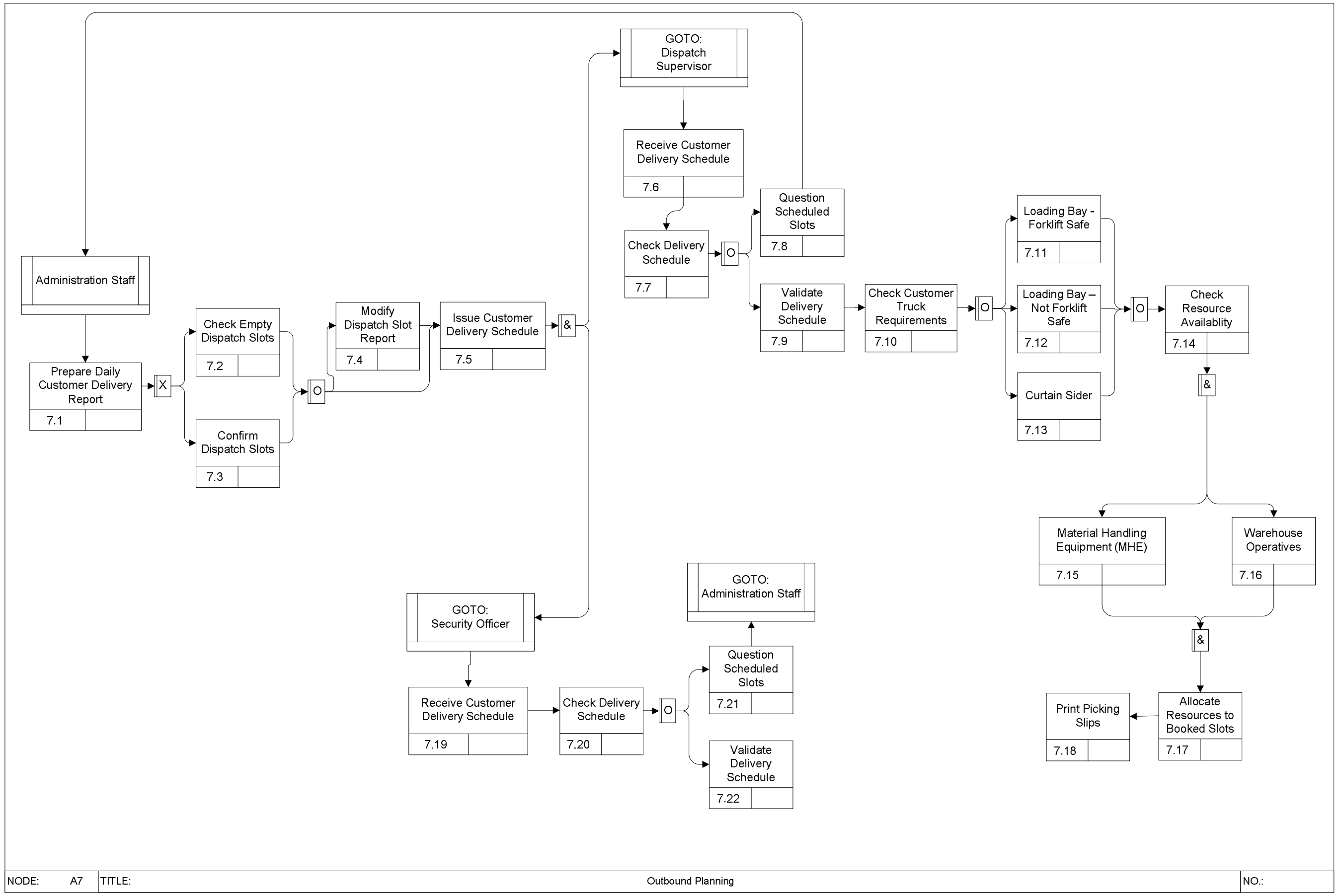
A4: IDEF3 model for Inbound Planning function



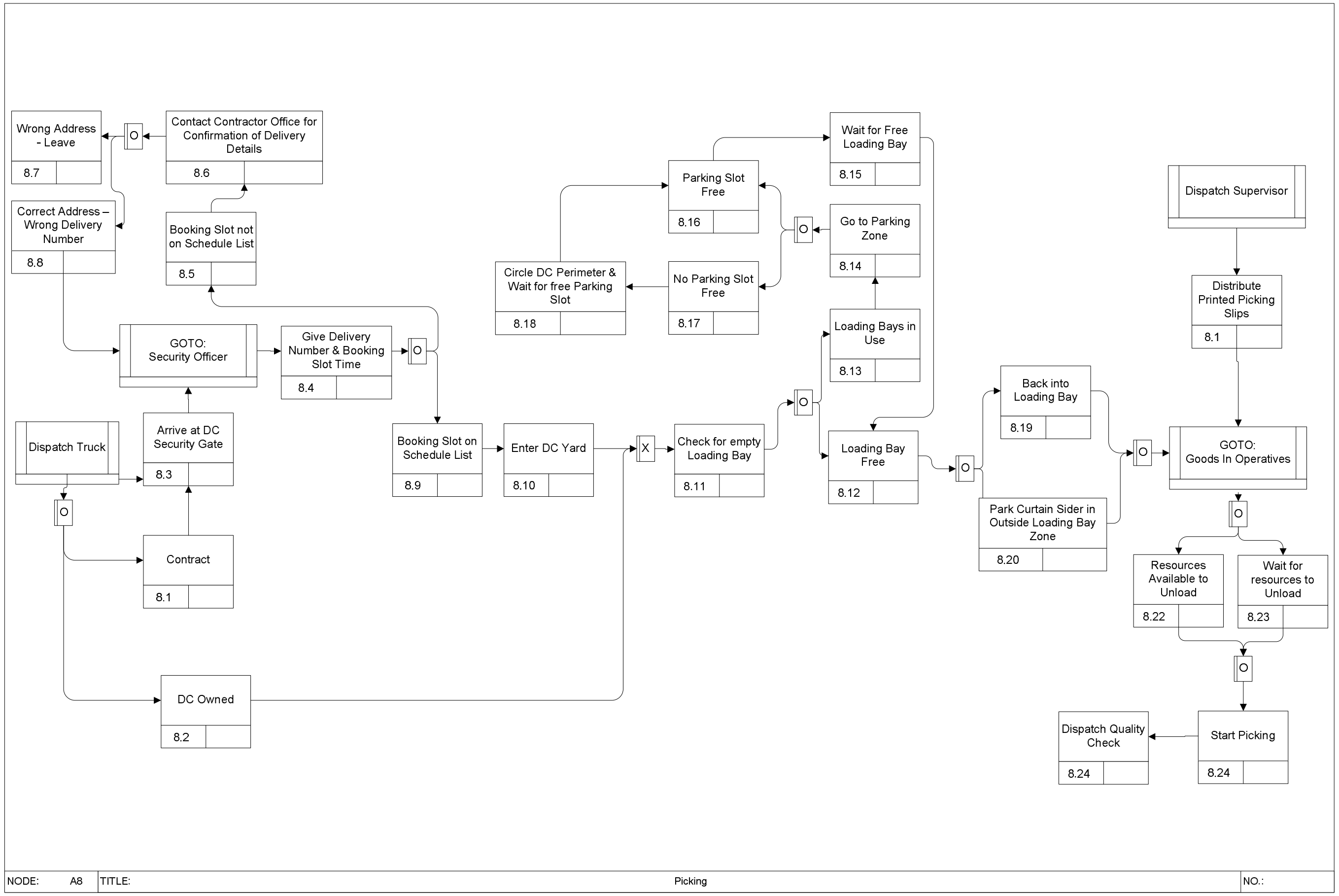
A5: IDEF3 model for the Unloading function



- A7: IDEF3 model for the Outbound Planning function



A8: IDEF3 model for the Picking function



A9: IDEF3 model for the Dispatch Check & Loading function