Lean in the warehouse

Measuring lean maturity and performance within a warehouse environment

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Rotterdam School of Management

Erasmus University Rotterdam

Author: J. (Jeffrey) de Visser

Student number: 345226

MSc program: Supply Chain Management

University coach: M.B.M. de Koster

Company coach: P. van den Brink

Co-reader: B.M. Balk

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Author:

Jeffrey de Visser

Student MSc Supply Chain Management

Rotterdam School of Management

Under the supervision of:

University: Prof. M.B.M. (René) de Koster
Professor of Logistics and Operations Management
Department of Technology and Operations Management
Rotterdam School of Management

Co reader: B.M. (Bert) Balk
Professor emeritus Economic Measurement and Economic-Statistical
Department of Technology and Operations Management
Rotterdam School of Management

Company: Paul van den Brink
Transport Manager
DC NWE, Commercial Supply Chain
Philips Lighting B.V.

Preface

This thesis represents the final step of my Master in Supply Chain Management at the Rotterdam School of Management Erasmus University. It also represents a period of almost 8 months of hard work on the topic of lean warehousing and warehouse performance. These past 8 months have been a valuable learning experience to my scientific, professional, and personal development.

Therefore I would like to thank Philips Lighting for the opportunity to write my thesis at the company. It has been a pleasure to work in the challenging environment of a multinational firm. In particular I would like to thank Paul van den Brink my company supervisor for his support during the project.

I would also like to thank Prof. Rene de Koster my University supervisor. I am grateful for his input, feedback, and flexibility. Furthermore, his network within the logistics community offered me the opportunity to come in contact with the biggest companies in the field of logistics and warehousing. Besides my University supervisor, I am also thanking my co-reader Dr. Bert M. Balk for his support during the thesis.

Last but not least I would like to thank my family and friends for supporting, encouraging, and stimulating me in their own ways during my educational experience.

Thanks for all the help, opportunities, and support,

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Executive Summary

Lean production has become the standard in most European, Asian, and American manufacturing company due to its reputation of delivering extra output with less input. Because the success stories in production and manufacturing lean production is an often-implemented management system in other environments. Examples can amongst others be found in service industry, healthcare, and logistics. This study focuses on lean production as a management system in warehousing and logistics.

The research is performed at Philips Lighting. Philips Lighting has one warehouse organization in Netherlands. This organization is responsible for worldwide export and distribution of products to North-West Europe, hence referred as DC NWE. Implementation of lean production is very common within Philips Lighting, but DC NWE is the first and only warehouse organization within Philips Lighting that has implemented lean production. Because of that the actual value creation by lean production is unknown. This study should contribute to Philips Lighting by evaluation the success of DC NWE's lean program in comparison with lean programs at other warehouse operations.

The main objective of this study is to investigate the impact of lean maturity – resulting of lean philosophy and practices within a warehouse environment – on warehouse performance. Theory and practice show both positive and negative relations between lean production and warehouse performance. Hence, the main research question is:

How does lean warehousing influence the performance of a warehouse operation?

Warehouse performance is defined as a construct consisting of three measures. Warehouse performance involves productivity, quality, and employee satisfaction. Based critical review of literature lean warehousing can lead to improved productivity, quality, and employee satisfaction. However, empirical evidence for this claim in a warehousing environment is limited. Lean production aims to banish waste by reducing non-value adding activities. Non-value adding processes do not generate output; hence a true lean organization should be able to generate the same amount of output with less input. Besides waste reduction lean production should lead to culture in which employees operate customer focused and strive for perfection every single day. It is proposed that these cultural aspects of lean production should lead to increased delivery quality. A third aspect of lean culture is the empowerment of employees. Lean production involves employees at all levels in decision-making and continuous improvement. It is proposed the increased involvement of employees can lead to increased employee satisfaction.

Based on a comparison of six warehouses it can be concluded that lean warehousing influences performance. Although this relationship is not all cases positive. The linkage between lean warehousing and performance depends on the definition of warehouse performance. Warehouse performance was measured based on productivity, quality, and employee satisfaction. There seems to be no relationship between lean maturity and employee satisfaction. Both the scatter plots and correlation matrix show no sign of a linkage between the concepts. The theoretical framework suggested that employee involvement could have a positive impact on employee satisfaction. Based on the results of this study this linkage cannot be confirmed. Lean warehousing does influence productivity. Surprisingly the findings of this research suggest that lean warehousing has a negative impact on productivity. However, this can also be caused by the fact that the sample consists of both private and public warehouses. When performance is defined in terms of quality lean maturity has a positive impact. There seems to be a positive linear relationship between lean maturity and the percentage of error free orders shipped.

Lean warehousing is a powerful tool to improve quality by reducing errors. Due to the amount of resources required for implementation the effect on productivity and efficiency is rather positive than negative. Because of that warehousing organization have to define their value proposition before applying lean practices. If a warehouse is focused on cost reduction and efficiency lean is not the appropriate management philosophy to adopt. However, when delivery reliability is key to warehouse organization's strategy lean practices and principles can be implemented to support the strategic objectives.

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Chapter 1: Introduction

1.1 Problem description

By the publication of *A Machine that Changed the World* Womack, Jones and Roos (1991) introduced lean manufacturing within Western countries. Lean techniques became a widespread phenomenon within multiple industries due to the work of Womack et al. To become and stay global competitive many manufacturing firms have adopted techniques suggested by the previously mentioned work (Shah and Ward, 2003; Womack and Jones, 1996). Although lean was mainly developed as an approach to reduce waste in a manufacturing environment, it developed towards a philosophy implemented in all the stages of many companies' value chain. Nowadays, firms within different professional fields increasingly adopt lean techniques. For example in service and logistics industries (Dehdari, 2013; Womack and Jones, 1996; Overboom et al.,2010).

Lean also found its way into a warehouse environment. Lean techniques are increasingly applied within the warehouse environment. Companies such as Philips, Bosch, Menlo and CEVA Logistics have implemented programs to stimulate warehouses to adopt lean management practices and techniques (Dehdari, 2013; Overboom et al., 2010). Although, these firms invested significant amounts of resources into the implementation of lean techniques, they are struggling to measure the impact of these techniques. Researchers and practitioners developed multiple tools to measure leanness in manufacturing and production environments, for example by the use of maturity assessment models (Nightingale et al., 2002 ;Mahfouz, 2011; Doolen and Hacker, 2005). Unfortunately there is a lack of tools developed to measure lean maturity within a warehouse environment.

For example, Philips developed a well-refined model to measure lean maturity. The model firm wide implemented to measure lean maturity of manufacturing plants. The maturity model consists of five phases. Each phase consists of multiple specific milestones and objectives. After completing all the milestones an external audits determines whether the operation achieves a higher level of lean maturity. The model has a proven record within a production environment and is therefore also used to measure lean maturity within different Philips warehouses. Although some measures used are applicable to measure leanness in a warehouse environment, most measures are only valid and applicable within a production environment.

Lean warehousing should lead to improvement in the delivered added value towards customers and the performance of internal processes. Eventually an organization with a lean philosophy reduces non-value adding processes to a minimum, which increases the amount of resources available for value adding activities. Summing it all up; organizations dedicate serious amounts of resources to improve performance by becoming leaner, without having a refined method to measure leanness within a warehouse environment and without knowing if and how it actual improves warehouse performance.

1.2 Research objective

Based on exploration of theory and practice the objective of this research is; 'to investigate the impact of lean maturity – resulting of lean philosophy and practices within a warehouse environment – on warehouse performance'. The literature exploration of this research proposal indicates that researchers assume the existence of a positive relation between lean maturity and warehouse performance, but empirical evidence for this claim is limited. This study tries to assess the impact of lean maturity on performance of a sample of warehouses by comparing the lean maturity and performance of these warehouses to (semi) publicly available data.

1.3 Research questions

The main research question of this thesis will be:

'How does lean warehousing influence the performance of a warehouse operation?'

To answer the above stated question, the following sub research questions are formed:

1. How do we define lean?
2. How can warehouse performance be measured?
3. What different lean maturity assessment models do exist?
4. How can lean maturity be assessed in warehouses?
5. Is there indication to assume that there is a relationship between a warehouse's lean maturity and performance?

1.4 Background

This thesis project is carried out with the support of Philips Lighting. Philips Lighting is one of Royal Philips NV's three main divisions. Frederik Philips and his son Gerard founded Royal Philips N.V. in 1891 as a family enterprise. Around the start of the 20^{th} century Philips became an important player in the lighting industry. In the early 1930s Philips diversified it's business by the production of vacuum tubes, electric razors and radios. Nowadays, Royal Philips N.V. is an electronics multinational divided into three business units; Healthcare, Lighting and, Consumer Lifestyle. In 2013, Royal Philips N.V.'s sales totaled €23,329 billion resulting in EBIT of €1,991 billion.

Philips Lighting is a vital part of Royal Philips N.V's core activities. Philips Lighting produces and sources goods to serve five markets; professional lighting, lumileds, automotive, consumer lighting and, consumer luminaires. Environmental awareness has a large impact on Philips Lighting's business and hence the firm observed large growth in the lumileds market and other LED based product groups. This thesis research is carried within the context of Philips Lighting's distribution organization North-Western Europe. This distribution organization consists of two warehouses located in Southern Netherlands. These warehouses serve as European Distribution Centre and as Export Distribution Centre. Both warehouses are part of Philips Lighting's commercial supply chain. Hence, the function of the warehouses is to distribute products through the commercial channels of Philips Lighting. The commercial channel distribute products to other Philips subsidiaries and external parties such as DIY shops, construction companies, and other manufacturers.

The warehouses are private owned by Philips Lighting and are managed by a single management team. In total the warehouses employ approximately 280 people. The main focus of Philips Lighting's distribution organization is delivery reliability. Although costs are also used in the evaluation of warehouse performance, delivery reliability is the main key performance indicator. Because of that strategy of both warehouses is focused on increasing delivery performance while keep the cost level stable.

Chapter 2: Literature review

2.1 Lean production

2.1.1 Historical background

Lean production originates from the Toyota Production System. The TPS is a production method invented by Taiichi Ohno, a former Toyota engineer. Taiichi Ohno realised Toyota had to implement a production method that would incorporate the benefits of both craft-production and mass-production if the company wanted to compete with Western automotive companies (Womack et al., 1991). The TPS delivered Toyota a sustainable competitive advantage over the Western competition within the automotive industry (Warnecke and Huser, 1995). Toyota's success story caused a widespread dispersion of lean production practices. The diffusion started within the Western automotive companies and diffused over the years within other industries, organizations and countries (Shah and Ward, 2007).

The ultimate goal of the Toyota Production System is to create a continuous flow by absolute elimination of waste, or *muda* in Japanese. The two main methods to reduce waste are just-in-time and autonomation. Just-in-time means that parts go only to the next process after a trigger of end customer demand. Autonomation refers to automation with a human touch (Ohno, 1978). By these principles Toyota tried to eliminate seven wastes (Womack et al., 1991; Ohno, 1978):

1. Defects
2. Overproduction
3. Waiting
4. Unnecessary motion
5. Unnecessary inventory
6. Transporting
7. Inappropriate processing

The Toyota Production System was introduced to the Western world by *The Machine that Changed the World*, a publication of Womack, Jones and, Roos (1991). These MIT researchers tried to grasp the secret of Toyota's success as part of an International Motor Vehicle Program's benchmarking study. Womack et al. (1991) described TPS as a production system capable of delivering the benefits of both mass-production and crafts production. TPS enables Toyota to make small batches of a variety of products whenever needed and eliminate large stocks. By doing so Toyota is able to cut costs and improve the flexibility of their operation. According to Womack et al. (1991) most elements of TPS have a high applicability within manufacturing companies, also at companies outside the Japanese automotive industry. Womack and Jones (1996) see lean production as a way to maximise the value delivered to customers by reduction of operational waste.

2.1.2 Lean production definition

Although lean production is widely implemented in practice, there is no strict definition of the concept. Reviewing the literature provides an overview of the definitions used by different studies. It shows the confusion in theory and practice about the operational and conceptual definition of lean production. Furthermore, it serves as a starting point to create a measure of leanness in a warehouse environment. At conceptual level lean production is defined as a combination of management practices working synergistically to create high quality systems producing high quality products or services without any waste, driven by customer demand (Shah and Ward, 2003). Katayama and Bennett (1996) define lean as a production system striving for increased customer satisfaction through high output performance while also consuming less input factors. Warnecke and Huber (1995) define lean management as a system of measures and methods, which has the potential to bring a lean and competitive state throughout product development, chain of supply, shop floor management, and after-sales service. Where Ohno invented the TPS to reduce waste within a production environment, Warnecke and Huber (1995) propose a lean management philosophy that reduces waste throughout the whole value chain.

At a more operational level lean production definitions have a clear tool and/or practice-based focus. Shah and Ward (2003) reviewed 16 studies on high performance and lean manufacturing. The review shows companies most often adopt just-in-time production, continuous improvement programs, pull/kanban systems, continuous flow production and, quick changeover methods. Another operational definition of lean is based on determinants. Determinants consist of the actions taken, the tools and practices implemented, and the change made to an organization to achieve higher performance levels. According to Karlsson and Åhlström (1996) lean manufacturing consists of 8 determinants. It is a system approach built on waste elimination, continuous improvement, multifunctional teams, JIT, zero defects, vertical information systems, decentralization of responsibilities and pull based production.

To capture the breadth scope of possible practices implemented when adopting a lean production system Shah and Ward (2003) developed a definition based on bundles. The work of Shah and Ward is regarded as standard work when studying lean management Overboom et al., 2010). Shah and Ward (2003) define lean production by four bundles of 22 practices:

The first bundle defined is *Just In Time (JIT).* JIT is the key element of lean production (Arnheiter and Maleyeff, 2005) and consists of all practices related to JIT. These practices focus primarily on waste reduction by cutting WIP inventory and unnecessary delays (Harrison and Hoek, 2005). These wastes are reduced by production flow practices, such as lot size reduction, cycle time reduction, quick changeover, cellular manufacturing and, bottleneck removal. JIT implies a pull based production system. Pull production systems apply a make-to-order strategy if possible, meaning nothing is made until the end-customer demands it (Arnheiter and Maleyeff, 2005).

The second bundle involves all practices related to *Total Quality Management (TQM)*. TQM focuses on continuous improvement. Improvement starts with *kaikaku*, a radical improvement of existing processes, in most case through Value Stream Mapping (VSM). After initially rethinking the process, the process is continuously improved through *kaizen,* incremental improvements of existing processes without disrupting the process (Arnheiter and Maleyeff, 2005).

The third core element of lean production is *Total Productive Maintenance (TPM)*. This bundle includes all preventive and predictive maintenance practices and maintenance optimization techniques adopted to maximize production equipment effectiveness (Shah and Ward, 2003). Besides maintenance, this bundle also includes safety improvement programs. Safety improvement programs are a typical practice implemented in a lean warehouse. Most lean warehouses adopt a 5S housekeeping policy. As shown in table (1 5S is an abbreviation of shine, sort, straighten, standardize and sustain. By applying a 5S companies have a safer

Japanse 5S	**English 5S**
Seiri	Sort: Sort items and discard unnecessary items.
Seiton	Straighten: Arrange items in a logic order, to increase the ease of working.
Seisio	Shine: Planned and preventive cleaning of the workplace.
Seiketsu	Standardize: Set standards with respect to the first 3s and confirm with these standards.
Shtisuke	Sustain: Sustain the previous Ss by training and auditing people on regular base.

Table 1 5S

shop floor and will be able to identify and eliminate waste (Ahuja and Khamba, 2008; Kobayashi et al., 2008).

The last bundle of Shah and Ward's (2003) definition of lean production is *Human Resource Management* (HRM). As described in section 2.1.3 most companies focus on the practices and tools involved in lean production, whereas more cultural factors often get less attention. Within the initial TPS, workers were empowered to stop the product line when a problem arises and solve this problem with other shop floor workers (Womack et al., 1991). Furthermore, workers should be multi skilled to enhance a firm's flexibility (Ohno, 1978). To develop the skills of workers companies should implement job rotation, job enlargement, employee involvement and formal training practices (Shah and Ward, 2003).

Table 3 summarizes 9 studies with regard to the definition of lean production used. All of these studies were scanned based on the practices mentioned and used to define lean production or lean manufacturing. Definitions used in research involve most of the time Pull/kanban, continuous improvement programs/kaizen, single piece flow, Single-Minute Exchange of Die and worker involvement. Total Quality Management, supplier base reduction, Value Stream Mapping, production smoothing, cycle time reduction are the least popular practices in literature. An explanation of the lack of these practices in literature could be that these practices are taken into account within other practices, for example production smoothing involves often pull based production and single piece flow. TQM is not often used in literature on lean production since TQM is seen as a production system or management philosophy on its own. VSM is most often used as a tool to support continuous improvement and therefore not often cited in lean production definitions. Table shows the development of the research field of lean production, more recent studies involve a wider variety of practices.

After reviewing the literature on lean production definition it can be concluded that lean production involves a wide variety of tools and practices. Therefore, Shah and Ward (2007) suggest companies to adopt a configurational point of view with regard to lean. This means lean production should be viewed as a configuration of practices and tools, rather than a fixed set of techniques and practices. A company has to be critical in selecting the appropriate lean practices instead of implementing all lean practices. Depending on environmental factors most improvement initiatives have a positive impact on some performance aspects, but some practices also negatively impact other performance aspects (Wan and Chen, 2008). Therefore, companies should ask themselves how lean a system should be before and during the implementation of lean practices (Wan, 2006). Especially if companies see lean production as a journey towards perfection, companies often focus more on the process of becoming lean than on the desired outcome. In such a situation Radnor and Roaden (2004) state that a companies risk to miss the optimum point of leanness and by doing so move into a state of anorexia instead. Corporate anorexia is defined as a state in which an organization is not able to utilize and allocate resources effectively (Radnor and Roaden, 2004).

Although lean production is widespread adopted in various manufacturing based industries, especially in high volume and high repeatability industries, the adoption rate in other industries is low (James-Moore and Gibbons, 1997). According to Womack (2013) and Arnheiter and Maleyeff (2005) this phenomenon is caused by four key misconceptions:

1. *Lean means layoffs*.
2. *Lean is all about manufacturing.*
3. *Lean only works within certain environments*.
4. *Lean improvements are made by production workers only.*

2.1.3 The impact of lean on performance

Various studies have investigated the effect of lean production on performance. Table 2 gives an overview of improvements in performance found by these studies. As can be seen lean production can lead to reduction in cost, time, and inventory as well as improvements in quality and productivity.

Study	**Scope**	**Observed impact**
Cook et al. (2005)	Warehousing	71% decrease in inbound cycle time, 76% decrease in inventory levels, required storage space decreased by 51%.
Dehdari (2013)	Warehousing	Implementing lean based on Dehdari method to a level of 30 will increase warehouse productivity by at least 5%.
Demeter and Matyusz (2011)	Manufacturing	35,8% reduction of inventory days of raw materials, 33,8% reduction of inventory days of WIP, 46,9% reduction of inventory days of finished goods.
Jaca et al. (2012)	Warehousing	9,34% improvement in overall warehouse productivity.
Shah and Ward (2003)	Manufacturing	Lean production has a significant positive influence on scrap costs, cycle time, lead-time, labor productivity and manufacturing costs.
Swank (2003)	Services	60% reduction in response time, 28% reduction in labor costs and, 40% reduction of reissues due to errors.
Yang et al. (2011)	Manufacturing	Significant effect of $\beta = 0,394$ on market performance and $\beta = 0,283$ on financial performance.

Table 2 The effect of lean production on performance

Lean practices	Source								
	1	2	3	4	5	6	7	8	**Total**
Kanban/pull	X	X	X	X	X	X	X	X	8
Continuous improvement programs	X	X	X	X	X			X	6
Single piece flow	X	X	X	X	X			X	6
SMED/quick changeover	X	X	X	X		X		X	6
Worker involvement	X	X	X	X			X	X	6
Cellular Manufacturing	X	X	X		X		X		5
Cross functional workforce	X		X	X		X	X		5
Supplier involvement		X	X		X	X		X	5
TPM	X	X	X	X		X			5
Training			X	X		X	X	X	5
7 Wastes		X		X	X	X			4
Kaikaku/production process redesign		X	X		X			X	4
SPC			X	X		X	X		4
Customer involvement			X			X		X	3
Five S / Safety improvement program	X	X					X		3
JIT	X			X	X				3
Visual management		X					X	X	3
Poka yoke				X	X	X			3
Cycle time reduction	X				X				2
Production Smoothing			X					X	2
VSM		X					X		2
Supplier base reduction		X							1
TQM	X								1

Table 3 Lean practices in literature

1) Shah and Ward (2003), 2) Bhasin and Burcher (2004), 3) Shah and Ward (2007), 4) Karlsson and Åhlström (1996), 5) Arnheiter and Maleyeff (2005), 6) James-Moore and Gibbons (1997), 7) Green et al. (2010) 8) Wahab et al. (2013)

2.1.4 Lean thinking: a philosophical point of view

According to Shah and Ward (2007) lean production is generally described from two perspectives. One can describe lean production from a practice-based point of view, as done in the section 2.1.2 of this thesis. Another perspective is the philosophical point of view. A lean philosophy embraces besides lean practices also the more cultural side of lean (Bhasin and Burcher, 2006). In the early nineties most companies in US that tried to adopt lean production failed. These companies implemented lean production entirely tool-focused, totally neglecting the cultural of lean production approach (Hines et al., 2004). This proves cultural and social aspects are important during a lean journey.

Womack and Jones (1996) introduced the philosophical perspective of lean production in the Western world by their second publication *Lean Thinking: Banishing Waste and Create Wealth in your Corporation.* The emphasis of Womack et al.'s (1991) first book on lean production was on manufacturing, with some sidesteps to other areas of the firm. *Lean Thinking* describes lean practices not as lean manufacturing, but as lean enterprises. According to Womack and Jones (1996) lean thinking means: "*to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively*." The authors introduce five lean thinking principles to achieve this:

1. *Specify value from the viewpoint of the end customer.*
2. *Map all your value streams derived from product families.*
3. *Create flow throughout the company.*
4. *Produce based on pull.*
5. *Perfection.*

The lean thinking concept triggered researchers to study cultural elements of lean production. Henderson et al. (1999) state a lean culture is at least as important as the tools implemented to benefit from lean production. Whereas many organizations see lean production as tactical or operational method to improve operations, the right approach is to see lean as a strategic journey with a clear defined end goal. In the end lean production should be a way of solving problems and a true companywide mindset, rather than a bundle of tools and practices (Elliot, 2001). According to Bhasin and Burcher (2006) a lean culture and mindset consists of the following elements:

- Empowerment of employees by making decisions on the lowest possible level.

- Lean champions at different levels of the organization should support lean production implementation.
- Involve the supplier base and establish relationship based on mutual trust and commitment.
- Measure and visualize the progress of the implementation of lean production.
- Focus on the customer and involve them in your operation.
- Long-term commitment towards a lean strategy and vision.
- Promote lean leadership at all levels of your organization.
- Maintain the challenge of continuous improvement of existing processes.

Karlsson and Åhlström (1996) argue performance metrics should be in place to stimulate a lean culture. Continuous improvement should be measured through the number of kaizen suggestions per employee per time period. Furthermore, companies should measure the degree of job and leadership rotation. Leadership rotation trains every employee as a potential team leader on the shop floor and rotates the leadership among all the employees. By clearly defining objectives concerning the lean culture of an organization and measure on a frequent base lean culture is stimulated.

The findings of Karlsson and Ahlstrom and Bhasin and Burcher are confirmed by Angelis et al. (2011). According to these researchers affective commitment is conditional to successfully implement lean production. Affective commitment is the strongest form of commitment, enabling people to go beyond the boundaries of their job by attaching to and identifying with an organization (Meyer et al., 1993). The degree of affective commitment is a result of positive and negative influencers. Affective commitment is positively influenced by giving people a sense of autonomy and control and negatively influenced by increased work demand under poor labour conditions, for instance poor ergonomics and tools (Angelis et al., 2011). Poor ergonomics and tools can easily be fixed by practices associated with lean. Poor ergonomics are part of 5S philosophy and the condition of tools can be managed by TPM. Job rotation, leadership rotation, line stopping and employee involvement in continuous improvement offer employees a sense of control and autonomy. These features are considered as main features of a lean culture (Bhasin and Burcher, 2006; Karlsson and Åhlström, 1996). This shows multiple lean practices can create the required affective commitment to eventually adopt a lean strategy.

2.2 Lean in logistics and warehousing

2.2.1 Applicability of lean in different environments

Ohno (1978) developed the Toyota Production System based on a manufacturing environment with high-volume and high-repeatability. Toyota's manufacturing environment is characterized by discrete processes, with predictable demand. Because of that not all practices discussed in this literature review apply to other environments, e.g. to the warehouse. Some practices can be implemented in other environments, but do not deliver the same added value as in a production environment. Other practices can be implemented easier and more effective in other environments, e.g. line stopping (Åhlström, 2010). Wilson (2010) acknowledges that lean production is only partly applicable within environments other than manufacturing. Within these environments lean production may not deliver the same benefits. An organization in which lean production could be applied should meet the following criteria:

- The organization should be in a strong competitive market. Implementation of lean requires a change of culture, which can only be enforced by an urgency to change.
- The organization should have a clear customer-focus. The organization has a clear definition of customers, their needs and what they want.
- The organization supplies value to customers, this either be tangible and intangible products as well as services. The supply of value can be mapped in a VSM to identify and eliminate waste.
- The organization has a long-term focus, also when practices harm the short-term results. Lean practices try to achieve sustainable improvements based on employee involvement. This requires investments meaning in some cases firms will not be able to attain their short-term financial goals (Jaca et al., 2012).

The above-mentioned criteria apply to almost every warehouse. Warehouses operate in a highly competitive environment. Most warehouses are part of a company's supply chain and therefore not seen as a source of profit. This does not mean these operations do not operate in a competitive environment. For instance most insourced warehouse operations have to prove constantly that they are able to operate at least as efficient and cost effective as third-party logistic suppliers. Furthermore, warehouses are in most cases the last link between a company and its customers. This implies that warehouses have a strong customer focus and supply a value stream towards customers. As in every industry the focus of a warehouse depends on its management and can either be long term or short term oriented.

From the criteria provided by Wilson (2010) cannot be concluded that lean production is not applicable in a warehouse environment.

Swank (2003) and Åhlström (2010) prove the criteria specified by Wilson (2010) suffice to implement a lean strategy. These studies provide examples of lean production implemented in a service environment with high variability. To implement lean production in a service environment a service has to be seen as a process of steps adding value to the work in progress (Swank, 2003). This process should be improved by applying the general waste elimination tools described earlier. Because of the involvement of customers in services eliminating waste from the process is more complicated. What may seem as waste in the service process might to some customers be adding value to their experience (Åhlström, 2010). The involvement of customer in service also complicates the implementation of lean in service processes. The implementation of lean may never disrupt the operation, since customers directly interact with it. Firms therefore introduce lean through a model cell rollout, in which only a minor part of the service process is fully transformed by lean (Swank, 2003). Furthermore, goal setting is much more important in a service environment. People rather than machines "produce" services to motivate these people goals are vital. Shop-floor goals should be linked to a firm's strategic goals (Swank, 2003).

If TPS fits the service environment, which differs significantly from a standard manufacturing environment, warehouse operations should also be able to adopt the production system.

2.2.1 Lean warehousing

Lean philosophy focuses on reduction of inventory, since it is seen as a waste. In most supply chains warehouses are utilized to store inventory and can be therefore be seen as a form of waste. However, in practice most warehouses add value to the customer by creating time and place utility. To maximize the value added a supply chain lean companies adopt lean distribution. Lean distribution can be defined as minimizing waste in the downstream supply chain, while making the right product available to the end customer at the right time and location (Reichart and Holweg, 2007). The warehouse is an important part of the downstream supply chain. Research on lean warehousing is not abundant. In recent years multiple researchers have studied the impact of lean warehousing on performance and how to measure lean maturity (Dehdari, 2013; Sobianski, 2009; Mahfouz, 2011; Shan, 2008). This suggests that lean warehousing is an upcoming research field. Upcoming research fields often lack clear definitions, measurements and concepts.

Adoption of a lean culture in a warehouse environment enables the supply chain to deliver extra added value. Dehdari (2013) therefore defines lean warehousing as a leadership concept, rather than a set of tools and practices. The leadership concept aims at continuous, sustainable and measurable improvements in the warehouse environment by employee involvement and an attitude to gain perfection in each corporate action. Although lean warehousing focuses on culture and leadership, implementing a lean program in the warehouse encompasses a broad scope of practices instead of a single and isolated set of lean practices (Flinchbaugh, 2005). According to Mahfouz (2011) lean warehousing aims at increasing responsiveness to market demand and the reduction of total cost by simplifying distribution operations. Responsiveness is often associated with agile production practices instead of lean production. Lean and agile are two concepts that are not mutually exclusive. Both concepts focus on reduction of lead times and a strong customer focus (Baker, 2004). Value in a warehousing is created by being responsive to customer order and because of that lean warehousing encompasses elements of agile production.

Within a warehouse environment orders are the products assembled. Therefore lean in the warehouse focuses on assembling warehouse orders in the most efficient way, minimizing non-value adding activities in receiving, put a way, picking, packing and shipping (Myerson, 2008). To minimize non-value adding activities warehouses have to identify wastes. The seven wastes of lean production have be converted to a warehouse environment (Haan et al., 2009):

1. Defects → handling and shipment of defective products.
2. Overproduction → replenishing, packing and picking products not yet needed.
3. Waiting → Picked goods waiting for inspection, shipment or packing.
4. Unnecessary motion → unnecessary movement of pickers and packers due to inefficient routing.
5. Unnecessary inventory → storing to many inventory, having inventory on the shop floor as a consequence of batch system.
6. Transporting → inefficient movement of products through inefficient layout and routing.
7. Inappropriate processing → unnecessary inspection of picked orders and unnecessary packing.

Hines and Rich (1997) studied the Toyota part supply system, shown in figure 1, to identify Toyota's method of lean logistics. Toyota applies the same type of thinking within warehousing as within production, but uses slightly different methods. Within warehousing

Toyota's main aim is to minimize bin sizes and to enhance picking effectiveness parts, by storing goods by part type with an ABC storage policy. Toyota also uses specific routing methods. It has standard binning and picking routes based on part type, divides the working day and tasks into standard work cycles, synchronizes order-pick-pack-dispatch and delivery steps for each delivery route (again a milk round) based on demand flows. Progress is controlled through binning or picking ticket bundles for each cycle to prevent working ahead and by visual control boards. Furthermore, Toyota logs irregularities and prioritization in order to conduct root cause elimination of the most frequent problems to prevent recurrences and hence improve the process.

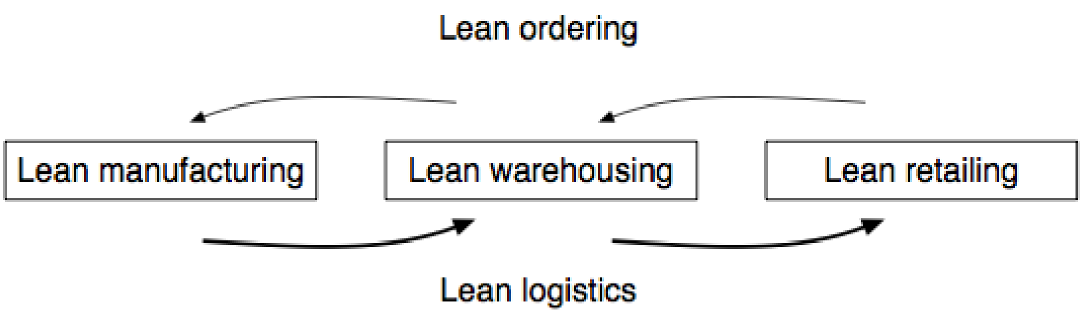

Figure 1 Lean distribution

According to Green et al. (2010) lean in a material-handling environment encompasses two main elements; value stream mapping to define the optimal future situation and analysis of the logistics flows used to move products in order to optimize the facility layout. Both practices aim to continuously improve the operation. Traditional warehouses should become cross-dock operations. Lean cross-docking operations should integrate principles as heijunka planning, advanced routing methods and kanban. These principles would create flow in picking, packing and replenishing while simultaneously reducing average order cycle time (Cook et al., 2005).

Based on experience and theoretical input Bozer (2012) was able to provide a rather complete definition of lean warehousing. Based on Bozer's research lean warehousing is a management system composed of the following principles:

- Use 5S to achieve perfection within the warehouse.
- Continuously improve your warehouse through problem solving and kaizen. Promotion of continuous improvement is of utmost importance to achieve meaningful improvements.

- Visualize the work within the warehouse real-time. Furthermore, start shifts with meetings to discuss performance, improvement opportunities and potential difficulties.
- Standardize your warehouse. Use standardized equipment within your warehouse and standardize process through paper-based work instructions.
- Reduce the number of "touch points" for every order.
- Reduce excess inventory by single piece flow and frequent small replenishment cycles.
- Measure, improve, and justify cubic and square-feet storage density with the intent to improve storage as well as travel times.
- Create flow by scheduling inbound/outbound shipments by time windows and dispatching orders based on available capacity. Furthermore, create level the workload between different functional departments within the warehouse.
- Store products to enable the minimization of travel distance, minimization of picking time and optimization of storage density.
- Train blue collar workers on Lean principles, and stimulate lean leadership on the warehouse floor. Implement by pilot facilities for lean rather than full implementation from the start. Implementation and lean leadership have to be enabled by continuous learning and training.

2.3 Conclusion

The literature review conducted in this chapter provides an overview of literature on lean production, lean thinking and lean warehousing. It can be concluded that lean production is not only applicable within production or manufacturing environments. Also other environments can benefit from the principles of lean production. Although multiple researchers identified the potential of lean within for example a service environment or a logistics environment, empirical evidence of the benefits implementing lean within these environments is limited. Section 2.1.3 shows researchers observed increased productivity and reduced amounts of errors after implementation of lean practices in a warehouse. Unfortunately these studies do not use a generalized measure of performance and a comparable definition of lean. Hence the value of some of these studies is questionable. The findings of Dehdari (2012) provide empirical evidence of the positive effect on productivity of lean warehousing. Using a control group and a time based experimental design Dehdari proves lean warehousing has a positive impact on warehouse productivity. The methodology chapter will further elaborate on the methods used within Dehdari's study.

To study the phenomenon of lean production within a warehouse environment a clear definition of the concept is needed. Section 2.2.1 provides a comprehensive overview of lean practices applicable in the warehouse. Warehouse and production environment differ and hence the definition of lean production differs from the definition of lean warehousing. Production environment can be often described as repetitive, large batch sizes, mechanized and low volatility. Within the warehouse each order is unique, although processes used to process an order can be similar, the batch size is often one and value is added by employee rather than by machines. Furthermore, production is typically triggered by forecasts, whereas warehouses operate using a make-to-order policy (Dehdari and Schwab, 2012). These differences make certain lean practices less relevant or even irrelevant within a warehouse environment. Therefore, measuring and defining lean warehousing should take these differences in consideration.

The principles mentioned by Bozer (2012) give a broad overview of lean in the warehouse. Practices and cultural aspects mentioned by Bozer encompass elements that most other studies use to define lean production. The principles contain elements of Total Preventive Maintenance, Flow and Pull, Statistical Process Control, Continuous Improvement and Employee Involvement. Unfortunately the principles do not grasp the core of lean production. The core of lean production is a customer focused mentioned. Hence, the definition used within this study adds customer focus and elimination of non-value adding processes and activities to list of principles of Bozer (2012).

Chapter 3: Exploration of Practice

Besides all that has been written on lean in warehousing an exploration of practice can also be useful to create a broader insight in often adopted lean practices within the warehouse. Practice was explored by interviews with lean warehousing specialist from practice and by guided warehouse tours through four warehouses. According to the practitioners lean warehousing is all about culture and less about practices implemented. Within a production environment lean is all about creating pull and flow by operating based on customer demand instead forecasts. Almost all warehouse processes are driven by customer orders and hence the focus on pull and flow is less relevant for lean in a warehouse operation. Practices normally used to create flow and pull as for example heijunka planning and kanban systems are not necessary in a lean warehouse, although these tools can be used within specific warehouse processes. For example in three warehouses that were visited the supply of packaging materials in the parcel department was based on a kanban system.

The starting point of lean practices in all visited warehouses was 5S or 6S. 6S is combines all 5S with a safety focus. According to lean practitioners 5S creates a safer and more structured working environment. Because of that in all four warehouses daily 5S practices were mandatory and scheduled. Two of the four warehouses assigned the responsibility of 5S activities of specific zones to specific shop-floor employees to empower and involve employees on the lowest level. Furthermore, three of warehouses assessed the 5S score of the total facility and all different departments monthly. The interviewed practitioners mentioned that 5S results in a more organized and cleaner operation, which enables to expose non-value adding activities in processes easier.

To create a lean culture the four warehouse operations organized mandatory and voluntarily trainings and seminars for both shop floor employees and management. Two of the four warehouses gave every new employee a safety instruction training including the basic principles of the lean program implemented at the facility. Furthermore all warehouses maintained and visualized lists of the skills and experience of the employees to stimulate training and education. Another practice implemented is a sort of self-assessment of shop-floor employees. Every day one shop-floor employee is asked to assess the knowledge of another employee by asking three questions with regard to lean production. According to the practitioners education and training is one of the key elements of implementing a successful lean program. Training and education give employees on all levels of the organization the tools to constantly seek for opportunities of improvement and solving problems by using structured and validated problem solving methods.

A third practice that was observed in all warehouses and mentioned by all practitioners was *kaizen*. *Kaizen* forms the base of continuous improvement in the warehouse. In all the warehouses departments are obliged to come up with a certain amount of improvement suggestions or kaizen every month or two months. Execution of kaizens is a team effort of the department and all warehouses provide guidance by middle or top management to stimulate involvement. Another best practice observed in three warehouses is a monthly selection of the best kaizen to stimulate all employees to come up with excellent improvement ideas. Especially the shop floor employees seem to appreciate the idea of the possibility of reward for a kaizen. The lean specialist indicate that kaizen is a powerful tool, but that forcing to deliver certain amount of kaizen every month creates infeasible and useless improvement ideas. Furthermore, improvements based on kaizen are very time consuming due to the use of structured forms and methods. Some improvements could be implemented faster and easier when the specific kaizen methods are not applied. The experts indicate that kaizen creates a culture of continuous improvement, but can also be a hurdle to implement small improvements.

Lean warehousing also emphasizes the importance of visualization and performance measurement. On the warehouse floor the lean production can be observed by the presence of communication cells. In all "lean" warehouses visited department had their own communication cells. Communication cells are information boards with an overview of department specific KPIs, often measured on a daily base. Examples of such KPIs are internal complaint rates, department specific productivity rates, on time shipment, and accident rates. The communication cell functions as a starting point of every shift. At the begin of every shift employees gather around the communication cell discussing amongst others last day KPIs, expected workload for the coming shift, potential problems, and potential improvement actions. Typically every employee is responsible for a certain KPI to create commitment within the team to the performance.

All before mentioned lean practices observed in practice and discussed with experts are aimed at shop floor employees. On a more tactical or even strategic level lean warehousing focuses on other areas. The most important lean practices applied by top and middle management is value stream mapping. By mapping the current value stream and desired value stream management provides a guideline for process redesign and reduction of non-value adding steps in processes. Lean experts of 2 warehouses indicated that value stream mapping is a complicated process for warehouse operations. Most warehouses are organized based on functional departments rather than on value streams. Hence, mapping value streams involves multiple functional departments making the process of value stream mapping complicated.

Moreover, on a tactical level lean warehousing involves creating efficiencies in storage, picking, and shipping. Reducing travel distance according to the experts interviewed creates efficiencies in storage and picking. Therefore lean warehousing involves practices as ABC storage, flow picking, and storage for easy picking. All these principles are not specific to lean warehouses and are also applied non lean warehouses. However, the focus on waste reduction should increase the emphasis on the before mentioned practices. The lean experts mention that management is not always aware of the importance of these kinds of improvements and rather focus on more visible lean practices.

The warehouses visited and practitioners interviewed have different opinions on the benefits of lean principles in the warehouse. However, all experts stated that increased productivity is hard to measure. Especially, since increased productivity can be the effect of changes in environment or customer orders. Two warehouses claim that the reliability of deliveries increased through the implementation of lean practices and that employees show higher satisfaction scores. The third party logistics suppliers involved in this study see lean warehousing as a marketing tool with additional benefits. Customers of 3PL suppliers are impressed by the lean principles in the warehouse, because warehouses look structured, clean, and much more advanced than traditional warehouses. Another 3PL supplier actually studied the influence of lean on productivity and employee satisfaction. This study did not provide any prove of improvements in productivity and employee satisfaction caused by lean practices. According to the 3PL supplier improvements were marginal and these improvements could just a nice be caused by other circumstances.

Exploration of practice provided a broader overview of lean practices in the warehouse. Compared to the findings of the exploration of theory many similarities can be found. The principles listed by Bozer (2012) are observed in the warehouses visited. Of course this does not mean that warehouses visited are perfectly lean. Although the principles can be found in a warehouse, does not automatically mean that the principles are implemented consistently and in the right way.

Chapter 4: Methodology

4.1 Research design

The research carried out in this thesis should be classified as exploratory (Bryman and Bell, 2007). The choice for an exploratory type of research is driven by the lack of studies on lean management in a logistics or warehouse environment. Most research carried out on lean management is carried in a manufacturing or production environment. Therefore this thesis will try to develop a lean maturity assessment model suitable for a warehousing operation and try to link the degree of leanness to warehouse performance.

To explore the existing literature on lean in different environments an extensive literature review is carried out. The literature study reviewed the definition of lean, different lean practices and lean philosophy. Based on this literature study and an exploration of practice the most important lean practices in the warehouse are identified. This defined is used as the main source of input to the criteria used in the lean maturity assessment model. Furthermore, the thesis will provide an overview of existing lean maturity assessment models and measures of leanness. The suitability of these models in warehouse environment is assessed and discussed in section 4.2.1. The discussed lean maturity assessment models together with the criteria found in literature are the foundation of the model developed in this thesis to assess a warehouse's lean maturity.

This study uses a comparative case study design to study the relationship between *lean maturity* and *warehouse performance*. This method uses more or less identical methods to study two or more contrasting cases. The case study will be based on a representative or typical case, a case that exemplifies a situation or form of organization (Bryman and Bell, 2007). A case study design is probably not the most used research design to study causal claims, since an experimental design is most suitable for studying cause and effect relationships. An experimental design requires a control group. Since the research is carried out within the environment of a real organization it is not possible to create a control group. The warehouses that are part of this study have already implemented lean practices and measures. Because of that finding a control environment without lean practices in place is impossible.

The best alternative for studying the linkage between lean maturity and warehouse performance is a comparative case study. The research will compare the lean maturity and achieved warehouse performance of a subset of warehouses. Due to time and resources constraints the number of warehouses studied is limited, as a consequence the external validity of this research design is limited. To cope with this problem and to increase the feasibility the data of the subset of warehouses is compared to another dataset. The source of this dataset is a study carried out by de Koster and Balk (2008), which benchmarks of a set of warehouse by using data envelopment analysis. By comparing the results of this external sources the external validity of the study will be higher. This will increase the value of conclusions drawn from the study.

4.2 Theoretical concepts

4.2.1 Lean maturity

Numerous researchers have developed methods to measure the degree of implementation of lean practices. These studies either assess lean maturity or the degree of leanness. The popularity of maturity models stems from the Capability Maturity Model Integration. CMMI measures organizations' maturity level on a five-point scale. The CMMI defines processes as initial, managed, defined, quantified and optimizing (Paulk et al, 1993). The scales and methods used by many lean maturity assessment models are derived from this model. Leanness measures how efficient resources are used. Efficient use of resources is achieved by waste reduction through the implementation of lean practices (Narasimhan, 2006). Leanness is often measured on an ordinal scale. In general leanness measures are more suitable using a survey based method, whereas maturity models require the assessment of external or internal specialists.

Table 4 gives an overview of different lean maturity and leanness measurement models. The table summarizes the environment for which each method is developed, the practices involved in the measurement constructs and important remarks with respect the developed of the measurement model.

Study	Scope	Measurement constructs	Method/Remarks
Bhasin (2008)	Lean maturity audit developed for manufacturing environment.	Overall safety, cleanliness and order; production and operation flow; process and operations; visual management; Quality designed into the product; continuous improvement; Lean change strategy; Lean sustainability; culture - employee oriented; organisational culture - organisational practices; Lean treated as a business; and Lean philosophy.	Method constructed based on feedback of 20 manufacturing organizations and firms. Audit primarily developed to identify an organization's stage of transition.
Bosch Warehouse Logistics Assessment Dehdari (2013)	Lean maturity assessment within multiple Bosch warehouses.	*Continuous improvement*: System CIP and process CIP. *Overall subjects*: Failure prevention systems, employee involvement and standardized work. *Warehouse processes*: Overhead, inbound, storage, packing, picking and outbound.	Development of lean maturity assessment matrix to evaluate impact of lean on warehouse productivity. Experiment research design, with control group. Assessment done by specialist, so non-survey based.
LESAT Nightingale and Mize (2002) / Hallam (2003)	Lean self- assessment matrix developed for aerospace industry in UK and USA.	Lean Transformation (28 measures) and Leadership, Life-Cycle Processes (measures) and Enabling Infrastructure (8 measures).	Matrix based lean capability maturity model, composed of 54 practices measured on a 5-point maturity scale. Developed by MIT to self-assess a firm's leanness. Both of assessment current level and of desired level of leanness.
Sobanski (2009)	Lean assessment model developed at 3PL Menlo warehouses	Standardized processes, people, quality assurance, visual management, workplace organization, lot sizing, material flow and continuous improvement.	Very extensive assessment model consisting of both questions assessing the presence of certain practices and questions measuring the degree of implementation of practices. Method assesses 58 lean practices by multiple measures. Assessment has to be carried out by lean specialist; due to complexity of the method self-assessment cannot be carried out.
Meijer and Forrester (2002)	Degree of leanness in tableware industry, measured at firm level.	*Degree of leanness:* *E*limination of waste, continuous improvement, zero defects, JIT delivery, pull, multifunctional teams, decentralization, integration of functions and vertical IS. *Management commitment*: Commitment to JIT/TQM, quality leadership, problem solving, training and empowerment.	Survey based research based on the findings of Karlsson and Ahlström (1996). Measuring lean adoption, degree of leanness and managerial commitment towards lean. Firms classified as LEAN, IN-TRANSITION or TRADITIONAL.

Overboom et al. (2010)	Measurement of degree leanness within two 3PLs in the Netherlands.	Lean *concepts*: receiver communication, pull, flow standardization, speed, SPC, employee involvement, TPM and outsider commitment/agreement.	Lean maturity model adapted to warehouse environment from Shah and Ward (2007). Leanness measured through a questionnaire, analyses of company websites and structured interviews with company representatives.
Philips Lighting Lean Maturity Assessment	Internal Philips measures developed to assess lean maturity within production environment.	Leadership philosophy, education and training, customer and process focus, heijunka and load smoothing, visual management, accountability, built-in quality, problem solving, empowerment, CIP, internal logistics, SMED, TPM and NPD.	Matrix based lean capability maturity model, composed of 40 practices measured on a 5-point maturity scale. Measurements are rather practice/tool based, e.g. 5S, kaizen and heijunka scheduling. Matrix to be filled out by external auditors.
Singh et al. (2010)	Leanness in Indian automotive industry, manufacturing scope.	Supplier issues, investment focus, lean practices, various wastes and customer issues.	Measurement approach based on expertise of different specialists. Using fuzzy theory to measure leanness and address bias of human judgment.
Wan and Frank – Chen (2008)	Leanness of manufacturing systems.	*Inputs*: time to process a product, total time in system of products, cost of material, labor/machine hour and inventory costs. *Outputs*: perfect products and less-than- perfect products.	Use of DEA to approach quantify and measure leanness. Inputs are weighted based on cost, time or value. Results are benchmarked to ideal leanness based on historical data.
Shah and Ward (2007)	Leanness within production environment.	Supplier related: Supplier feedback, JIT based supply, supplier involvement, Customer Related: customer involvement Internal related: Pull, flow, setup time reduction, TPM, SPC and employee involvement.	Survey based approach to quantify the degree of leanness. Critical factors of lean identified through empirical research. Measurement constructs created based on confirmatory factor analysis. Constructs measured on a 5-point scale, varying from no implementation to complete implementation.

Table 4 Lean Assessment models

This section provides an assessment of the assessment models shown in table 5. Based on these models the measurement model used to quantify leanness will be developed. To assess these models the following criteria are used:

- Warehouse focus: the focus of this study will be a warehouse environment, hence a method developed within a warehouse is preferred above methods developed for production or manufacturing. Warehouse focus is scored on a yes or no base.
- Research method: assessment methods can be either survey or non-survey based. Due to the limited amount of time to complete this research and difficulties to find warehouses willing to participate in this research survey based methods are preferred. Although survey based research has its limitations, especially in terms of biases, the ease of participation is much higher. Extensive assessment models require warehouse tours, structured interviews and unstructured interviews and are therefore too time-consuming for the purpose this study. Research method is scored on a yes or no base.
- Tested in practice: methods used to quantify lean maturity should be validated by extensive testing practice. This can either be during the development of the method or through extensive adoption of practice. This criterion is scored on a three-point scale.
- Consistency with lean definition: lean warehousing is defined in the literature review of this study. This definition is a combination of practices and cultural elements. The used measurement model should encompass both these elements. This criterion is scored on a three-point scale.

Table 5 gives an overview of the scores of each study on the criteria mentioned above. Based on this table the models developed by Dehdari (2012), Sobanski (2009), and Shah and Ward (2007) suit the best with the purpose of this study. Other studies are either developed within a manufacturing or production environment or not validated in practice. Therefore, the measurement model used to quantify lean maturity within this study will be either one of above-mentioned studies or a combination of constructs developed within these studies.

Dehdari (2013) developed his lean maturity model at Bosch GmbH. The model, named Bosch Logistics Warehouse Assessment is partly derived from the Bosch Production System Assessment and hence partly confidential. Although some parts are freely available, most of the measures are not. These measures are reported through the use of more generic statements that cannot be used to measure, but give an idea of the concept behind the measurement construct or item. Dehdari (2013) uses a two-stage measurement model. This model distinguishes for every criterion a standard and execution measure. The standard level measures to what extent a certain practice is implemented. The execution level tracks the improvement in a certain performance indicator that is linked to the implemented standard. Both standard and execution level should be present to achieve a score higher than zero on an assessment criteria. For example to score high on standard level of a certain criterion measures to create a safe working environment should be implemented. To score high on the execution level of this criterion the number of accidents in a certain should be decreased by a certain value. This method ensures that implementation of practices result in measurable achievements.

Study	Warehouse focus	Consistent with definition	Survey based	Validated in practice
Bhasin (2008)	NO	*	YES	**
Dehdari (2013)	YES	**	NO	***
Nightingale and Mize (2002) / Hallam (2003)	NO	*	NO	***
Sobanski (2009)	YES	***	NO	**
Meijer and Forrester (2002)	NO	**	YES	*
Overboom et al. (2010)	YES	**	YES	*
Philips Lighting Lean Maturity Assessment	NO	*	NO	**
Singh et al. (2010)	NO	*	YES	*
Wan and Frank–Chen (2008)	NO	*	NO	*
Shah and Ward (2007)	NO	**	YES	***

Table 5 Assessment of Lean Maturity models

Dehdari (2013) identifies six measurement constructs, consisting of multiple measurement items. According to Dehdari's study continuous improvement is a key element of lean warehousing. Continuous improvement is divided into *System Continuous Improvement Processes (CIP)* and *Point Continuous Improvement Processes*. System CIP contains continuous improvements based on planned system improvement sessions carried out by specialists. These improvements use sophisticated problem solving techniques, such as value stream mapping and SPC. From System CIP a new target condition is derived. A target condition consists of a standard, e.g. a Key Performance Indicator (KPI), and a deviation limit.

Point CIP activities are responsible for continuously improving parts of the system in order to meet the deviation limit.

The third construct assessed in this method is *failure prevention systems.* This construct measures whether statistical process control systems are in place and whether errors are visualized. Furthermore, Dehdari's assessment measures *employee involvement*. A construct measured through the flexibility of operators, rotation of team leadership, and leadership involvement. The fourth construct measures the degree of implementation of *standardized work*. Standardized work means all processes in the warehouse have a standardized worksheet that is visualized on the warehouse floor. Furthermore, all equipment has its own specific place on the warehouse floor and employees follow standardized trainings to achieve standardized capability levels among employees. The last construct measures the leanness of all *warehouses processes.* Warehouse processes contain inbound, storage, picking, packaging and shipping.

The Bosch Logistics Warehouse Assessment is not survey based. Applying the assessment to a warehouse takes a team of three to five specialists at Bosch on average two workdays. The link between practices and the performance gains achieved by this practices makes the assessment very time consuming. It is therefore not realistic to use this method for the purpose of this study. Furthermore, the method measures elements of both the independent variable and the dependent variables of this research. Hence the results when using this method will be not valid in this context. A third complication is the limited availability of this method. Most of the measurement constructs used in this study are not reported in Dehdari's report and therefore hard to reproduce.

Shah and Ward (2007) developed a valid measurement tool to quantify the leanness of an organization. Although the model is developed to measure leanness in a production environment, it could be useful to use the method in other environments. Based on citation score and journal ranking the Shah and Ward paper is one of the outstanding papers in the field of lean research. In comparison to other survey based lean maturity measurements the model developed by Shah and Ward performs high on reliability and validity. The measurement constructs are developed through a confirmatory factor analysis (CFA) on a sample of 280 firms. These firms were asked to self-assess their degree of leanness based on the implementation of an extensive list of lean practices. The CFA grouped 43 operational measures into 10 operational constructs. The operational constructs can be divided into supplier related, customer related and internally related constructs. Empirical analysis shows significant positive correlation between the 10 operational constructs, which suggests that lean production can be measured through these constructs where each construct represents a unique element of lean production. Lean production measurement constructs are interrelated since lean production is an integrated system. This system is composed of highly interrelated practices and elements.

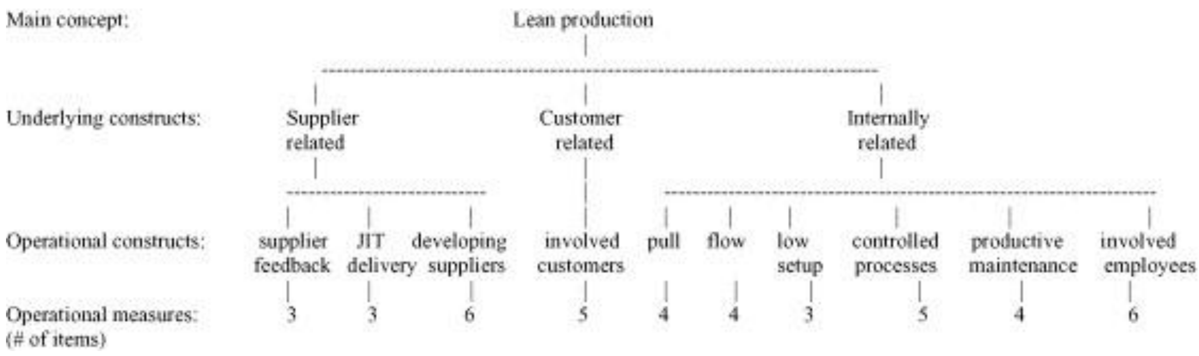

Figure 2 Leanness measure (Shah and Ward, 2007)

Figure 2 gives an overview of the model as developed by Shah and Ward (2007). The model has proven to be valid and reliable in a production and manufacturing. However, the specific environment of the warehouse makes some operational measures irrelevant. Shah and Ward (2007) assume lean production is an integrated system that incorporates both supplier and customer relations in all value chain processes. Since logistics and warehousing is only part of the value chain not all measures are relevant. Operational measures with regard to involvement of suppliers in new product development is not relevant for warehousing, since warehouses do not develop new products. This is also the case for customer involvement. One operational measure proposed by Shah and Ward is the involvement of customers in new product offerings. In most cases warehouses are not responsible for introducing new goods.

Also some internally related operational constructs and measures tend to be less applicable to measure leanness in a warehouse. The operational construct *pull* measures whether production is pulled by end demand instead of pushed by forecasts. As mentioned earlier processes in a warehouse are generally spoken pulled by a customer order, hence operating based on customer demand is not a good identifier of being lean in a warehouse environment. Also the operational construct *low setup time* is not relevant for lean warehousing. Low setup times enable a production firm to be responsive to changes in demand by quick-changeovers. The whole idea of benefiting from low setup time is based on the assumption that machines can produce multiple goods after certain changeovers. So by reducing the time it takes to changeover a machine, a firm can be more reactive to customer demand fluctuations. Within the warehouse more or less standardized processes are used to produce a service, rather than a product. To fulfill orders no changeovers are needed, because all orders require the same processes. So reduction of setup time does not deliver added value within a warehouse environment and is therefore no identifier of being a lean warehouse operation.

Based on this analysis the Shah and Ward's operational measure of lean maturity cannot be reproduced to quantify lean within a warehouse environment. However, the division of constructs based on the CFA can be useful as a guideline to develop an operational measure of leanness for a warehouse environment.

A third potential method to measure of leanness within a warehouse environment is developed by Sobanski (2009). This method is based on eight lean principles; standardized work, people, quality assurance, visual management, workplace organization, lot sizing, material flow, and continuous improvement. Based on these lean principles eight measurement constructs were identified. These eight constructs consist of 58 lean practices measured with a mix of ordinal, nominal, and interval scales. Warehouse operation specific elements were measured through six constructs; inbound operations, outbound operations, inventory control, material returns, general facility operations, and warehouse office functions. Together with the items used to measure the degree of implementation of lean practices the assessment consists of 208 measurement items. Due to the complexity of the assessment tool assessing warehouse operations is very time-consuming process. Hence, for the purpose of this study and to prohibit non-response reproducing this method is not an option. Besides the fact that using Sobanski's method is very time-consuming, the construction of certain measurement constructs is questionable.

It can be concluded that none of the previously mentioned lean assessment tools are preferred as measurement instrument for the purpose of this study. Hence, parts of the three assessment models can be used as measurement constructs or items. Based on this conclusion in section 4.2.2.1 a new lean assessment tool will be developed.

4.2.2 Warehouse performance

Warehouses are responsible to deliver goods according to the distribution principles. Which means products are delivered at the right place, at right time, in the right quantities, and in the quality as demanded by the customer (Bowersox et al., 2012). By doing so a warehouse adds indirectly value to the product. However, distribution according to these principles comes with a cost. By implementing lean principles it is assumed warehouses become more efficient and therefore less costly, while also maintaining higher quality standards due to a more customer focused operation (Jones et al., 1997). To study the impact of the implementation of lean practices on warehouse performance, analysis should aim to capture both the assumed improvement in efficiency and the increased quality of delivery.

Warehouse performance can be measured with multiple performance indicators. This study is focused on performance measures that are able to quantify potential improvements in the material handling functions of the warehouse operation. These indicators measure how well the warehouse operates within the physical distribution function. According to van Goor et al. (2003) warehouse performance indicators can be divided in to internal performance measures and external performance measures. Internal performance indicators measure throughput times of all warehouse functions, the amount of resources required to process orders, the operational cost of a warehouse, and the number of order handled per time unit. External performance indicators are mostly focused on error rates and reliability. Although these indicators are useful to assess the performance of a warehouse based on given standards, comparing warehouses asks for a different approach. These indicators are mutually dependent and the outcome of the indicators depends largely on a set of inputs. Hence, the scores on performance indicators of different warehouses are not always comparable (de Koster and Balk, 2008).

To compare the performance of different warehouses the complexity of the warehouse has to be taken into account. Faber et al. (2002) state that the complexity of a warehouse operation has a large impact on warehouse performance. For example, the number of SKUs or the degree of automation impacts the productivity and quality of a warehouse. Since this study tries to define the linkage between warehouse performance and lean practices, the used constructs should represent indicators that can be influenced by lean practices. As mentioned earlier lean production aims at cutting waste and by doing so create a more efficient operation. Furthermore, lean production strives for total perfection. Therefore, a lean warehouse should be able to deliver with no or very few errors. An efficient warehouse operation should lead to high productivity rates and a high percentage of error-free orders.

4.2.3 Employee satisfaction

Most research on lean production emphasizes the importance of people to create maximum added value. A typical lean culture empowers employees to make decision on the lowest level, stimulates employees on all levels to continuously improve working conditions and processes, and promotes leadership at all levels of the organization (Bhasin and Burcher, 2006). Due to these principles employee involvement increases strongly. Employee involvement creates motivating jobs. Motivating jobs must allow a worker to feel responsible for a meaningful part of his job and employees need to feel that individual performance contributes considerably to the end result (Hackman and Lawler, 1971). By making employees responsible for the continuously improving processes and acknowledging improvement made lean creates more motivating jobs.

In general increased employee satisfaction results in increased job performance. Although researchers opinion on the strength of this positive correlation differs, the many body of research assumes a positive correlation exists (Judge et al., 2001). A meta-analysis carried out by Iaffaldano and Muchinsky (1985) estimates the population correlation between employee satisfaction and job performance to be ρ = .17. Which means the connection between job performance and satisfaction can be classified as weak (Cohen and Cohen, 1983). Ellingson et al. (1998) found a correlation of ρ = .32 after correction for internal consistency between performance and employee satisfaction. Judge et al. (2001) confirm the findings of Ellingson et al. (1998). Their meta-analysis resulted in a correlation of ρ = .30 between employee satisfaction and job performance. Because of these findings increased employee satisfaction as a result of implementing lean practices can lead to increased warehouse performance.

According to literature lean production has not always a positive influence on employee satisfaction. Lean strives for perfection by continuous improvement. Because of that the working environment will be constantly changing. Organizational change concerns people with respect to what the impact of the change will be on themselves, their jobs and colleagues (Weber and Manning, 2001). Based on the findings of Rafferty and Griffin (2006) frequent change leads to a significantly higher level (ρ = .55) of uncertainty, which has a significant negative effect on employee satisfaction (ρ = -.16). This relationship is moderated by the amount of planning involved in change. The more planning involved in organizational change too lower the increase in uncertainty will be. Changes made based on lean principles follow strict planned cycles based on proven methods, hence the negative effect of continuous change will be reduced.

Based on this the impact of lean maturity on employee satisfaction can be either positive or negative. Empirical research has delivered prove for the claim in both directions.

4.2.4 Conceptual framework

Based on the previous mentioned this study will measure three independent variable and one dependent variable. Warehouse performance is defined as a construct composed of warehouse productivity, warehouse quality, and employee satisfaction. Within this section the linkage as proposed by literature between the dependent and independent variables are described. According to findings and propositions in literature warehouse performance seem to be influenced by the degree of leanness or the lean maturity. A lean philosophy involves dedication to perfection, empowerment of employees, and a strong focus on efficiency. Based on these three elements an increase in warehouse productivity, warehouse quality, and employee satisfaction is suspected.

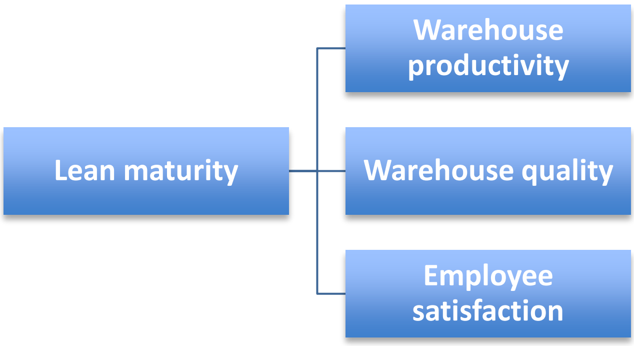

Figure 3 Cocneptual Model

4.3 Measurement approach

4.3.1 Lean Assessment tool

4.3.1.1 Scales and tool

Based on the analysis of section 4.2.1 the decision is made to develop a new tool to assess lean maturity in a warehousing environment. Existing tools are either not developed for this specific environment or too time consuming for the purpose of this study. The development of a measurement model from scratch is complicated in terms of validation and reliability. To develop new measurement constructs a factor analysis, internal consistency testing, and correlation testing is needed, unfortunately the limited sample size available for this research does not allow performing such analysis. Because of that the lean assessment tool used in this study is composed of existing lean maturity measurement as developed by Shah and Ward (2007), Sobanski (2009), and Dehdari (2012).

The operational lean maturity measure developed by Shah and Ward (2007) is taken as a starting point to develop the assessment tool. This implies that constructs are divided into customer related, supplier related, and internally related. All items and constructs relevant to quantify lean maturity within a warehouse environment are used. Because of the differences between warehouse environment and production environment some of the items and constructs are rewritten. Shah and Ward (2007) use a five-point scale to measure the degree of implementation of lean practices. Based on this scale the following scale labels are identified:

1. *No implementation*: lean practice is not implemented in the warehouse operation.
2. *Little implementation*: lean practice is implemented on small scale, for example in a model line. There is a lot of room for improvement and more widespread implementation of the lean practice.
3. *Some implementation*: lean practice is implemented in more than one area. The warehouse operation has a clearly defined implementation plan to improve the practice in the near future.
4. *Extensive implementation*: lean practice is implemented throughout the warehouse. All warehouse employees are familiar with the practice. Although the lean practice is fully implemented there is room for improvements left since a true lean philosophy strives to continuously improve operations.
5. *Complete implementation*: lean practice is fully implemented within each department of the operation. Lean practice only needs minor continuous improvements, but there is no clear room for major improvements.

4.3.1.2 Measurement construct

The adjustment process of Shah and Ward's lean maturity assessment models consisted of the following steps:

SUPPLIER RELATED

Shah and Ward use three constructs to measure the implementation of the following supplier related lean practices; supplier feedback, JIT delivery and supplier development. Not all used operational items are relevant for assessing lean maturity in warehouse. Table 6 shows the adjustments made to all items.

Item no	Item label	Applicability
Suppfeed_01	We frequently are in close contact with our suppliers	Applicable
Suppfeed_04	We give our suppliers feedback on quality and delivery performance	Adapted: suppliers of warehouses are only responsible for inbound delivery performance.
Suppfeed_05	We strive to establish long-term relationships with our suppliers	Applicable
SuppJIT_01	Suppliers are directly involved in the new product development process	Not applicable: warehouses are not involved in NPD.
SuppJIT_02	Our key suppliers deliver to plant on JIT basis	Adapted: JIT is not an issue in receiving goods in warehousing. The condition of received is more important.
SuppJIT_03	We have a formal supplier certification program	No action

Suppdevt_01	Our suppliers are contractually committed to annual cost reductions	Not applicable: procurement department is responsible for contract terms; warehouses are not involved in this process.
Suppdevt_02	Our key suppliers are located in close proximity to our plants	Not applicable: network design is not the responsibility of the warehouse.
Suppdevt_03	We have corporate level communication on important issues with key suppliers	Not applicable: warehouse is not responsible for corporate level communication.
Suppdevt_04	We take active steps to reduce the number of suppliers in each category	Not applicable: supplier evaluation is the responsibility of the procurement department.
Suppdevt_05	Our key suppliers manage our inventory	Adapted: to create lean warehouse with no excess inventory suppliers need to know a warehouse's inventory position.
Suppdevt_06	We evaluate suppliers on the basis of total cost and not per unit price	Not applicable: supplier evaluation is the responsibility of the procurement department.

Table 6 Supplier related measurement items I (Shah and Ward, 2007)

After these adjustments the operational construct *Supplier Involvement* consists of the following items:

Supp_01	We are frequently in close contact with our suppliers
Supp_02	We give our suppliers feedback on inbound delivery performance
Supp_03	We strive to establish long-term relationships with our suppliers
Supp_04	We use a standardized supplier certification method
Supp_05	We provide information about our inventory position to suppliers
Supp_06	Suppliers enable efficient material handling and flow by using appropriate conditional means

Table 7 Supplier related measurement items II

CUSTOMER RELATED

Shah and Ward developed one operational construct to measure customer related lean practices. Customer related practices are relevant to every lean organization, since lean is all about specifying value from the view the customer. Table 8 shows the adjustments made to the operational items proposed by Shah and Ward.

Item no	**Item label**	**Applicability**
Custinv_01	We frequently are in close contact with our customers	Applicable
Custinv_03	Our customers give us feedback on quality and delivery performance	Adapted: customers are only able to give feedback on outbound delivery performance.
Custinv_04	Our customers are actively involved in current and future product offerings	Adapted: warehouses are not involved in the product offering. However, in cooperation with customers warehouse can decide to introduce new VAL.
Custinv_05	Our customers are directly involved in current and future product offerings	Not applicable
Custinv_06	Our customers frequently share current and future demand information with marketing department	Adapted: warehouse has no marketing department. Demand information is relevant to the planning department.

Table 8 Customer related measurement items I (Shah and Ward, 2007)

Based on the adjustments described in table 9 customer related lean practices implementation is measured through the following items:

Cus_01	We frequently are in close contact with our customers*
Cus_02	Our customers give us feedback on outbound delivery performance
Cus_03	Our customers are actively involved in current and future Value Added Logistics offerings
Cus_04	Our customers frequently share current and future demand information with planning department

Table 9 Customer related measurement items II (Shah and Ward, 2007)

PULL/SETUP:

The operational constructs *Pull and Setup* were removed. The operational construct *pull* measures to what extent a production operation facilitates to produce on JIT base (Shah and Ward, 2007). Warehouses operate on a make-to-order base, which means goods are always processed on a just in time base. Therefore all warehouses facilitate JIT processing. The operational construct *setup* measures to what extent process downtime between product changeovers is reduced (Shah and Ward, 2007). Order fulfillment within warehouse operations typically do not require changeovers, hence the construct *setup* is abundant when measuring lean maturity in this environment.

FLOW:

Shah and Ward (2007) define flow as the established mechanisms to enable and ease the continuous flow of products. The operational construct *Flow* consists of operational measures that measure whether the layout of a facility facilitates a continuous flow. Although these layout decisions are part of a lean warehouse, in a warehouse these decisions are more focused on reducing travel distance and cycle time than creating flow. Flow in a warehouse is more concerned with workload balancing. Order fulfillment typically involves subsequent multiple processes, e.g. picking, packing and shipping. To create flow in a warehousing environment workload should be balanced based on available capacity at every process and takt-time of processes. Because of that the measurement items developed by Shah and Ward (2007) are replaced by items Sobanski (2009).

Pull_01	We plan the daily work activities to balance manpower and work flow between processes/operations
Pull_02	We level the flow between processes and areas to balance the daily activities between each area
Pull_03	We release orders to enable one-piece-flow rather than working in batches

Table 10 Pull and Flow measurement items I (Shah and Ward, 2007; Sobanski, 2009)

STATISCAL PROCESS CONTROL

The *SPC* measures the degree of statistical control within warehouse processes. By implementing SPC all warehouse processes are monitored and errors and mistakes are spotted quickly. By doing so SPC ensures a flow of error free orders through all warehouses processes (Shah and Ward, 2007). Real-time tracking and visualization of the progress in order processing is also a feature of SPC. By doing so resources can be allocated between different processes to level workload between different areas. Lean practices with regard to SPC are very useful when implemented in a warehouse operation. Table 11 shows the SPC items as formulated by Shah and Ward and the adjustment made to these items.

Item no	Item label	Applicability
SPC_01	Large number of equipment/processes on shop floor are currently under SPC	Applicable
SPC_02	Extensive use of statistical techniques to reduce process variances	Applicable
SPC_03	Charts showing defect rates are used as tools on the shop-floor	Adapted, replaced defects by errors and productivity, since defects are not a source of waste in the warehouse.
SPC_04	We use fishbone diagrams to identify causes of quality problems	Adapted, fishbone are too specific other standardized problem solving tools can also be applied
SPC_05	We conduct process capability studies before product launch	Adapted, new products are not an issue within warehousing. New logistics are an issue.

Table 11 SPC measurement items I (Shah and Ward, 2007)

Besides the items developed by Shah and Ward (2007) value stream mapping is a core lean practice within the construct SPC. When implementing lean production an organization should be seen as a collection of value streams rather than a collection of processes. Mapping value streams from the customer's point of view is one of the main principles of lean thinking. Dehdari (2013) and Sobanski (2009) both developed measurement items to measure the degree of implementation of this lean practice. Based on these items the following item is added to the construct *SPC:*

The current and desired state of all value streams are mapped from the viewpoint of the customer

Based on these adjustments the following items are used to measure the degree of implementation of statistical process control:

SPC_01	Large number of processes on shop floor are currently under SPC
SPC_02	Extensive use of statistical techniques to reduce process variances
SPC_03	Charts showing error and productivity rates are used as tools on the shop-floor
SPC_04	We use standardized problem solving techniques to identify the root cause of problems
SPC_05	We conduct process capability studies before introducing new logistics processes
SPC_06	The current and desired state of all value streams are mapped

Table 12 SPC measurement items II

TOTAL PREVENTIVE MAINTENANCE

In a production environment *TPM* addresses downtime through preventive maintenance of equipment (Shah and Ward, 2003). In a warehouse operation preventive maintenance should focus on the condition of the warehouse floor. Equipment used in warehousing, e.g.

reachtrucks or forklifts, are less sensible to downtime than advanced production machines. So in a traditional warehouse or distribution centre were the degree of automation is low to medium TPM should focus on preventing downtime of employees. Employees are the most important "piece of equipment" to process orders in a warehouse. To minimize the risk of warehouse accidents TPM should aim at creating a safe and structured working environment. Because of that most TPM practices in the warehouse are closely related to 5S activities.

Item no	Item label	Applicability
TPM_01	We dedicate a portion of everyday to planned equipment maintenance related activities	Applicable, 5S added
TPM_02	We maintain all our equipment regularly	Applicable, 5S added
TPM_03	We maintain excellent records of all equipment maintenance related activities	Applicable, 5S added
TPM_04	We post equipment maintenance records on shop floor for active sharing with employees	Applicable, 5S added

Table 13 TPM measurement items I (Shah and Ward, 2007)

Based on these adjustments the following items are used to measure the degree of implementation of statistical process control:

TPM_01	We dedicate a portion of everyday to planned equipment maintenance or 5S related activities
TPM_02	We maintain all our equipment regularly
TPM_03	We maintain excellent records of all equipment maintenance and 5S related activities
TPM_04	We post equipment maintenance and 5S records on shop floor for active sharing with employees

Table 14 TPM measurement items II

EMPLOYEE INVOLVEMENT

Employee involvement is as mentioned in the literature review one of the most important practices when implementing lean production in a warehousing environment. As mentioned earlier employees are the most important resources used in a warehouse to add value. This means that employees also know the processes by hard. By using the knowledge and experience of these employees non-value adding processes can be eliminated and value adding processes can be improved continuously. Shah and Ward (2007) measured employee involvement based on 4 items shown in table 15. Due to the importance of employee involvement in lean warehousing this does not suffice. Sobanski's lean assessment tool (2009) emphasizes the importance of people related lean practice. Because of that this method uses multiple constructs to measure the implementation of employee involvement practices.

Item no	Item label	Applicability
Empinv_01	Shop-floor employees are key to problem solving teams	Applicable
Empinv_02	Shop-floor employees drive suggestion programs	Applicable
Empinv_03	Shop-floor employees lead product/process improvement efforts	Adapted, warehouse do not involve in product improvement efforts
Empinv_04	Shop-floor employees undergo cross functional training	Applicable

Table 15 Employee involvement measurement items I (Shah and Ward, 2007)

Besides the practices mentioned in table 15 the operational definition of lean used in this study also emphasize the need for communication through daily meetings and empowerment of decision making with regard to operational decision to the lowest possible level. Furthermore, lean should be implemented through actively stimulating lean leadership at all levels. Lean leadership means employees proactively support and facilitate each other to achieve perfection by continuously improving processes.

Empinv_01	Shop-floor employees are key to problem solving teams
Empinv_02	Shop-floor employees drive suggestion programs
Empinv_03	Shop-floor employees lead process improvement efforts
Empinv_04	Shop-floor employees undergo cross functional training
Empinv_05	The qualifications of individual shop-floor employees are visible on the shop-floor using a qualification matrix
Empinv_06	Shop-floor employees are empowered by decision on the lowest possible level
Empinv_07	Lean leadership is actively promoted within all levels of the organization by training
Empinv_08	Before the start on each working day performance on KPIs and special events are communicated to shop-floor employees

Table 16 Customer Involvement measurement items II

WAREHOUSE RELATED

Shah and Ward (2007) do not capture warehouse specific lean practices. To reduce non-value adding activities improvement of picking processes is very important. In a typical warehouse operation the cost of order picking adds up to approximately 55% of total warehouse operating costs (de Koster et al, 2006). Lean practices to optimize picking processes can be found in storage policy, routing schedules, order dispatching, facility layout, and warehouse strategy. Products should be stored based on an ABC policy to reduce travel distance and cycle time. Furthermore, warehouse processes and areas should be located in such a way that travel distance is minimized. Besides order picking optimization the used lean principles specify that processes should be standardized as much as possible to reduce variability.

The best way to reduce order picking costs is by adapting a cross docking strategy, hence this strategy is preferred in a lean warehouse. One construct to measure the degree of implementation of lean warehousing is therefore cross docking. Within cross dock areas movement and waiting has to be minimized, since these activities are seen as waste.

This results in two constructs *Warehouse* and *Crossdock*. The items used to measure these operational constructs are based on items developed and validated by Sobanski (2009). Operational constructs and measurement items can be found in tables 17 and 18.

War_01	Storage, picking and packing processes are standardized
War_02	We design individual processes based on grouping similar items closer to their final destination to reduce travel distance
War_03	We store products based on ABC analysis to reduce travel distance

Table 17 Warehouse specific measurement items

Cros_01	We use a cross-dock strategy to reduce inventory levels and cycle time
Cros_02	Cross-dock items are moved, staged and wait a minimal amount of times
Cros_03	Cross-dock items are placed into adequate staging, clear identifiable and marked for shipment

Table 18 Cross docking measurement items

4.3.1.3 Structure

Figure 4 shows the structure of the lean assessment tool developed. Constructs are divided into customer related, supplier related and internally related. An overview of all the measurement items can be found in Appendix A. The lean assessment tool represents all lean principles identified in the conclusion of the literature. A warehouse that has fully implemented all the lean practices of this assessment tool can be classified as a lean warehouse.

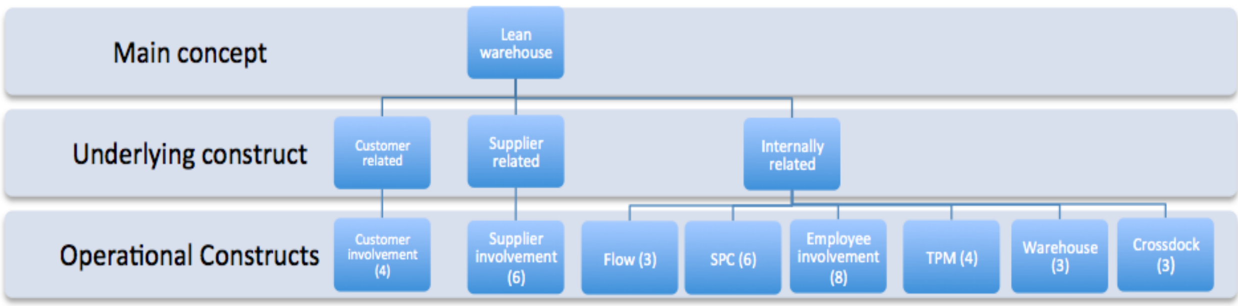

Figure 4 Measurement model

4.3.2 Data Envelopment Analysis

Section 4.2.3 mentioned the importance of taking into account the complexity of the warehouse when evaluating productivity. De Koster and Warffemius (2004) measure warehouse productivity as the average number of order lines shipped per employee per direct employee per day. Although this measure gives an indication of warehouse productivity, it does not consider the differences in complexity. To cope with this problem warehouse performance can be measured based on efficiency. Efficiency quantifies warehouse performance based on the used inputs and produced outputs (de Koster and Balk, 2008). By doing so warehouse can be benchmarked. Multiple researchers (Gu et al., 2009; de Koster and Balk, 2008; Ross and Droge, 2002) propose Data Envelopment Analysis (DEA) as an appropriate method to benchmark warehouse performance. DEA is suitable since it combines a variety of performance metrics in a structured way to evaluate performance (de Koster and Balk, 2008). DEA constructs a weighted productivity measure by approximation of a Production Possibility Set (PPS). The PPS consists of all input and output combinations that can be achieved, by doing so the PPS sets a boundary by describing how the efficient warehouse use inputs to generate outputs (Johnson and McGinnis, 2011). DEA can be used to evaluate financial as well as non-financial performance measures.

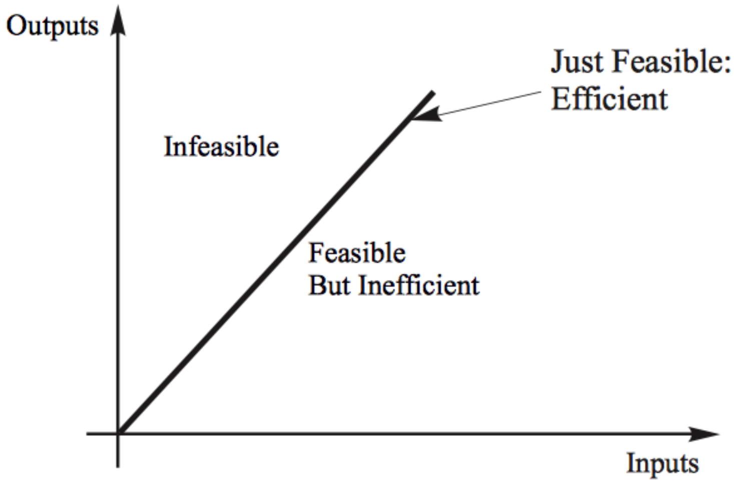

Figure 5 PPS frontier, adapted from Chatghayeh and Abassa (2011)

DEA measures the relative efficiency of a set of decision-making units (DMU). The set of decision-making units used in this study consists of multiple warehouses. A DMU is fully efficient if the performance of other DMUs show that inputs or outputs cannot be improved without worsening other inputs or outputs (Cooper et al., 2004). A fully efficient DMU will have an outcome similar to the best practice frontier. Data Envelopment Analysis comes in different forms. Models can be input oriented or output oriented. Input oriented models consider the ratio of virtual output to input. This study is interested in the virtual ratio of warehouse performance as output to warehouse complexity as input. Hence, the model used in this study will be input based. Typically the DEA analysis is constructed of multiple entities that consist of a ratio of multiple input and outputs. DEA analysis reduces this ratio to a situation with a single virtual input and virtual output for every output. By doing the analysis provides a measure of efficiency that is constructed of the multipliers of input and outputs (Cooper et al., 2004).

This DEA model is well known as a CCR construction. DEA assumes given N observed DMUs to be analyzed, that we use a set of data $\{n = 1, \ldots, N\}$. Each DMU uses *m* different inputs to produce *s* different outputs. The *m* inputs consist of quantities measured using a vector x = (x_1, …, x_m) and the *s* outputs quantities are measured by a vector y = (y_1, …,y_s). The CCR model assumes equivalent access to the same technology for all DMUs during a time period. Technology is defined as the set of all feasible combinations of input and output. These combinations represent all possible combinations such that output quantities can be produced by the input quantities (de Koster and Balk, 2008). A technology is defined as

$$S = \{(x, y) | x \; can \; produce \; y\}$$

This equation states that with a given quantity of input x, a certain maximum amount of output quantity y can be produced. It is possible to produce less output quantity with the given amount of input, but it is impossible produce more output quantity with this input quantity. Since the input and output quantity are the result of a multiplier, these inputs and output have to be estimated. All these combinations of inputs and outputs are enveloped in the technology set S. The technology set S can be estimated by

$$S = \{(x, y) | \sum_{n=1}^{N} z_n x^n \leq x, y \leq z_n y^n, z_n \geq 0 \; (n = 1, \ldots, N)\}$$

Figure 5 shows a graphical representation of the technology set S. All combinations of input quantity and output quantity within the technology set S are feasible, but not efficient. All combinations lying on the frontier of the technology set (the linear line) are just feasible and hence efficient. By performing a DEA the distance from every DMU n to the technology frontier is measured. For example, an efficiency score of 0.8 shows that all input quantities can be reduced 20% while the output quantities are still producible (Cooper et al., 2004; de Koster and Balk, 2008). The input-efficiency score of DMU N (n = 1, …, N) is represented by:

$$Input \; Efficiency(x^n, y^n) = \min\{\partial | (\partial \, x^n, y^n) \; \in S\}$$

To establish a technology frontier a certain sample size is necessary. Unfortunately this study involves not enough warehouses to carry out a DEA. Hence, an external dataset is used to measure and compare the productivity of the warehouse within the sample of this study. The DEA carried out in this study is based on the study of de Koster and Balk (2008). These authors studied the efficiency of European Distribution Centers (EDCs) in the Netherlands based on data acquired in previous research. De Koster and Balk (2008) based their DEA analysis partly on data from de Koster and Warffemius (2005).

Because the DEA carried out is based on previous work, the inputs and outputs have to be similar to the study of de Koster and Balk (2008). Based on the work of de Koster and Balk (2008) the following four input factors are proposed:

1. *Number of direct FTE.* Measured on an interval scale together with the number of indirect FTE.
2. *Size of the warehouse in square meter.* A larger warehouse often implies larger travel distance and time. Because of that the size of a warehouse influences the productivity achieved. Size is measured on a 6-point ordinal scale. Scale consists of: <1.000, 1.000-3.000, 3.000-5.000, 5.000-10.000, 10.000-20.000, and >20.000 m^2.
3. *Degree of automation*. Information Technology has become important within all warehouses. The fit of a Warehouse Management System (WMS) with the operation influences the possible output of the warehouse. Advanced methods in picking and storing, as for example barcoding, pick-by-light or pick-by-voice, enhanced the possible picking productivity. Because of that the degree of automation influences the productivity. The degree of automation is measured on a 5-point scale: very low (basic automation, like using a computer), low (a WMS is used), average (low level + barcoding techniques), above average (average level + RFID), and high (above average level + automated systems, like automated cranes, automated-guided vehicles).
4. *Number of different SKUs.* The size of the assortment stored in a warehouse impacts the potential output rate. The larger the amount of SKUs, the more different sorts of products are stored in a warehouse. Different products often require different handling processes, because of that limiting the output rate. The size of the assortment is measured through the amount of SKUs an 8-point ordinal scale. Scale consists of: <500, 500-1.000, 1.000-5.000, 5.000-10.000, 10.000-20.000, 20.000-50.000, 50.000-100.000, and >100.000.

Furthermore, de Koster and Balk (2008) propose five output factors. Not all these factors are relevant for the purpose of this research. This research focuses on productivity and quality. Hence, the output factors were reduced to the following two factors:

1. *The number of daily order lines picked per working day.* This measure is the most important indicator to assess the efficiency of the output of a warehouse. Order lines picked determines how much orders will be fulfilled every day.
2. *The percentage of error free orders shipped.* Besides quantity lean can also influence the quality. Therefore, the percentage of error free orders shipped is also taken into

account in the DEA analysis. The interval of this measure is relatively small with a minimum 90% and a maximum of 99,96%. To make pattern more visible a log transformation is used.

The input and output factors of the warehouse in the sample received through a questionnaire, which can be found in Appendix B. The DEA was carried out using EMS 1.3. EMS is an open source software package developed by Holger Scheel of the University of Dortmund. The DEA analysis uses convex envelopment based on constant returns to scale. The orientation was set to input and distance was calculated multiplicatively. In order to rank the efficient warehouses in the sample the superefficiency was also calculated using the same efficiency measures and settings.

The output factors are not only used in the DEA, but are also used as a second measurement to quantify the dependent variable. Productivity is also reported as order lines picked per day per FTE and the percentage of error free orders shipped.

4.3.3 Employee satisfaction

The degree of employee satisfaction is measured with an instrument developed by Hackman and Oldham (1974). Their Employee satisfaction Diagnostic Survey is a broad measure of employee satisfaction dimensions. From the Employee satisfaction Diagnostic Survey five questions were deduced to form the instrument used in this study. The Employee satisfaction Diagnostic Survey or parts of it is/are used by various researchers, amongst others de Koster et al. (2010) who used the diagnostic survey to measure employee satisfaction within a comparable environment. The Employee satisfaction Diagnostic survey was used because the survey has proven to be valid, reliable and, useful within a comparable warehousing environment. The questions used can be found in table 19.

	1 Totally disagree	**2 Somewhat disagree**	**3 Neutral**	**4 Somewhat agree**	**5 Totally agree**
1 In general I am satisfied with my job					
2 I often think about quitting this job					
3 In general I am satisfied with the nature of work I have to do in this job					
4 Most of my colleagues are satisfied with their job					
5 My colleagues often think about quitting their job					

Table 19 Employee satisfaction measurement items

Cronbach's Alpha	N of Items
,677	5

The measurement construct employee satisfaction is constructed by summing up the scores of all five questions. Questions 2 and 5 have a reversed line of question and have therefore to be recoded. To assure the reliability and internal consistency of the measurement constructs Cronbach's alpha is reported. The assessment of internal consistency based on Cronbach alpha uses a rule of thumb. The rule thumb defines that an alpha of 0,7 or higher indicates a high degree of internal consistency. Based on the five measurement items the Cronbach alpha of the measurement construct is 0,677. Table 20 shows that after deleting item 5 the Cronbach alpha increases to 0,717. Hence, the measurement construct employee satisfaction consists of four measurement items instead of five. The measurement construct employee satisfaction is the sum of the scores of measurement items 1 to 4.

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
satis	15,96	3,829	,549	,576
quit	15,94	4,157	,406	,636
nature	16,11	3,503	,612	,539
colsatis	16,96	3,797	,411	,637
colquit	16,63	4,573	,211	,717

Table 20 Cronbach alpha

4.4 Data collection

4.4.1 Secondary data collection

Secondary data was obtained from scientific journals and textbooks and presented in the literature review. The main purpose of the secondary data collection is defining the concepts studied in this thesis and to describe the existing theoretical frameworks in the field of lean, lean maturity and the linkage with performance. According to Bryman and Bell (2007) written sources have to be authentic, credible, representative and comprehensible.

Although a lot has been written on lean management, only a few articles have been published in premium scientific journals. Within this research the quality of a scientific journal is defined by the rank on the *SCImago Journal and Country Rank* (SJR). The position of a journal on the SJR is based on the amount of cites per document. The most important journal in the field of Supply Chain Management is according to SJR *Journal of Operations Management (JOM)*. The sources used within this thesis are preferably published in premium journals. Although a lack of publications in these journals on certain fields forces to also use other journals. The books used in this research are ranked based on the amount of citations.

To search for scientific articles and textbooks Google Scholar, ABI/Inform and Science Direct search engines are used. Furthermore, the collection of the University Library of Erasmus University Rotterdam is scanned for books and articles on lean. To search within the above mentioned collections the following search words where used: ‘ lean production’, ‘ lean management’, ‘ lean thinking’, ‘lean philosophy’, ‘lean warehouse(ing)’, ‘lean logistics’, ‘lean distribution’, ’lean performance’, ‘ lean maturity’ and ‘leanness’. Furthermore, secondary data was retrieved through the reference list of the previously found articles and books. The articles found through this rigorous search where scanned based on the abstract and conclusion.

4.4.2 Primary data collection

Besides secondary data, the conclusion of this thesis will also be based on primary data. Primary data can be obtained through multiple techniques. In this thesis primary data is generated through interviews, questionnaires and observations. Primary data collection started at Philips Lighting. Since the lean assessment tool is not a reproduction, but an aggregation of measurement construct developed by multiple authors pretesting was necessary. The lean assessment tool was pretested during two unstructured interviews with lean specialists at Philips Lighting. During these interviews the interpretation of scales, as defined in section 4.3.1.1, was discussed. Furthermore, all measurement items were treated and discussed separately to ensure that the lean assessment consists of objective and clear questions. Based on this discussion a manual was written to make sure non Philips Lighting respondents are able to apply the assessment tool correctly. The manual describes the meaning of the scales used, definitions of most important concepts, the objective the research, and information regarding the other questionnaires that had to be filled out.

Three questionnaires including instruction manual were sent to participating warehouses by email. These questionnaires measure lean maturity, productivity parameters, quality, and employee satisfaction. Participating warehouses were instructed that the lean maturity assessment questionnaire had to be filled out by a person responsible for the implementation of lean practices. If no one within the organization is responsible for lean deployment the warehouse’s operations manager had to fill out the questionnaire. The employee satisfaction questionnaire had to be filled out by at least 20 shop-floor employees. These shop-floor employees should be a representation of the total population of all shop-floor employees in terms of contract type, tasks, experience, and gender. Participating warehouses were advised to let a business analyst fill out the productivity questionnaire.

4.4.2.1 Sample

The selection of participating warehouses was done based on knowledge with regard to lean implementation within logistics firms. Knowledge was gathered based on professional and academic sources. In total four firms were identified as participators. These firms were besides Philips Lighting three third party logistics suppliers. Two of the three 3PL firms were willing to participate in the study; the third 3PL supplier offered a warehouse tour to gain a broader image of lean programs. In total 9 warehouses were identified as potential participators. Two warehouses are private owned and the other seven are public warehouse owned by a 3PL supplier. Warehouses differ in terms of products stored, layout, size, and number of employees.

Six of the 9 warehouses actually participated to this study. The local management teams of the other warehouses decided not participate in this study. In total 6 lean professionals filled out the lean assessment tool. In total 125 shop-floor employees filled out the employee satisfaction survey. The results chapter will give an overview of the most important attributes of the warehouses in the sample.

Chapter 5: Results

The objective of this study is to verify whether there is indication to assume that there is a linkage between lean warehousing and warehouse performance. As mentioned earlier the sample of this study is small. Because of that statistical analysis is not possible. Testing for significance, correlation or other statistical concepts requires based certain conditions a larger sample. The results of this study will therefore not be presented in that way. The results section will give an overview of the descriptive statistics of the dependent and independent variables and try to find out whether there are linkages between the means of different variables. Although significant testing is not possible the results can be the starting point of future research.

5.1 General Warehouse information

Although the sample of this study is small, the sample's warehouses are diverse in terms of product types stored, number of employees, size, and number of daily customer orders. Two warehouses are privately owned by Philips Lighting. These warehouses serve as regional and European distribution center, as well as worldwide export center. Because of this function and the wideness of Philips Lighting's assortment the number of SKUs stored in these warehouses is large. The other warehouses are public owned warehouses and operated by 3PL supplier. The 3PL warehouses store various products and also vary strongly in terms of number of different SKUs stored. As table 21 shows the warehouse are very different, because of that productivity cannot be assessed based on the number of order lines picked per FTE.

Ware-house	Public/ Private	Product types	Total employees	Size (in m²)	# SKUs	# Customer orders
W1	Private	Lighting	132	10.000 – 20.000 m²	20.000 – 50.000	740
W2	Private	Lighting	131	> 20.000 m²	20.000 – 50.000	646
W5	Public	IT and marine spareparts	159	> 20.000 m²	500 – 1.000	2500
W6	Public	Load carriers	130	10.000 – 20.000 m²	<500	250
W5	Public	Hifi, IT, and motorcycles	90	> 20.000 m²	1.000 – 1.500	100
W6	Public	Food and beverage	130	> 20.000 m²	500 – 1.000	120

Table 21 Warehouse sample

Based on Holland International Distribution Council's (1997) definition of a European distribution center all warehouses in the sample can be classified as European Distribution

Center (EDC). An EDC is a European warehouse, the origin of at least 50% of the inbound flows is a location in a different country, and the goods are distributed to at least 5 European countries. As a result the dataset used by de Koster and Balk (2008) and de Koster and Warffemius (2004) can be used as benchmark for the sample. 5.3 gives an overview of DEA efficiency scores of all warehouses based on this dataset.

5.2 Lean assessment results

Six lean practitioners filled out the lean assessment question. Constructs consisted of multiple items measured on a five-point scale. Every construct was constructed by calculating the total average score of all measurement items. The total lean maturity score for every warehouse was calculated by averaging the scores of all constructs. The degree of implementation of lean practices differs strongly among the different constructs. The average lean maturity of the warehouse in the sample is 2,96 measured on a five-point scale. According to the classification used on average the warehouses in the sample implemented lean principles and practices in multiple areas in the warehouse, with a clearly defined implementation plan to improve the practice in the near future. Table 22 shows an overview of the scores of all warehouses. Hereafter the lean scores of all warehouses will be discussed.

Table 22 shows that supplier involvement, customer involvement, and TPM have the highest degree of maturity of all lean practices ($\mu = 3{,}86$; $\mu = 3{,}33$; $\mu = 3{,}42$). Because of the nature of the 3PL warehouses in the sample supplier are often also the customers of the 3PL supplier operating the warehouse. Hence, the table shows that lean warehousing is a customer centered management philosophy. The construct employee involvement measures the implementation of the more cultural aspects of lean warehousing. Based on the scores of this construct most warehouses in the sample implement a lean program focused on practice and tools rather than cultural aspects. Warehouses in the sample do in general not use a cross docking strategy to a high extent, although this strategy enables companies to decrease excess inventories significantly. It can be concluded that the degree implementation of lean practices within the warehouse varies.

	Supplier involvement	Customer involvement	SPC	TPM/5S	Employee involvement	Warehouse specific	Pull/ Flow	Cross docking	Total
W1	3,00	3,25	3,50	4,25	3,67	3,50	3,00	2,00	3,27
W2	3,67	2,75	3,50	4,00	3,67	3,50	3,25	3,33	3,46
W3	4,00	3,00	2,00	3,75	2,44	3,50	2,50	1,00	2,77
W4	4,17	4,00	1,17	2,25	2,44	2,50	3,00	2,33	2,73
W5	4,17	3,75	2,17	3,50	2,22	3,75	2,50	2,00	3,01
W6	4,17	3,25	2,00	2,75	2,33	2,25	2,25	1,00	2,50
Total	3,86	3,33	2,39	3,42	2,80	3,17	2,75	1,94	2,96

Table 22 Lean Maturity Assessment

W1

Warehouse W1 has a lean maturity of 3,27, which above the sample's average. The warehouse scores well above average on all measurement constructs. The warehouse implemented lean practices with respect to employee involvement on an above average level (μ = 3,67). Furthermore, statistical process control practices are used within the warehouse (μ = 3,50). Performance rates are visualized on the work floor, the current and desired state of almost all value streams are mapped, and problem are solved based on standardized techniques. The warehouse uses a TPM/5S program with daily 5S routines, feedback 5S performance, and excellent documentation of maintenance and 5S records (μ = 4,25). Despite of the high lean maturity, the warehouse remains excess inventory since a cross docking strategy is only implemented to a very limited degree.

W2

Warehouse W2 has the sample's highest degree of lean maturity with a score of 3,46. Because of the implementation of a standardized lean production program within the company scores on multiple constructs tend to be very similar to the scores of warehouse W2. In comparison with warehouse W2 the degree of implementation of practices with regards to statistical process control, employee involvement, W4 and warehouse specific processes is similar. However, the lean practices implemented in W2 seem to be more supplier oriented whereas the practices implemented in W1 are more customer oriented. Due to this difference the W2 warehouse is able to achieve a higher maturity score on cross docking strategy (μ = 3,33).

W3

Overall warehouse W3 scores below average on lean maturity with a score of 2,77. In comparison with the private owned warehouses the public owned warehouses are more supplier oriented (μ = 4,17). All four public owned warehouses score well above average on supplier involvement. Supplier of a public owned warehouse are often the customers of the organization responsible of operating the warehouse, hence contact with these parties will be more intensive. This conclusion can be drawn from the scores of W3, W4, W5, and W6 on the supplier involvement construct. Warehouse W3 uses 5S and TPM in the operation (μ = 3,75), but does not always dedicate a portion of the workday to 5S/TPM related practices. The warehouse uses statistical process control on a very limited base (μ = 2,00), although KPIs are visualized on the work floor. Also the involvement of employees is limited (μ = 2,44), improvement is driven by management rather than shop floor employees, decision are taken by management, improvement is not officially rewarded, and training with respect to lean practices is restricted to management level.

W4

Warehouse W4 has a lean maturity score of 2,72 on a five-point scale. This below average score is mainly caused by the limited implementation of statistical process control (μ = 1,117), 5S/TPM (μ = 2,25), and warehouse specific lean practices (μ = 2,50). In comparison with the other warehouses W4 is the only warehouse that does not dedicate a portion of the workday to 5S related practices. Furthermore, visualization and communication of KPIs is limited. Although warehouse processes are standardized and documented, the implementation of lean practices such as ABC storage, grouping processes to create flow, and travel distance optimization is very limited. The lean practices applied in W4 are focused on supplier and customer involvement, and enabling pull and flow.

W5

Warehouse W5 is according to the measurement model the most lean mature of the four public owned warehouses. With a lean maturity score of 3,01 W5 scores above average, but below the scores achieved by the Philips Lighting warehouses. Warehouse W5 aims lean efforts at warehouse specific practices (μ = 3,75). All processes are documented and standardized, all products are stored based on ABC analysis, the layout of the facility is designed to create flow, and WMS releases orders such that workload is balanced between departments. Another prominent observation is the low degree of implementation of employee involvement practices (μ = 2,22). Practices such as continuous improvement driven by shop-floor employees, lean training, employee empowerment, and rewarding continuous improvement initiatives are not implemented.

W6

Warehouse W6 turns out to be the least lean mature with a score of 2,50. In comparison to the more lean mature warehouses W6 does not use a cross docking strategy (μ = 1,00) and statistical process control techniques (μ = 2,00). Furthermore, the warehouse operation does not operate on a flow and pull base, only a limited amount of products are stored based on ABC analysis, and facility layout does not enable reduction of travel distance. In general W6 does apply a customer-centered strategy, but other lean practice are not or only to very limited degree implemented in the daily operation.

5.3 Productivity and quality

The main results for the analysis of the productivity and quality are presented in table 23. This table shows the efficiency and super efficiency as calculated in the DEA and the percentage of error free orders. Furthermore, the amount of daily order lines picked per FTE is also reported. The data envelopment analysis is carried based on the dataset of de Koster and Balk (2008). The original dataset consist of 76 warehouses, adding the 6 warehouses of this study the total dataset consists of 82 warehouses. The average efficiency of warehouses is 65,16% (μ = 0,6516; σ = 0,2352). The number of efficient warehouses turned out to be 17. To analyze the efficiency surplus of efficient warehouses super efficiency was calculated. This analysis returns an average efficiency of warehouses is 75,04% (μ = 0,7504; σ = 0,5399). On average orders shipped by the 82 warehouses ship consists in 3,68% of the time errors (μ = 96,32; σ = 3,385). Based on the simple productivity calculation the FF warehouse is the most productive warehouse in the subsample and the W2 warehouse the least productive (51,074). As mentioned earlier this ratio is not the best measure to compare warehouse productivity. Besides productivity, warehouse performance also involves quality. Based this parameter warehouse W1 performs the best (99,96%) and the W6 the worst (99,0%). Although W6 performs the worst of the sub sample, it outperforms the average quality rate of the total dataset by far. Meaning the warehouse in the subsample are superior in terms of quality.

Warehouse	Efficiency	Superefficiency	Productivity	Quality
W1	46,60%	46,60%	51,074	99,96
W2	43,54%	43,54%	10,000	99,85
W3	70,24%	70,24%	27,438	99,20
W4	100,00%	105,07%	10,909	99,10
W5	60,13%	60,13%	28,302	99,60
W6	70,87%	70,87%	35,000	99,00
Total sample	65,16%	75,04%	49,631	96,32

Table 23 Warehouse performance overview

Table 24 gives an overview of the input/output factors and efficiency of the six warehouses. The input and output factors of the subsample are different and because of that the not all the warehouses can be seen as direct peers. This means the comparability of the warehouses' efficiency score is limited, but for the purpose of this research efficiency scores are compared. So it is assumed that all warehouses are direct peers and can be compared. W2 is the only efficient warehouse in the subsample, reporting an efficiency score of 1 (superefficiency = 1,0507). The public owned warehouse appear to be more efficient than the Philips Lighting warehouses.

Input/Output	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**
FTEs	121	112	89	110	53	100
Size	5	6	6	5	6	6
Degree of automation	3	3	3	3	3	3
SKU	6	6	2	1	3	2
Daily order lines	6180	1120	2442	1200	1500	3500
Error free order lines	99,96	99,85	99,20	99,10	99,60	99,00
Efficiency	0,4660	0,4354	0,7024	1	0,6013	0,7087

Table 24 Input/output factors

The main objective of this study is to determine whether lean warehousing influences warehouse performance. To determine there is reason to believe that there is a connection between these concepts the means of lean maturity and warehouse performance are plotted. Figure 6 shows a plot with on the x-axis the lean maturity and on the y-axis the efficiency score. Based on the plotted trendline the efficiency decreases when the lean maturity increases. The W2 warehouse appears to be the most lean mature (μ = 3,46), but also is the least efficient according to the DEA (0,4354). Whereas the only efficient warehouse in the subsample shows a low degree of lean maturity (μ = 2,73). Expect for W4 all plotted coordinates lie close to the trendline, which points at a negative linkage between efficiency and lean maturity,

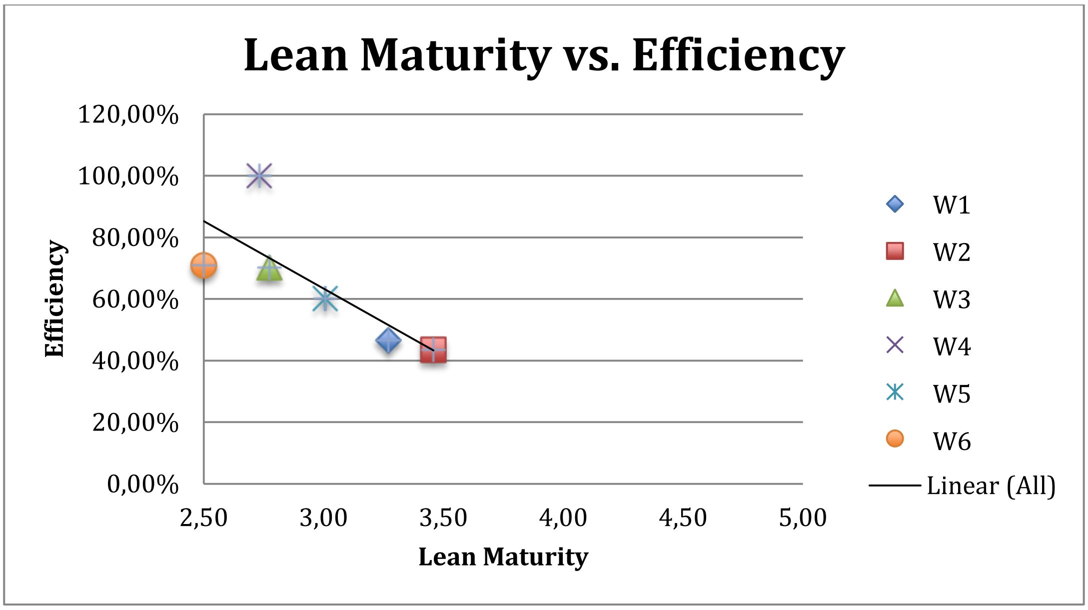

Figure 6 Lean maturity vs. Efficiency

The linkage between lean maturity and the percentage of error shipments is presented in figure 7 Similar to the previous relationship a trendline is drawn to determine the nature of the relationship between the two concepts. Based on the plot the relationship between lean maturity and error free shipment is positive. An increased level of lean maturity leads to an increased percentage of error free shipments. The increase percentage of error free shipments is rather small, since the minimal percentage of the subsample is 99,0% and the maximum percentage is 99,96%. The distance between the linear trendline and the plotted coordinates is small. Hence, based on the six warehouses the proposition can be made that lean maturity has a positive effect on quality as defined in this study.

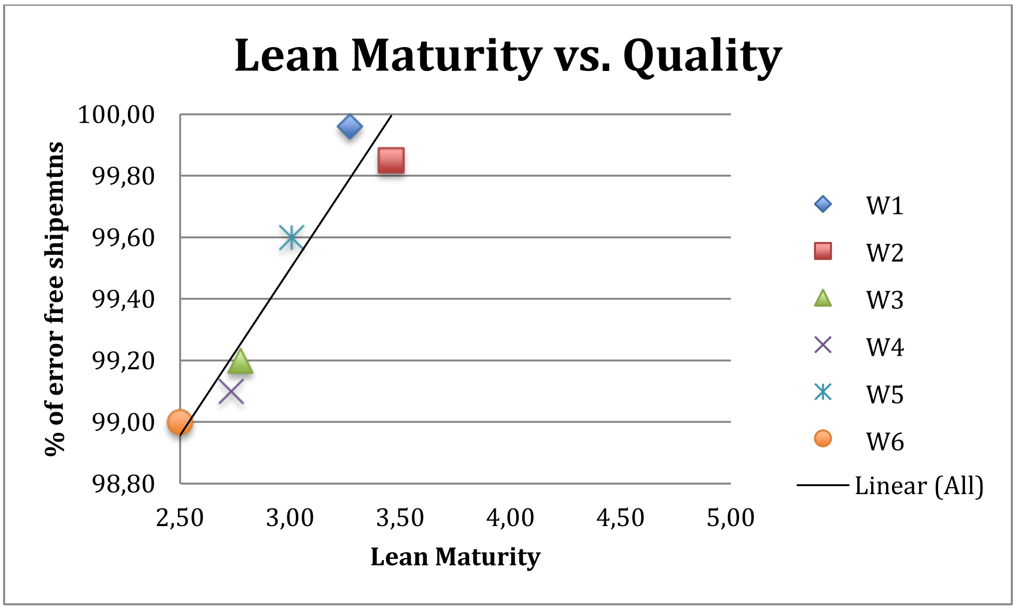

Figure 7 Lean maturity vs. Quality

5.4 Employee satisfaction

The employee satisfaction score measured based on the response of 125 warehouse employees is 16,632 (μ = 16,632; σ = 2,139). Most employees are satisfied with their jobs (μ = 4,44; σ = 0,677), as well as with the nature of work performed (μ = 0,429; σ = 0,739). Hence, it is not a surprise most employees do not often think about quitting their job (μ = 4,46; σ = 0,679). Although most employees seem to be satisfied with their job, the evaluation of how colleagues think about the job is less positive (μ = 3,44; σ = 0,807). This could be a result of a lack of knowledge about how satisfied coworkers are with their jobs. The respondents differ based on multiple attributes and hence these attributes can influence employee satisfaction. The most important attributes are gender and contract type. In the warehouse flexible contract are very common, it could well be that employees with a fixed are either more or less satisfied. Based on an independent t-test it can be concluded that the gender does have a significant effect on employee satisfaction (t = -1,3991; p = 0,321). Also contract type has no significant effect on employee satisfaction (t = 0,226; p = 0,147).

Item	Mean	Std. Deviation	N
satis	4,44	,677	125
quit	4,46	,679	125
nature	4,29	,739	125
colsatis	3,44	,807	125
Total	16,632	2,139	125

Table 25 Employee satisfaction I

Table 26 shows that the employee satisfaction differs among the different warehouses. The table also shows that the composition of respondents differ for every warehouse. Three warehouses employ more people with a fixed contract than with a flexible contract. Furthermore, four warehouses employ more men than women. However, the previous mentioned t-test gives no reason to assume that this causes differences in employee satisfaction. Employees employed by W6 are the most satisfied with their job (μ = 18,15; σ = 1,62715), while employees working at W4 are the least satisfied (μ = 15,5217; σ = 2,27375). These warehouses are both public owned, so it is not likely that the ownership structure has an significant influence on employee satisfaction. A t-test confirms this assumption (t = -1,022; p = 0,289).

Warehouse	%Fixed	%Male	Mean	N	Std. Deviation
W1	27,3%	77,3%	15,7727	22	2,32854
W2	30%	40%	17	20	2,31699
W3	31,6%	52,6%	16,6316	19	1,86221
W4	73,9%	82,6%	15,5217	23	2,27375
W5	57,1%	76,2%	16,9524	20	1,1821
W6	60%	80%	18,15	21	1,62715
Total	59,4%	68,3%	16,632	125	2,1385

Table 26 Employee satisfaction II

The linkage between lean maturity and employee satisfaction is presented in figure 8 Based on this figure no direct relationship between employee satisfaction and lean maturity be proposed. The distance between the plotted coordinates and the trendline is large for most coordinates. The trendline shows a negative effect, but due to the scattering in the plot no relationship can be assumed.

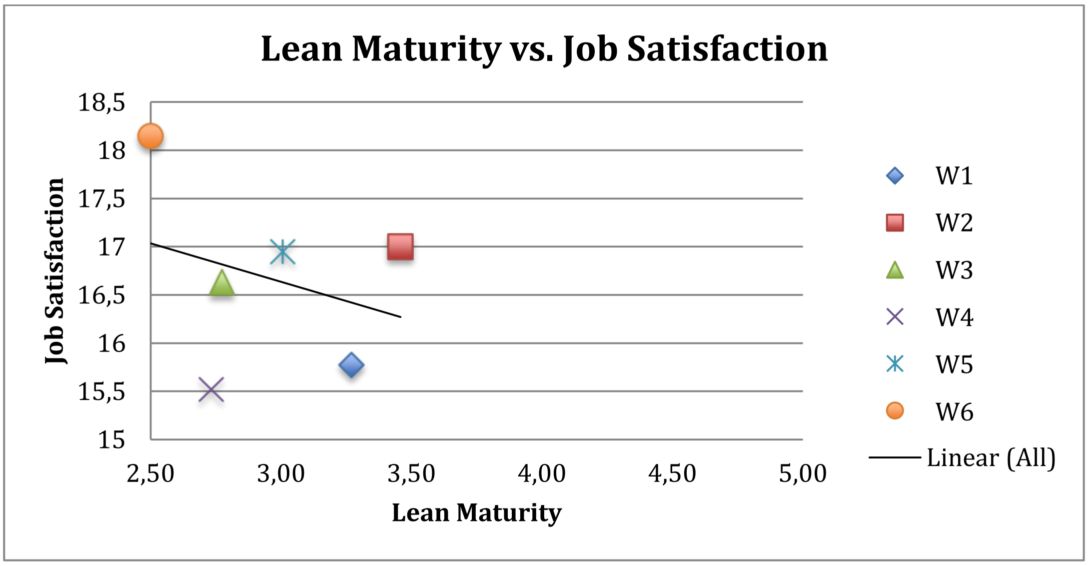

Figure 8 Lean maturity vs. Employee satisfaction

Based on the conceptual model a relationship between the degree of employee involvement and employee satisfaction can also be expected. Figure 9 shows the plot of this relationship. As with the linkage between lean maturity and employee satisfaction no clear relationship can be extracted from the plot. The coordinates are too scattered to propose a relationship in either positive or negative direction.

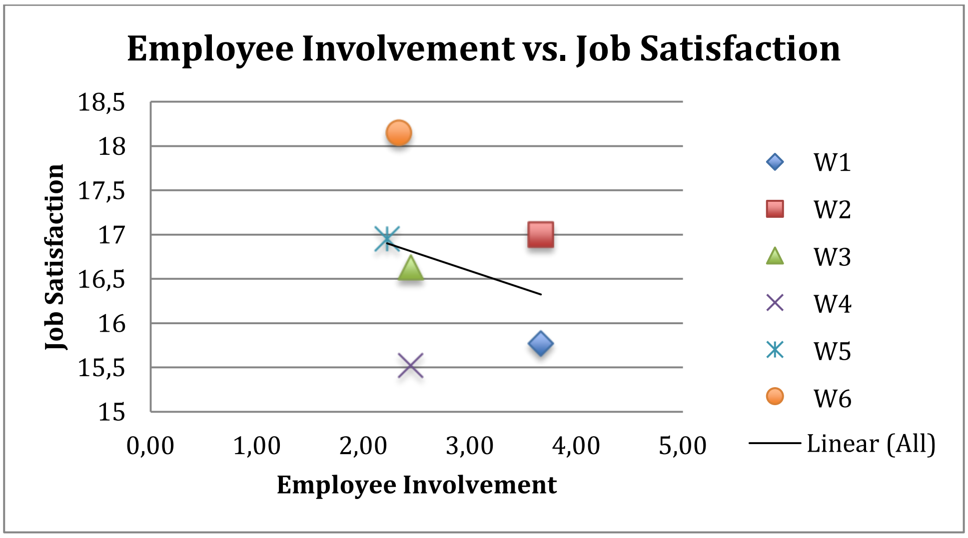

Figure 9 Employee involvement vs. Employee satisfaction

Chapter 6: Conclusion and discussion

6.1 Discussion

This research contributes to the growing research body on lean production in a warehousing and logistics environment. In recent years multiple researchers have studied the implementation of lean practices in the warehouse. Although these studies give an overview of practices typically implemented in the warehouse, research towards the effect on warehouse performance is limited. Early adopters in of lean production outside Japan failed to incorporate the more cultural principles involved in lean (Hines et al., 2004). Based on the six warehouses studied for purpose of this study this phenomenon can also be partly observed within warehousing. The results of the lean assessment made clear that lean in the warehouse is mainly focused on customer involvement, employee involvement, and 5S. A customer centered culture is key to lean and warehouse seem to be able to incorporate this in their cultures. But according to Bhasin and Burcher (2006) a lean culture also involves decision making at the lowest possible level, continuous improvement driven by shop-floor employees, and lean leadership at all levels of the organization. The implementation of these principles is limited within the warehouses studied. To benefit from lean production warehouses should incorporate these principles into their culture (Henderson et al., 1999). This observation can be an explanation of the absence above average performance while implementing lean practices.

Based on the results of this study productivity and efficiency will rather decrease than increase due to lean practices. Other researchers had contradicting findings. Dehdari (2013) found empirical prove for the proposition that an increase in lean maturity has a positive impact on productivity. Other studies (Swank, 2003; Shah and Ward, 2003) show that lean has a positive effect on resource required to produce a certain output. The findings of this study do not comply with these studies. An explanation of this effect could be due to the fact that implementation of lean practices costs time. For example, dedicating a daily portion of time to 5S means that during that time employees are not productive. During interviews with lean experts of Philips Lighting it became clear that the minor improvements in labor productivity observed after implementing lean practices do hardly outweigh the absence of employees as a result of training. Furthermore, de Koster and Warffemius (2004) state that Asian warehouses implement lean practices, such as kaizen, statistical process control, and quality circles, significantly or close to significantly more than American firms. While implementing these practices, there are no differences observed between Asian and

American warehouses in productivity. The results of this study may be contra dictionary, but the mentioned studies show that the positive relationship between lean practices and productivity is not always present. Especially not in situations comparing business-to-business deliveries with business to consumer deliveries. While business-to-business warehouse operations tend to be less productive (de Koster and Warffemius, 2004). The last possible explanation for the decrease in productivity can be found in the ownership structure of the warehouse. The worst performing warehouses are both private owned. De Koster and Balk (2008) state that public owned warehouses perform better than private owned warehouses due to the competiveness of the environment.

In contrast to productivity, quality seems to improve when implementing lean practices. The results of this study suggest that the percentage of order lines shipped without errors increases when the degree lean maturity increases. Research suggests that this phenomenon can be explained by an improved customer focus (Wan and Chen, 2008). Furthermore, Jones et al. (1997) assume that an increased customer focus leads to higher quality standards. These standards may stress the importance of reduction of errors and hence improve the delivery quality. Womack and Jones (1996) specify that a lean organization strives for perfection on a daily base. Although aiming for perfection may not always lead to speeding up processes, perfection has a positive effect on the amount of errors. Radnor and Roaden (2004) mention that a high degree of lean maturity can cause corporate anorexia. Corporate anorexia emerges when companies emphasize the importance of efficiency. Based on this study the opposite is true for lean in the warehouse. Lean in the warehouse may even focus too much delivery reliability, causing decreased productivity.

Lean practices seem to have no effect on employee satisfaction based on the results of the six warehouses studied. As mentioned earlier according to literature the employee involvement introduced by lean practices can have a positive effect employee satisfaction, but the constant change and uncertainty can also have a negative impact on employee satisfaction. Based on the results it cannot be established whether the former outweighs the latter. This can be caused by the individual perception of similar situations. Hackman and Oldham (1980) state employee satisfaction is rather influenced by the individual to a situation than by the situation itself. Vidal (2003) states that the workers attitude towards employee involvement shows a normal distribution. Meaning the relationship between employee involvement and employee involvement is not linear. A small proportion of workers are positive about employee satisfaction, a small proportion is negative, and the major part of workers is somewhere in the middle of both. Based on these findings the results of this study are not surprising.

6.2 Research limitations and recommendations

Obviously the conclusions of this study are limited due to the limited sample size. Because of the limited sample size statistical analysis based on significance testing and correlation was not possible. Although the results section shows more or less linear relationships between the independent variable and two dependent variables, it cannot be concluded that there is a correlation between lean warehousing and warehouse performance. To increase internal validity and content validity the results of this study were verified with existing sources in literature, opinions of experts, and principles observed in practice.

The method to quantify lean maturity was constructed of multiple studies. In general Confirmatory Factor Analysis is used to create constructs. Again, due to limited sample size this step towards the development of a measurement was not possible. To increase reliability and validity constructs taken from other studies were only slightly adapted. Furthermore, the resulting measurement model was verified in structured interviews with lean specialist from various companies. Despite of these steps the assessment of lean maturity depends largely on the respondents' interpretations of the lean questionnaire. Some questions within the questionnaire are slightly subjective.

Despite these limitations, the research provides propositions that can be applied and tested in further research. This study provides an easy applicable and feasible method to measure lean in a warehouse. Furthermore, the results and discussion of this study provide propositions that can be used as potential hypothesis for future research. The propositions should be tested with a larger sample. In that way future research can reject or accept the findings by applying more advanced statistical analysis. By doing so the external validity of the findings will increase. Further research can also focus on factors mediating the implementation of lean practices and the impact of lean on performance. For example, the orientation of leadership can be used as a moderating variable to study the degree of implementation and success of lean production in the warehouse.

6.4 Conclusion

The research provides a theoretical framework to quantify lean production and measure performance in a warehouse environment. The lean maturity model was constructed based on intensive exploration of theory and practice. The model developed is easy to apply as self-assessment tool. The scores can be used to identify areas of improvement in a warehouse’s lean implementation. Based on the results and discussion section of this thesis the main research question can now be answered:

‘How does lean warehousing influence the performance of a warehouse operation?’

Lean warehousing does influence warehouse performance. Although this relationship is not all cases positive. The linkage between lean warehousing and performance depends on the definition of warehouse performance. Warehouse performance was measured based on productivity, quality, and employee satisfaction. There seems to be no relationship between lean maturity and employee satisfaction. Both the scatter plots and correlation statistics show no sign of a linkage between the concepts. The theoretical framework suggested that employee involvement could have a positive impact on employee satisfaction. Based on the results of this study this linkage cannot be confirmed. Lean warehousing does influence productivity. Surprisingly the findings of this research suggest that lean warehousing has a negative impact on productivity. However, this can also be caused by the fact that the sample consists of both private and public warehouses. When performance is defined in terms of quality lean maturity has a positive impact. There seems to be a positive linear relationship between lean maturity and the percentage of error free orders shipped.

Lean warehousing is a powerful tool to improve quality by reducing errors. Due to the amount of resources required for implementation the effect on productivity and efficiency is rather positive than negative. Because of that warehousing organization have to define their value proposition and strategy before applying lean practices. If a warehouse is focused on cost reduction and efficiency lean is not the appropriate management philosophy to adopt. However, when delivery reliability is key to warehouse organization’s strategy lean practices and principles can be implemented to support the strategic objectives.

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Appendices

Appendix A Lean Assessment Model

Category	Construct	Item no	Warehouse Lean Assesment Item label	1: No implementation	2: Little implementation	3: Some implementation	4: Extensive implementation	5: Complete implementation
External:	Supplier involvement	Supp_01	We are frequently in close contact with our suppliers					
		Supp_02	We give our suppliers feedback on inbound delivery performance					
		Supp_03	We strive to establish long-term relationships with our suppliers					
		Supp_04	We use a standardized supplier certification method					
		Supp_05	We provide information about our inventory position to suppliers					
		Supp_06	Suppliers enable efficient material handling and flow by using appropriate conditional means					
	Customer involvement	Cus_01	We frequently are in close contact with our customers*					
		Cus_02	Our customers give us feedback on outbound delivery performance					
		Cus_03	Our customers are actively involved in current and future Value Added Logistics offerings					
		Cus_04	Our customers frequently share current and future demand information with planning department					
Inter	SPC	SPC_0	Large number of processes on shop floor are currently under SPC					

nal		1						
		SPC_02	Extensive use of statiscal techniques to reduce process variances					
		SPC_03	Charts showing error and productivity rates are used as tools on the shop-floor					
		SPC_04	We use standardized problem solving techniques to identify the root cause of problems					
		SPC_05	We conduct process capability studies before introducing new logistics processes					
		SPC_06	The current and desired state of alll value streams are mapped					
	TPM/5S	TPM_01	We dedicate a portion of everyday to planned equipment maintenance or 5S related activities					
		TPM_02	We maintain all our equipment regularly					
		TPM_03	We maintain excellent records of all equipment maintenance and 5S related activities					
		TPM_04	We post equipment maintenance and 5S records on shop floor for active sharing with employees					
	Employee involvement	Empinv_01	Shop-floor employees are key to problem solving teams					
		Empinv_02	Shop-floor employees drive suggestion programs					
		Empinv_03	Shop-floor employees lead process improvement efforts					
		Empinv_04	Shop-floor employees undergo cross functional training					
		Empinv_05	The qualifications of individual shop-floor employees are visible on the shop-floor using a qualification matrix					
		Empinv_06	Shop-floor employees are empowered by decision on the lowest possible level					
		Empin	Lean leadership is actively promoted within all levels of the organization by					

		v_07	training					
		Empinv_08	Before the start on each working day performance on KPIs and special events are communicated to shop-floor employees					
		Empinv_09	We developed and implemented a process to formally capture, track, and reward continuous improvement ideas provided by employees					
	Warehouse	War_01	Storage, picking and packing processes are standardized					
		War_02	We design individual processes based on grouping similar items closer to their final destination to reduce travel distance					
		War_03	We store products based on ABC analysis to reduce travel distance					
	Pull and Flow	Pull_01	We plan the daily work activities to balance manpower and work flow between processes/operations					
		Pull_02	We level the flow between processes and areas to balance the daily activities between each area					
		Pull_03	We release orders to enable one-piece-flow rather than working in batches					
		Pull_04	We use Kanban systems to trigger internal logistics processes, e.g. replenishment of packing materials					
	Cross docking	Cros_01	We use a cross-dock strategy to reduce inventory levels and cycle time					
		Cros_02	Cross-dock items are moved, staged and wait a minimal amount of times					
		Cros_03	Cross-dock items are placed into adequate staging, clear identifiable and marked for shipment					

Appendix B Productivity Questionnaire

Company information[1]
Company name: …………………………………………………

Company address: ………………………………………………

Post code and City: ………………………………………………

Telephone number: ………………………………………………

Warehouse address: ……………………………………………..

Post code and City: ………………………………………………

Telephone number: ………………………………………………

Contact person

Name: ……………………………………………

Function: ………………………………………..

Telephone number: ……………………………..

E-mail address: …………………………………

Questionnaire

0 General warehouse information

0.1 Which of the following represent main functions of your warehouse? (multiple choices possible)

- ☐ Product warehouse
- ☐ Wholesale warehouse
- ☐ Retail store warehouse
- ☐ Cross-docking
- ☐ Regional distribution center
- ☐ European distribution center
- ☐ Others………

0.2 Is your warehouse managed and owned by a 3PL service provider?

[1] This information will only be used to contact the company in case of obscurities.

☐ Yes
If yes, the warehouse is:

☐ Public warehouse, serving multiple customers.

☐ Dedicated or contracted warehouse, serving one customer.

☐ No

0.3 How many FTEs (full time equivalents) work in your warehouse on average per year? ....

a) Direct FTEs[2]........

b) Indirect FTEs.........

0.4 What is the size of your warehouse (in m^2)?

☐ < 1.000 m²

☐ 1.000 – 3.000 m²

☐ 3.000 – 5.000 m²

☐ 5.000 – 10.000 m²

☐ 10.000 – 20.000 m²

☐ > 20.000 m²

0.5 To what extent has your warehouse been automated with regard to information systems?

☐ Very low: basic automation, such as use of computers and/or Excel spreadsheets

☐ Low: use of warehouse management information system (MIS), or WMS

☐ Average: all above and with use of bar codes and scanners

☐ High: all above and with (partly) paperless operation

☐ Very high: all above and with multiple paperless picking communication systems

1 Products and order information

1.1 What type(s) of products are stored in your warehouse

[2] Direct FTEs are blue-collar workers, working on the work floor in the warehouse, all other FTEs are indirect.

1.2 What is the average number of SKUs (Stock Keeping Units) stored in your warehouse (in m^2)?

- ☐ < 500
- ☐ 500 – 1.000
- ☐ 1.000 – 5.000
- ☐ 5.000 – 10.000
- ☐ 10.000 – 20.000
- ☐ 20.000 – 50.000
- ☐ 50.000 – 100.000
- ☐ > 100.000

1.3 What is the average number of customer orders per day?

……

2 Processes and systems

2.1 Which of the processes mentioned below play an important role in your warehouse? (multiple choices possible)

- ☐ Quality control of received products
- ☐ Receiving and processing of returned products
- ☐ Repacking received products
- ☐ Cross-docking/Transshipment
- ☐ Regular counting
- ☐ Internal product relocation for optimization purposes
- ☐ Delivery truck planning and routing
- ☐ Other special processes, namely ……………………………………………

2.2 What is the level of value-added logistics (VAL) carried out on a regular basis in your warehouse?

- ☐ No VAL
- ☐ Low-end value-added logistics (e.g. labeling, adding manuals, kitting, etc.)
- ☐ High-end value-added logistics (e.g. repair, sterilization, final product assembly, product installation, etc.)

3 Warehouse performance

3.1 How many *orders* are picked on average per day?
…………………………………………………………………………………………….

3.2 How many *order lines* are picked on average per day?
…………………………………………………………………………………………….

3.3 How many *units/pieces* are picked on average per day?
…………………………………………………………………………………………….

3.4 Which percentage of order lines is shipped without error per day?
…………………………………………………………………………………………….

3.5 Indicate below how you assess your warehouse compared with competitors in terms of

	Much worse than main competitor	**Worse than main competitor**	**Equal to main competitor**	**Better than main competitor**	**Much better than main competitor**
The ease at which fluctuation in the number of orders can be handled	☐	☐	☐	☐	☐
The ease at which late changes in order composition(numbers and SKUs) can be handled	☐	☐	☐	☐	☐
The ease at which orders can be delivered more rapidly than originally ordered	☐	☐	☐	☐	☐

flexibility.

END OF THE QUESTIONNAIRE

Thank you for your cooperation!

Appendix C Employee satisfaction Questionnaire

<u>Personal Information</u>

0.1 Wat is your gender?: O Man O Woman

0.2 What is your age? ………………. Year

0.3 What is your highest completed education?

O Primary school	O High School	O MBO	O HBO	O University	O Other

0.4 How long do you work at the company?

O < 1 year	O 1 - 3 year	O 4 - 6 year	O 7 - 12 year	O > 12 year

0.5 Wat is the nature of your contract?

O Fixed	O Temporarily

0.6 How many hours a week do you work on average?

O parttime; < 12 hours	O parttime; 12 - 24 hours	O parttime; 24 - 36 hours	O fulltime 40 hours

<u>Satisfaction with work</u>

Please read the following statements carefully and and determine on a scale from 1= (totally disagree) to 5 (= totally agree) to what extent you agree with the statement and cross your answer.

	1 Totally disagree	**2 Somewhat disagree**	**3 Neutral**	**4 Somewhat agree**	**5 Totally agree**
3.1 In general I am satisfied with my job					
3.2 I often think about quitting this job					
3.3 In general I am satisfied with the nature of work I have to do in this job					
3.4 Most of my colleagues are satisfied with their job					
3.5 My colleagues often think about quitting their job					