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An Evaluation of Kitting Systems in Lean Production

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Dedication

This thesis work is dedicated to my mother E. Gülay, father M. Hilmi, and sister A. Özge whose sacrifices, which were realized by our loss of precious time together , were the most painful and yearning for me.

I have felt their true love, trust and support with me throughout my entire life. Without them I could not be the person I am.

M. Alper Corakci

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I feel this thesis work has been very informative for me and helped me to broaden my knowledge and experience in the area. I am totally sure that I will be able to benefit from this thesis in my future career.

Göteborg, October 2008

Abstract

One of the key decisions for every assembly line is the decision about the materials feeding system which means the method of supplying materials to the operators. This decision affects all of the other activities performed as well as the performance of the assembly line. In the industry, kitting is practiced as a method of materials feeding among others such as continuous supply, batching and sequencing.

Kitting is the name for the practice of feeding components and subassemblies to the assembly line in predetermined quantities that are placed together in specific containers. In the industry kitting activities are used to solve the issues of:

- Lack of space
- Quality
- Flexibility
- Materials Handling
- Learning

Kitting shows numerous benefits in all of five tracks if applied properly. Drawbacks of kitting are mostly caused by wrongly prepared kits, kitting too much or unnecessary parts. It is important to include all five of these aspects in business cases before the implementation of kitting, otherwise kitting activities are likely to cause further problems.

The main reason for kitting in Swedish industry is the space requirements. Most companies are aware of other benefits such as quality and learning aspects but are not considering them as their most important reason to initiate kitting activities. Companies are also hesitant to initiate kitting since it is an expensive solution compared to other solutions.

The biggest limitation of kitting seems as increased number of materials handling and the uncertainty about the level of kitting. Past experiences made companies more hesitant about kitting implementations.

Kitting in a lean production system is possible as long as kits are secured so that they are 100% correct in the first place and there is no machine downtime caused by invalid kits. Additionally, waste should be continuously eliminated from kitting operations and workers should be trained well to get involved with the processes.

Keywords: Kitting, Lean production, materials supply, materials feeding

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"Vision without action is merely a dream.

Action without vision just passes the time.

Vision with action can change the world."

Joel Barker

1. Introduction

In this chapter, the background for the research topic is presented initially. The motivation behind the research is explained in the purpose and problem description part which is followed by a brief literature review. The chapter is finished with a disposition over the structure of the research.

1.1 Background

In today's competitive world, an important concern for the manufacturing companies is to increase their customers' satisfaction by constantly improving their delivery yet to keep quality at its best level. Meanwhile, they need to keep their costs and prices as low as possible to be able to compete with others but still increase their profitability. In the literature, numerous researchers mention that in order to achieve this, a company should have a very good control on its production systems and look for improvements wherever possible.

Practices show that vision is as important as action to have the best control on the production system. One should have a strong vision and clear idea of its future goals to establish the most effective production system. Lean philosophies, which were initiated in Toyota Production System, are seen as this revolutionary change in the mindset, which manufacturers in the search of perfection are thirsty of, with its effects to the actions as well as to the visions. (Dennis, 2002)

Lean philosophies help companies not only to control their production but also help them to combine the improvements in operational and commercial aspects and manage them to find the way that provides long-term business success and the employee capability to continuously propel that company to further improvement. (Dennis, 2002)

In the industry, materials feeding decisions are really important since they enable a manufacturer to increase the control and affect the overall efficiency of its production system.

Kitting is practiced as a method of materials feeding among others such as continuous supply, batching and sequencing. (Johansson, 1991)

The practice of delivering components and subassemblies to the shop floor in predetermined quantities that are placed together in specific containers is generally known as kitting. Rather than delivering the required parts to an assembly station in component containers and in relatively large quantities, parts can be first pulled together in kit containers before they are delivered to the shop floor. (Bozer & Mc Ginnis 1992)

According to Medbo (2008), kitting activities are observed being used to solve the issues of:

- Lack of space
- Quality
- Flexibility
- Materials Handling
- Learning

Cultural differences are also observed in between the Japanese way and Swedish way of applying kitting activities. In Swedish context, lack of space is seen as the main motivation for applying kitting. However, in Japan and China it is more often used as a tool to improve quality, and even as a work instruction to improve learning. (Medbo, 2007)

Picking is the activity of moving a product from the storage to packing and linked to an actual order. Picking time and accuracy are then very important process because they directly affect the lead time. Order picking activities define the method how to feed the assembly line and therefore they are very crucial for any assembly line. The main difference of order picking activities between different production systems are characterized by variables such as ordering frequency, acceptable delivery time and order structure. All of these variables have an effect on the overall efficiency of the assembly line. (Tompkins, 1996)

Kitting, when applied properly, has been observed to show numerous benefits for the assembly line. Since kitting involves the gathering of all parts together from the stock, and placing the “kit” to the assembly line, it involves a lot of possible sources of waste. From a lean philosophy point of view, this is worthwhile to think about to find out how the ways to lean kitting are possible. (Vujosevic, 2008)

1.2 Purpose and Problem Identification

The purpose of this research is to *present an evaluation of kitting systems in lean production systems.*

The purpose will be divided into three research questions:

- *The reasons for applying kitting including the identification of limitations.*
- *Describe five different tracks that kitting is used to solve: Space, Quality, Flexibility, Materials Handling, Learning*
- *Describe the similarities in the lean philosophies and lean kitting.*

Therefore, the research is expected to evaluate different reasons for applying kitting as well as their drawbacks. Secondly, it is expected to identify the main differences between different tracks of using kitting. Finally, it is expected to present a lean approach to kitting discussing its fit and applicability with lean philosophies.

The department of Logistics and Transportation at Chalmers University of Technology has a tradition of researching on materials feeding and design of assembly lines. This research also aims to build and develop previous research in the field.

1.3 Literature Review

Research in kitting is mainly based on past researchers on kitting, parallelized assembly lines, materials feeding, order picking, work flows, lean production systems and warehousing.

In the literature, there are a great number of publications which has contributed to these topics.

The ones which were primarily used in this research were Ding & Balakrishnan (1990), Johansson (1991), Bozer & Mc Ginnis (1992), Engström&Medbo (1994), H. Brynzer (1995), Tompkins (1996), Medbo (2003) and Piasecki (2003) with their contributions about kitting, materials feeding, parallel assembly lines, order picking and work flows.

On the lean production side, the main researchers followed were Womack & Jones (1996), Dennis (2002), Liker (2004), Bicheno (2004) and Nicholas (2006) who built their works on three giants Deming, Juran and Ohno.

About lean kitting, the researches which were followed were Ding & Balakrishnan (1990), Smalley (2005) and Vujosevic (2008)

1.4 Report Structure

The report is basically structured to follow the points of focus explained above.

Starting point are the findings from the literature about lean production systems, materials feeding, picking activities which were considered crucial to have a better understanding of kitting concept.

In the following chapter, the findings about kitting concept from the literature are presented and supported by the ideas of professionals who work for the industry and university. The professionals who were interviewed and their organizations are as follows:

- Henrik Brynzer, Volvo Cars Torslanda Plant
- Lars Medbo, Chalmers University of Technology
- Sebastian Numler, Johnson Controls
- Peter Friberg, Volvo Cars Skövde Plant

Then, the findings about lean kitting are presented throughout the following chapter.

Finally, all findings are analyzed and concluded reviewed in the last two chapters.

2. Theoretical Framework

In this chapter the related theories about kitting are presented. In order to gain a deep insight of kitting in lean production systems, it is crucial to have an understanding of lean philosophy as well as the major activities and operations that take place in the production and assembly area.

2.1 Lean Production Systems

Today, manufacturers all over the world are adopting lean production. (Foremost represented by Toyota Production system) Just as mass production is recognized as the production system of the 20th century, lean production created by Taiichi Ohno is viewed as the production system of the 21st century. (leanadvisors.com)

Lean Philosophies

The philosophy, principles and techniques that make up lean production are conceptualized in the "House of Lean" model shown in figure 2.1 below:

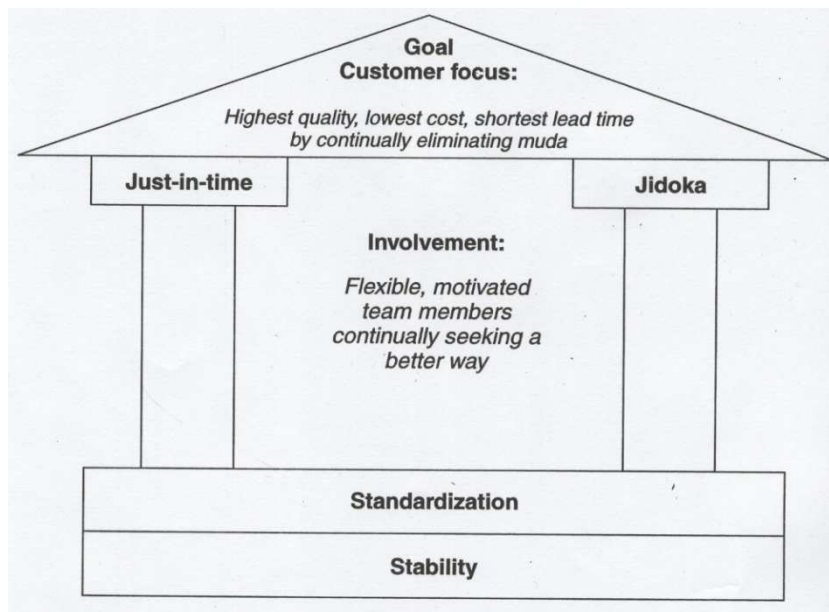


Figure 2.1 House of Lean Model (Dennis, 2002)

The ultimate goal is placed at the roof and it is customer focus. Customer focus implies the highest quality, at the lowest cost with the shortest lead time by continually eliminating waste. However, today customers have broader expectations than before. Thus, lean companies have added safety, environment and morale to their core goals. (Dennis, 2002)

Elimination of waste is at the core of lean philosophy. In the model, the way to achieve the ultimate goal is by continually eliminating muda. From a lean point of view, muda means any activity which the customer is not willing to pay for. Waste elimination is strongly related to lean, but it is only a means to achieve the lean ideal, it is not an end in itself. (Bicheno, 2004)

Workers in a lean system should always be ready to see waste and discover its sources. Therefore, efforts to eliminate waste are never-ending. (Nicholas, 2006)

Waste prevention is at least as important as waste elimination. Value is the converse of waste. All organizations need to continually improve the ratio of value adding to non-value adding activities. According to Nicholas (2006), there are two ways to do this:

- by preventing and reducing waste
- by going after value enhancement specifically

Bicheno (2004) mentions that Taiichi Ohno, the creator of Toyota Production System, originally defined seven wastes, however, later on, waste of untapped human potential was also added to the list as the eighth waste since lean production aims to create thinking people. Ohno's list with the additional eighth waste is as follows:

1. *Waste of Overproduction*: Producing items when there are no orders. Producing too much or too early or just in case creates waste in means of overstaffing, storage, transportation costs and excess inventory.
2. *Waste of Waiting*: It takes time when time is not used efficiently. Waiting time can be by workers, parts or customer and it is not value adding to the product.
3. *Waste of Unnecessary Movement*: Employees performing unnecessary motions such as bending, stretching, looking for parts or walking between processes create non value adding waste
4. *Waste of Transporting*: Inefficient transportation of materials, parts, finished goods between processes and in and out from storage adds no value.
5. *Waste of Over processing / incorrect processing*: Having unneeded or inefficient processes creates unnecessary motions and defects on parts.
6. *Waste of Unnecessary Inventory*: Excess raw materials and finished materials inventory cause product damage, late deliveries and imbalances. Inventory also hides problems in the system. Lowering inventories reveal the problems and lead to solve them.
7. *Waste of Defects*: Producing defective parts or correction cost time and money. The more time a defect remains undetected the more cost is added. For that reason, defects should be determined by prevention methods instead of inspection.
8. *Waste of Untapped Human Potential*: Waste is created by not engaging or listening to employees because it is a loss in the usage of human potential. It causes to lose time, ideas, skills, improvements and learning opportunities.

As House of Lean model suggests, lean is a conceptual and physical system, it is not a toolbox. Lean practitioners who consider lean as a toolbox and become familiar only one or few tools and try to implement them in their organization will be disappointed. (Liker, 2004; Nicholas, 2006)

The correct way of application of lean in an organization is to choose some of the foundation blocks according to the situation, appropriateness, importance, convenience or economics and to start with enough number of foundation blocks to put up one wall (JIT or Jidoka), and afterwards the philosophy which will be supported by the wall. Eventually, by adding more blocks and walls the organization, and also by experience and learning, the organization will be leaner at each step. This is a lengthy process but is also the only way how an organization can achieve a truly strong and self-perpetuating form of lean. (Nicholas, 2006)

Being as a system of thoughts and actions tailor-made for Toyota company and has been refined over the years, lean is not a method which other companies can implement directly to their system by simply practicing lean activities. Lean philosophy requires a total change of the mindset of the organisation. (Womack & Jones, 1996; Liker, 2004)

A lean transformation can be performed by using the framework seen in table 2.1. However, it is still worthwhile to state that once applied successfully and reached to a lean state, it does not mean that the organisation will be forever a lean organization so that the lean efforts can be diminished. Actually, it is totally the opposite way. In that sense lean is only the beginning. it is the beginning of a continuous process of eliminating waste in the organization, so this framework should be continuous and iterative. (Bicheno, 2004)

Step	Activity
1	Understanding the Lean Principles
2	Understanding Customers
3	Strategy, Planning and Communication
4	Understanding the System and Mapping
5	Product Rationalization and Lean Design
6	Implementing the Foundation Stones
7	The Value Stream Implementation Cycle
8	Building a Lean Culture
9	Working Lean Supply
10	Working Lean Distribution
11	Costing and Measuring
12	Improving and Sustaining

Table 2.1 Lean Framework (Bicheno, 2004)

Lean Principles

Lean thinking can be summarized in five principles as seen in figure 2.2 below:

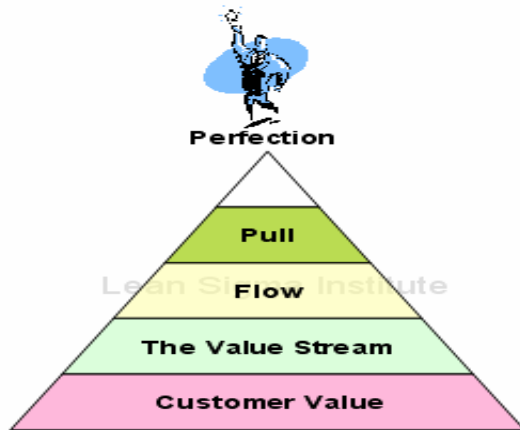


Figure 2.2 Lean Principles (Lean Sigma Institute)

1. *Specifying value from the point of view of the customer:* The critical starting point for lean thinking is value. Value can only be defined by the ultimate customer and it is only meaningful when expressed in terms of a specific product (a good or a service, and often both at once), which meets the customer's needs at a specific price at a specific time. (Womack & Jones, 1996)
2. *Identifying the value stream:* Value Stream is all the specific actions required to bring a specific product (whether a good, a service or a combination of two) through three critical management tasks of any business. These three tasks are problem solving or product definition task, information management task and physical transformation. (Bicheno, 2004)

The value stream map is a tool that:

- Allows you to diagram your current value stream.
- Identifies the bottlenecks that causes the delays
- Develops a vision of what your future lean system should look like.

Furthermore, it is also important to look at the whole supply chain, or more accurately the demand network. Concentration should be on the viewpoint of the object (product or customer), not on the viewpoint of the department or process step. (Bicheno, 2004)

3. *Make the value flow:* Making the value flow means working on each design, order, and product continuously from beginning to end so that there is no waiting, downtime, or waste, within or between the steps. The ideal state is a one piece flow at and between processes.

This usually requires introducing new types of organizations or technologies and getting rid of the obstacles. It is useful to work according to Stalk and Hout's Golden Rule and never delay a value adding activity because of a non-value adding activity. Instead, such activities should be done in parallel. (Bicheno, 2004)

4. *Customer pull:* Pull means short-term response to the customer's rate of demand, and not over producing.

Pull should be thought about on two levels. On the macro level, most organizations will have to push up to a certain point and respond to final customers thereafter. The aim is to push this point further and further upstream. On the micro level, there is responding to pull signals from an internal customer that may be the next process in the case of kanban. Attention to both levels is necessary.

Letting the customer pull the product from the value stream eliminates the following types of waste: designs that are obsolete before the product is completed, finished goods, inventories and elaborate inventory/information tracking systems. (Bicheno, 2004)

5. *Pursue perfection:* After having worked through the previous principles, perfection becomes more possible. In a lean context, perfection means producing exactly what the customer wants, exactly at the right time, at a fair price and with minimum waste. (Bicheno, 2004)

Bicheno (2004), also states these five principles are not a sequential, one off procedure, but rather a journey of continuous improvement.

According to Bicheno (2004), there are 20 common themes of lean which can be found in the literature of Womack & Jones, Schonberger, Hall, Goldratt, and Imai who built their works on giants Deming, Juran and Ohno. These themes can be seen in table 2.2 below:

Customer	Simplicity	Waste	Process	Visibility
Regularity	Flow	Pull	Postponement	Prevention
Time	Improvement	Partnership	Value Networks	Gemba
Variation reduction	Participation	Thinking small	Trust	Knowledge

Table 2.2 Common themes in lean literature (Bicheno, 2004)

Lean Activities

As described in House of Lean Model, the lean philosophy is based on a number of building blocks and foundation stones. All of these blocks consist of various day-to-day activities which contribute a successful achievement of lean philosophy. These lean activities can be seen in Figure 2.3 below.

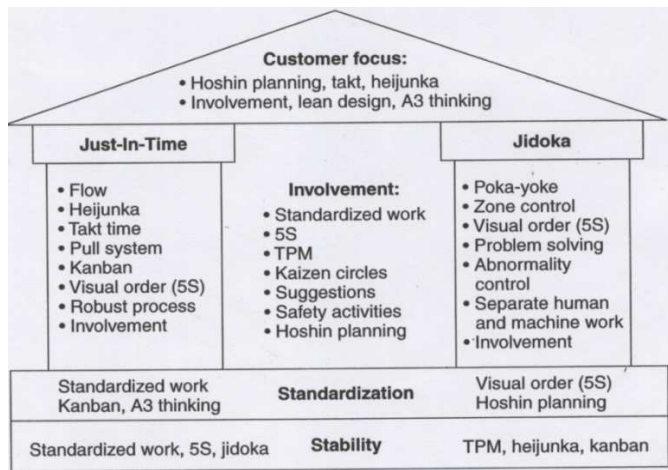


Figure 2.3 Lean Activities in the House of Lean (Dennis, 2002)

The foundation of the lean system is stability and standardization. The walls are JIT delivery and jidoka. The goal of the system is customer focus, and at the heart of the system there is involvement which is flexible and motivated team members continually seeking a better way of doing things.

Stability

Stability is one of the foundation blocks of the House of Lean. According to Dennis (2002), the improvements are impossible to achieve without stability in 4 Ms, which are:

- Man / Woman
- Machine
- Material
- Method

Stability starts with visual management and 5S system. 5S supports standardized work and TPM (Total Productive Maintenance) which are the keys to achieve production stability.

5S system is designed to create a visual workplace, which is self-explaining, self-ordering, and self-improving. 5S also supports JIT production by providing point-of-use information that eases decision making.

Dennis (2002) mentions 5S system is composed of:

- Sort: is the first principle of visual management and means to sort out what you don't need in the workplace.
- Set in order: is about placing machines, tools, storage shelves to reduce the waste of motion.
- Shine (and inspect): is about cleaning up the storage areas, equipment and surroundings to raise the team spirit.
- Standardize: is about putting simple, clear and visual standards for easier visual management.
- Sustain: is ensuring 5S develops deep roots in the company and becomes the normal way of doing business.

5S leads the organization to TPM, which is the key to machine stability and effectiveness. TPM is revolutionary in the sense that it changes the mindset of “I operate, you fix” into “We are all responsible for our equipment, our plant and our future.” (Dennis, 2002)

Standardization

Standardization is also one of the foundation blocks of the House of Lean. The tools of standardized work help to improve efficiency by identifying value and the waste in the process. According to Dennis(2002), a standard:

- Is a clear image of a desired condition.
- Makes abnormalities immediately obvious so that corrective action can be taken.
- Is good when it is simple, clear and visual.

Bicheno(2004) explains three key aspects of standard work which need to be understood:

- Standard work is not static, it should be updated when a better way is found.
- Standard work supports stability and reduces variations since the work is performed exact same way each time.
- Standard work is essential for continuous improvement.

Peter Wickens, Former HR Director of Nissan UK states that “In a western company, the standard operation is the property of the management or the engineering department. In a Japanese company it is the property of the people doing the job. They prepare it, work to it, and are responsible for improving it. Contrary to Taylor’s teaching, the Japanese combine thinking and doing, and thus achieves a high level of involvement and commitment.” (Bicheno, 2004)

According to Dennis (2002) the benefits of standardization can be listed as:

- Process stability
- Clear stop and start points for each process
- Organizational learning
- Audit and problem solving
- Employee involvement and poka-yoke
- Kaizen
- Training

The most important elements of standardized work are: Takt time, Cycle time, Work sequence and In-process stock. Takt time shows how frequently a product should be produced. Cycle time is the actual time it takes to do the process. The goal is to synchronize the takt time with cycle time. Work sequence defines the order in which the work is done, and should be clearly defined. In-process stock is the minimum number of unfinished work pieces required for the operator to complete the process without standing in front of a machine. Defining in-process stock clearly establishes WIP (work-in-process) standards per process, and again makes abnormalities obvious. (Dennis, 2002)

Just-In-Time

Just in Time production is one of the walls that built House of Lean and is based on a pull system. Pull means to produce only when there is a customer order. The opposite is push, and means producing even if there is no demand for it. (Dennis, 2002)

Dennis (2002) states that JIT production follows four simple rules:

1. Don't produce something unless the customer has ordered it.
2. Level demand so that work may proceed smoothly throughout the plant.
3. Link all processes to customer demand through visual tools (kanbans)
4. Maximize flexibility of people and machinery.

The components of a JIT system are:

- Kanban: is a system of visual tools that synchronize and provide instruction to suppliers and customers both internally and externally.
- Production levelling (heijunka) : The goal is to produce at the same pace every day so as to minimize the variation in the workload. Heijunka also supports quick adaptation to fluctuating demand.

Jidoka

The other wall which builds House of Lean is Jidoka. This term has been defined by Toyota as "automation with a human mind" and implies intelligent workers and machines identifying errors and taking quick counter measures. (Dennis, 2002)

Error proofing

Dennis (2002) states that high defect rates caused by the errors in production lead to frequent line stoppages, which make flow and pull, and therefore lean production impossible.

Hirano (1988) mentions ten different types of errors:

- Forgetfulness
- Errors due to misunderstanding
- Errors in identification
- Errors made by amateurs
- Wilful errors
- Inadvertent errors
- Errors due to slowness
- Errors due to lack of standards
- Surprise errors
- Intentional errors

Hirano (1988) also states that almost all errors can be prevented if the sufficient effort is put on identifying them and taking steps to prevent them by using poka-yoke methods. Poka-yoke

means implementing simple low cost devices that either detect abnormal situations before they occur, or once they occur, stop the line to prevent defects. (Dennis, 2002)

Typical examples of poka-yoke devices are guide pins, error detection, alarms, limit switches, counters and checklists. (Hirano, 1988)

According to Dennis (2002) a good poka-yoke satisfies the following requirements:

- Simple, with long life and low maintenance.
- High reliability.
- Low cost.
- Designed for workplace conditions.
- Sourced by shop floor team members.

Involvement

Involvement is at the heart of the House of Lean. The explicit goal of all involvement activities is to improve productivity, cost, delivery time, safety, environment and morale by:

- Solving specific problems by developing poka-yoke, reducing walk time by altering layout, reducing changeover time etc.
- Reducing hassles by applying 5S so that things are easy to see and find.
- Reducing risk by implementing poka-yokes to eliminate spills

According to Dennis(2002), the deeper goal is to improve team member capability. By strengthening the employee a company can face the future confidently.

Kaizen Circle Activity (KCA) is the best known involvement activity. It helps to strengthen team members their ability to work as a part of a team, as a leader as well as it improves their ability to think clearly and logically to solve problems. It also supports the team members build confidence. (Dennis, 2002)

Fast, Flexible and Flow

According to Bicheno(2004), fast, flexible and the flow is the basis for lean in manufacturing. Companies who are able to combine them in the best way can enjoy huge productivity and quality gains simultaneously. Fast, flexible and flow is the vision which lean requires going for waste reduction and continuous improvement. It means breaking down the barriers between traditional departments.

Bicheno (2004) also states that Fast is very important because speed is at the heart of lean as Ohno stated:

“All we are doing is looking at the time line...from the moment the customer gives us an order to the point where we collect the cash. And we are reducing the time line by removing non-value added waste”

In lean philosophy, the main focus is on economies of time, not on the economies of scale. Sufficient speed can be seen as an order qualifier but speed is increasingly an order winner.

Customers are often prepared to pay a premium for fast delivery. Besides, when producing fast becomes the goal it leads automatically to waste reduction, to improved layout, to reduction of over production, to closer working relationships, to better quality, to smaller batches, and to value stream thinking. (Bicheno, 2004)

Flexible is also very important for lean, because it holds key to answer market need as quick as possible and to gain competitive advantage. Today, Toyota by the use of lean philosophy has the flexibility advantage compared to its western competitors. By making subtle changes in the mix of vehicle models in the production schedule, Toyota can adjust its production output to meet rising or falling customer demand yet keep plants running at full capacity. In that sense, western companies are far less flexible and the consequences are idle plants, too much inventory or lost sales. (Nicholas, 2006)

In a lean organisation, there are different types of flexibility and strategies available, which are shown in table 2.3 below:

Flow is also very important in lean. It means working steadily at the customer rate, not hurry-up and wait as in batch and queue, or concentrating on the value adding seconds whilst ignoring non value adding hours. Going for flow means not only competitiveness through more satisfied customers but also greater productivity through reducing the wastes of waiting and inventory. (Bicheno, 2004)

Process Flexibility	Product Flexibility	Volume Flexibility	Labour Flexibility
Link customer requirements directly to production, so that decisions are based on real customer demand, rather than on demand forecasting.	Bring customization closer to the customer to avoid relying on stocks of finished products.	Reduce dependency on full capacity by negotiating with workers and suppliers.	Capacity / Time flexibility, in order to adjust labour to demand levels.
Integrate suppliers to make orders visible to all value chain partners.	Manage product variety by understanding the cost and profit implications of choice.	Diversify production plants, using dual-plant or multimodal plant strategies to cope with volume variability.	Skill flexibility, whereby people can fulfill various tasks.
Perpetuate sales data through the supply chain to avoid any time delays and enable a fast response to changes.	Make support structures more mutable to support total responsiveness.	Use incentives to manage demand and profits, rather than reactively discount excess stock.	Geographical flexibility(ability to move workers between plants).

Table 2.3 Flexibility and strategies available in a lean organization (Bicheno, 2004)

2.2 Materials Feeding Systems

One of the key decisions for every assembly line is the decision about the materials feeding system which means the method of supplying materials to the operators. This decision affects all of the other activities performed as well as the performance of the assembly line.

Johansson (1991) mentions three principles of materials feeding system for an assembly line which are batch supply, continuous supply and kitting. These principles are categorized with regard to two main variables as seen in figure 2.4 below:

- Whether a selection or all of the part numbers are displayed at the assembly station
- Whether the components are sorted by part number or assembly object

	Selection of part numbers	All part numbers
Sorted by part number	BATCH	CONTINUOUS
Sorted by assembly object	KITTING	

Source : Johansson, 1991

Figure 2.4 Materials Feeding Principles

Later on, a fourth principle which is called sequential supply is added to the list by Johansson & Johansson (2006) and it will be defined later in this chapter.

Continuous Supply

Johansson (1991) defines continuous supply as the case where material is distributed to the assembly stations in units suitable for handling and where these units are replaced when they are empty.

Bozer and McGinnis (1992) mention the same concept as line stocking. Bulk delivery of the materials is the usual way of materials feeding. Every different part number is supplied to to the assembly line in an individual container. The most significant advantages of this way are that no preprocessing of the parts are necessary and the continuous availability of stock at the assembly line. In the case that one part is missing or defected, assembly operator can easily pick another one from the container. However, there are some disadvantages too. If there are an excess number of parts to be assembled it means a lot of capital is tied up in stock, shop floor is becoming overcrowded by the parts, and the assembly operator has to move a lot to get the parts and loses time looking for the correct part numbers.

Batch Supply

In batch supply systems the material is supplied for a number of specific assembly objects. The batch of materials can be a batch of the necessary part numbers or a batch of these part numbers in the requisite quantities. (Johansson, 1991)

Sequential Supply

Johansson & Johansson (2006) defines sequential supply as the supply method that part numbers needed for a specific number of assembly objects are displayed at the assembly stations, sorted by object. The main motivation for sequential supply is the fact that if the product is assembled on a serial line where only a few components are assembled at each station, kitting is less advantageous since it will require a lot of extra materials handling to prepare different kits for each station. The sequencing process can be located within or outside the assembly plant which means that the materials feeding principle can differ between the assembly station and the supply chain. This is also true for the other materials feeding principles.

Johansson (1991) states that these principles exist simultaneously in one system and for different kinds of parts complement each other. In practice, pure systems can hardly be described due to variety in systems and solutions.

According to an example from the industry given by Limere & Van Landeghem (2008), in a case study, it was found that for a total of some 3500 part numbers, 52% of the parts were supplied to like line with continuous supply, 31% was sequenced at the supplier, 5% was sequenced internally and the remaining 12% was repacked or kitted internally.

2.3 Order Picking Activities

Another critical decision about the assembly line is the decision about order picking activities.

Order Picking is the process of removing items from storage to meet a specific demand. It can be performed manually or partly automated. It represents the basic service that the warehouse provides for the customer. In a manufacturing area, assembly line is accepted as an internal customer for the warehouse. (Tompkins, 1996)

Brynzer (1995) mentions one way of classifying order picking systems is whether the picker is travelling to picking locations (picker-to-part) or the materials are brought to the picker (part-to-picker). Picker to part is more commonly used in the industry.

According to Piasecki (2003), among all warehouse processes order picking tends to get the most attention since the ability to quickly and accurately process customer orders has become an essential part of doing business. It means high level of importance placed on order picking operations is its direct connection to customer satisfaction. According to annual member survey of Warehousing Education and Research Council, order picking activities constitute 50% of the total operating cost in a typical warehouse. The distribution of the cost is as seen in figure 2.5 below:

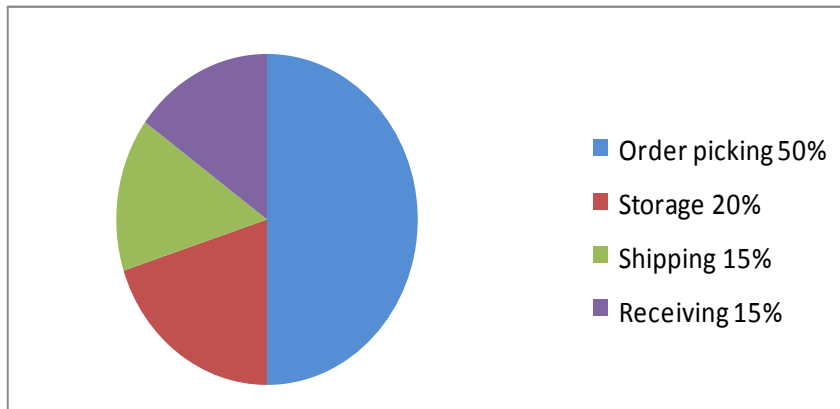


Figure 2.5 Distributions of Costs in a Typical Warehouse(Piasecki, 2003)

Frazelle(2001) lists a number of work elements related to order picking as follows:

- Travelling to, from and between pick locations
- Extracting items from storage locations
- Reaching and bending to access pick locations
- Documenting picking transactions
- Sorting items into orders
- Packing items
- Searching for pick locations

The typical distribution of the working time of an order picker is as shown in figure 2.6 below:

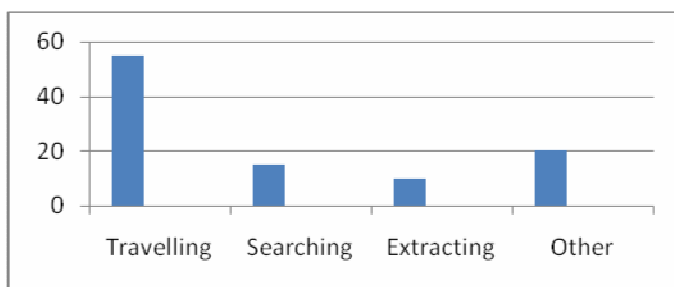


Figure 2.6 Distribution of the working time of an order picker (Piasecki, 2003)

Frazelle (2001) recommends some methods to reduce (or eliminate) these working times. Such as bringing pick locations to the picker to reduce travelling time, to automate information flow to reduce documenting time, presenting items at waist level to reduce reaching time, illuminating pick locations to reduce searching time and automated dispensing to reduce extracting time.

Tompkins(1996) recommends a number of principles to plan order picking:

- Encourage and design for full-pallet as opposed to loose case picking and full case as opposed to broken case picking

- Bring the pick locations to the picker
- Eliminate and combine order picking tasks when possible
- Batch orders to reduce total travel time
- Establish separate forward and reserve picking areas
- Assign the most popular items to the most easily accessed locations in the warehouse
- Balance picking activity across picking location to reduce congestion
- Assign items that are likely to be requested together to the same or nearby locations
- Sequence pick location visits to reduce travel time
- Organize picking documents and displays to minimize search time and errors.
- Design picking vehicles to minimize sorting time and errors to enhance the picker's comfort
- Eliminate paperwork from the order picking activity.

The Avery Way, which is a warehousing consultant company in US, has its eight secrets to perfect order picking (elogistics101.com) which are:

1. *To automatically verify everything*: Design your order picking system to double-verify every step of the picking process. People are open to make mistakes due to human nature but double checking will catch the mistakes. A system that requires scanning of barcodes, along with a blind entry of the quantity picked, will guarantee the right pick is made.
2. *Touch items once*: Order pick process should allow enough verified accuracy that further repacking, quality checking, or shipping checking, is not required. A pick unit should go to the customer (assembly line) touched only by the original picker's hands.
3. *Minimize walking*: Walking time can be minimized by picking from both sides of the aisle, placing slow-moving items on side aisles which are entered only when needed, picking many smaller orders in one trip (batch picking.)
4. *100% product availability*: Replenishment system must be designed in a way to insure an order picker never has to face an empty pick slot waiting for replenishment, and that orders never need to be segregated.
5. *Use ABC item analysis*: Prioritization should be done between items. For example, if 10% of the items can completely satisfy 50% of the orders (typically true), then these items can be called "A" items. A short pick line comprised of only these "A" items can be set up, and immediately half of the orders require walking through only 10% of the pick area.
6. *Stop pick and pass line picking*: Pass-along picking slows all orders to the speed of the slowest picker, or, to the capacity of the busiest pick station. Pick rates of the better pickers can often be increased by 30% to 200%, just by switching from conveyor picking to individual cart picks.

7. *Invest in training and quality circles*: Even the best designed order picking systems undermine its original excellence by changing customer requirements. An investment in productivity and accuracy improvement (Total Quality), and management supported quality circles that meet regularly to identify problems and propose solutions, will pay big dividends in continuous improvement of even an already excellent system.
8. *Walk your talk*: The least costly and most effective way to improve the order picking is through direct, continuous and enthusiastic top and middle management support, of the workers' striving for the highest level of picking accuracy and efficiency. Workers sense immediately, if management is only giving "lip service" to their commitment to excellence.

Key objectives of designing an order picking operation include increases in *productivity*, reduction of *cycle time*, and increases in *accuracy*. Sometimes these objectives may conflict with one another in that a method that focuses on productivity may not provide a short enough cycle time, or a method that focuses on accuracy may sacrifice productivity. (Piasecki, 2003)

Decisions about order picking systems are very important for kitting because as stated by Bozer & McGinnis (1992) and also supported by other researches like Brynzer (1995) and Medbo (2008) conceptually kit assembly is an order picking operation itself.

2.4 Assembly Line Performance

As mentioned earlier, the decision about the material supply system and order picking activities affect the performance of the assembly line. It is not very straightforward how to measure the performance of the assembly line.

According to Medbo (2007), there are five main areas where the assembly system performance can be measured:

1. *Physical design*: Materials façade length, materials façade area, station length and materials façade depth.
2. *Work task*: Value adding time, indirect time, disturbances, work load, walking distance, handling of components, time for handling empty packaging, buffers.
3. *Information and support*: Sound information, structured.
4. *Flexibility*: The free space, portability, easy to rearrange.
5. *Materials planning*: Packaging size, lot sizes, run out time, sequence demand, phase-out components, part numbers, SKU displayed.

Chow (1990) mentions the performance measures can be derived from workstation capacity, yield, line scheduling policy, job dispatching policy, parts availability, line layout and material-handling method. These measures can be complemented with:

1. Line capacity
2. Production lead time
3. Work-in-process
4. Workstation utilization

3. Kitting Systems

In this chapter the theories about kitting are presented. The reasons for applying kitting as well as the benefits and drawbacks are explained. The chapter ends with examples of opinions of professionals from various disciplines.

The practice of feeding components and subassemblies to the assembly line in predetermined quantities that are placed together in specific containers is known as *kitting* in the industry.

For discussion purposes, a kit may be generally viewed as a container which holds a specific assortment of parts that are used in one or more assembly operations in the plant. (Bozer & McGinnis, 1992)

In kits, all items are presented in a logical order so they can be removed from the container as quickly as possible without damage. It is important to keep it simple and the kit itself is structured or laid out in a predetermined and effective way. (Lean Advisors, 2008)

The type of components and subassemblies required for each kit type is given by the kit structure. Kit assembly is an operation where all the components and/or subassemblies that are required for a particular kit type are physically placed in the appropriate kit container. Conceptually, kit assembly is an order picking operation. (Bozer & McGinnis, 1992)

Kit assembly is commonly considered as a non-productive work. However, some researchers like Öjmertz (1998) states the assortment of components could itself be viewed as value adding since it improves prerequisites for the assembling operator.

Kit assembly can be performed by pickers or by the assemblers themselves. Further, the picking can either be performed in a central storage or decentralised areas located close to the assembly area, so called materials markets. (Brynzer, 1995)

Two types of kits were observed by Bozer & McGinnis (1992), which are stationary kits and travelling kits. A stationary kit is delivered to a workstation and it remains there until it is depleted. The product which is assembled moves from one station to another. A travelling kit is handled along with the product and it supports several workstations before it is depleted.

There are also two types of travelling kits. In the first type, the kit and the product travels in the same container as product is assembled. In the second type, the product travels in one container and the kit follows it in parallel in a separate container.

A kit typically does not contain all the parts required to assemble one unit of the end product due to the complexity or product size. Besides, certain components such as fasteners, washers are almost never included in kits, instead bulk delivered to the shop floor. (Bozer & McGinnis, 1992)

Kitting can be performed in-house or by the supplier at lower hourly cost. However, the lead time will increase due to the transport from the supplier to the production line. Since the kits are often supplied in the correct sequence of the production schedule, this will complicate the job of supplying operator. Besides, the distribution of kitting activities over several suppliers sometimes leads to suboptimal installations and largely manual operations. (Limere & Van Landeghem, 2008)

Reasons for Kitting

In the search for more efficient and flexible production systems together with the possibility of better work conditions, highly parallelized assembly systems with long cycle times have been developed. Generally, product lines require more and more part numbers due to a growing diversity of variants. (Elser, 1985)

One disadvantage with these parallel and long cycle time systems is their complicated materials feeding. Therefore, kitting systems have been considered and developed. (Johansson, 1991)

The reasons to use kitting still look somewhat not well understood and controversial in the literature. Bozer & Ginnis (1992), state that proponents of kitting point out that it gives the user better control of WIP, and helps reduce floor space. On the other hand, opponents claim that the man-hours consumed in the picking process is non-productive labour and that kitting is used primarily to conceal poor manufacturing operations management. (Brynzer, 1995)

In parallel assembly systems, more part numbers must be exposed at every work station compared to serial assembly. This leads to a lack of space when continuous supply is used. Moreover, the number of storing areas for a part number will be increased since every part number is supplied to several parallel stations instead of one station. In this situation, with the use of continuous supply administrative problems occur. Besides, problems about flexibility occur which result in large amount of tied-up capital in the storage and in the production system. (Brynzer, 1995)

Additionally, Brynzer (1995) mentions that kitting has also shown to be proper:

- When a large number of variant components demand a large floor area in the assembly system.
- For minimising the risk of assembling the wrong component.

From a product flow point of view, parallel flow and long cycle time assembly systems might look confusing to the engineers who wants to smoothen the flow of products and components within a plant, since the product flow in this type of plant does not mirror the actual assembly work. Since the operators constantly move around the products and alternate between the products and subassembly stations, the work pattern only mirrors the assembly work but not the product flow. Therefore, an important reason for kitting is the product description aspect. A basic principle is that the materials kit should function as a structured puzzle which is an assembly instruction enabling the operators to monitor their work. By this way the operators' assembly work is supported. (Medbo, 2003)

The theory about parallel flow and long cycle time assembly systems has been focused mostly on efficiency and organisational aspects. Arguments underlined are that increased job enlargement, through long cycle time assembly work, combined with parallel product flows, enables job enrichment and autonomous workgroups. However, merits in the form of flexibility are also becoming more and more important due to shorter product life cycles, increased product variation and shorter lead times. (Medbo, 2003)

Major Benefits of Kitting

In the literature, numerous advantages for the usage kitting are mentioned. Many of them are repeated by more than one researcher.

For the purposes of this research, it was found beneficial to group them under previously mentioned five tracks. Here, it is worthwhile to mention some benefits can be thought for more than one tracks, for example the elimination of searching time can be thought as a benefit both from a materials handling point of view and also from a learning point of view since it will cancel some of the required training for the order picker.

These benefits all together can be seen as a table in the appendix section.

Benefits to solve space problems:

- Saving space in the work stations, if the materials were supplied in materials containers, i.e. tote pans, with numerous identical components in the same container, this would have resulted in an enormous plant (Bozer & Mc Ginnis, 1992; Medbo 2003)
- Savings in manufacturing space and a better organized shop floor. (Bozer & Mc Ginnis, 1992; Medbo, 2003)
- Inventory costs could be reduced due to integrated storage and assembly. (Sellers & Nof, 1986; Schwind, 1992)

Benefits to solve quality problems:

- Parts could be damaged lying idle in open packages. (Schwind, 1992)
- Safer use of components that are similar in appearance. (Schwind, 1992)
- Components can be presented in sequential or assembly order in special packages that ensure correct assembly. (Schwind, 1992)
- Kitting ensures that the latest bill of material is used. (Schwind, 1992)
- High value components can be secured in kitting package. (Schwind, 1992)
- Early identification of low quality components. (Sellers & Nof, 1986; Bozer & Mc Ginnis, 1992; Medbo, 2003)
- There will be less damage in the transportation process. (Bozer & Mc Ginnis, 1992; Medbo, 2003)

Benefits on materials handling:

- Reduced material handling, instead of sending single parts, a collection of parts will be sent to the assembly line. (Sellers & Nof, 1986; Ding & Balakrishnan, 1990; Medbo 2003)
- The elimination of searching time. Order pickers do not need to search for the required parts, since all parts are in a single kit. Therefore, increased productivity. (Ding & Balakrishnan, 1990; Medbo, 2003)
- Better control over WIP, the parts of existing kits provide immediate information regarding the WIP level, since each kit consists of a predetermined quantity of parts. (Ding & Balakrishnan, 1990)

- It could be ensured that all components are available prior to scheduling work. (Schwind, 1992)
- Better control of material flow. (Sellers & Nof, 1986)
- When kits are standardized, this offers an opportunity to implement robotic handling. (Boldrin, 1982; Bozer & Mc Ginnis, 1992)

Benefits on flexibility:

- The assembly areas could become more flexible and free from leftover components. (Schwind, 1992)
- If traditional materials feeding through line stocking is utilised in parallel flow assembly, control of the number of components to store, replenishment, and the numerous design change orders will be complicated to administer and handle. (Medbo, 2003)
- Improved control over and better visibility of the flow of components on the shop floor. As a consequence part availability will also better besides product changeover can be easily accomplished. (Conrad& Pucanic, 1986; Bozer & Mc Ginnis, 1992; Medbo, 2003)
- Less work-in-process at the work stations, and consequently shorter lead times. (Medbo, 2003)

Benefits on learning:

- Kits are easier to learn for assembly workers which leads easier training (lower learning curves) and also reduces the training cost. (Ding & Balakrishnan, 1990; Medbo 2003)
- Using the materials as work instruction. (Medbo, 2003)
- Complex products can be overviewed and be understood. (Medbo, 2003)
- It would be easy to notice if a component is missing, given that the kit package is properly designed. (Schwind, 1992)

Major Drawbacks of Kitting

It is crucial to mention the drawbacks of kitting concept to be able to give an unbiased representation. The major drawbacks which were mentioned in the literature are as follows:

- Preparing the kits requires some time and effort which is a non value adding activity.(waste) (Bozer & McGinnis, 1992)
- Kitting is likely to increase in storage space requirement, especially when kits are prepared in advance. (Bozer & McGinnis, 1992)
- When different kits contain common parts, an assignment of available parts to kits needs to be done. (Bozer & McGinnis, 1992)
- Temporary shortage of parts will decrease the overall efficiency of kitting. (Bozer & McGinnis, 1992)

- Spare parts might be needed at the assembly line in the case that a part in the kit is wrong or defected, otherwise the production will be disrupted. (Bozer & McGinnis, 1992)
- Components that may even fail during the assembly process will require special consideration or exceptions. (Bozer & McGinnis, 1992)
- If parts shortages develop, some kits may get cannibalized. That is, short parts may be removed from some of the existing kits. This may further complicate the shortage and it may lead to problems in parts accountability. (Bozer & McGinnis, 1992)
- An increased number of handling occasions increases the probability of damaging the components, therefore not all components are suitable for kitting. (Johansson & Johansson, 2006)

These drawbacks can be seen as a table all together in the appendix section.

In the literature, there are many comments about the problems by using improperly or incompletely assembled kits. The “complete kit” concept is introduced by Ronen (1992) as the readiness of the kit prior to release to the shop-floor. There are two major components of a complete kit as hardware and information. The rules how to use the complete kit are threefold:

1. Do not start assembly unless the kit is complete. Assign one person as the gater to be in charge of the complete kit and gater’s tasks are defined as follows:
 - Making sure that only the jobs that need to be produced according to the schedule will be released.
 - Auditing the batch sizes and ensuring that only small lots that conform with the demand will be released.
 - Monitoring the buffers on the floor. Once the buffers are full, he should not release more WIP to the floor.
 - Making sure that only complete kits are released.
2. If the process / assembly or subassembly time exceeds 50% of total lead time, the levels of assembly should be redefined.
3. All entities needed to complete the process are included in the kit.

The fact that working with a complete kit is being significantly important indicates there should be some problems working with an incomplete kit. These problems are defined by Ronen (1992) as follows:

- *More WIP*: an incomplete kit causes an increase in WIP due to the job waits for the arrival of additional components.
- *Longer lead time*: the practice of using an incomplete kit causes more setups and the double handling means more time per part is spent.

- *High variance of quoted lead times:* It is very difficult to quote a lead time when a major item of information (arrival time of missing items) is unknown and difficult to predict.
- *Poor quality and more rework:* Incomplete kits tend to wait in inadequate storage facilities for too long until the missing item arrives.
- *Decline in throughput:* An item that is processed without being sold is not considered throughput. When resources are utilized on products that cannot be sent, other jobs that can turn into throughput have to wait.
- *Decline in productivity:* Experience shows that releasing an incomplete kit to the floor means spending 40% more working hours than working with a complete kit.
- *More operating expenses:* High WIP causes more operating expenses on account of more holding costs, more scrap and more work put into the job.
- *Decline in workers' motivation:* Regardless of their education and training, and level of complexity of the work they are doing, the people lose motivation and trust in the system when they feel that they are forced to do apparently unnecessary work.
- *Increase in complexity of controls:* Even a simple flow chart may become inordinately complicated when incomplete kits are allowed in the system.
- *Less effort to ensure arrival of the missing kit items:* Releasing an incomplete kit to the floor gives both to the customer and the producer the illusion that every effort is being made to get the job done.

Opinions about Kitting Operations from Professionals

Henrik Brynzer, Volvo Cars Torslanda

Henrik Brynzer is a manager in material handling engineering department of Volvo Car Corporation. He has long years of experience about kitting systems both in the research area and also in the industry.

Brynzer initially mentions three main problem area in which kitting is used as a solution, which are: space, quality and learning. He states that if there are problems about fitting a high number of parts efficiently in the production area or if there are quality issues about some parts then kitting could be a very good solution. Besides, if there are some similar or tricky parts, kitting can be used as a work instruction for the operators.

Brynzer highlights that having an efficient picking information system to support picking is very vital for the success of kitting operations. Information systems are costly but this amount of money should be installed to provide a quality sure and efficient kitting set up. He also emphasized that kitting operations must be located as close as possible to production line. Therefore, in Volvo Cars they prefer to keep kitting activities in-house with direct connection to production area to be lean, more responsive and make more efficient changes by faster feedback. He also gives an example from Ford in which they are doing the kitting operations on-line.

Brynzer states that in the industry pick to voice and pick to light systems are available. If it is very big parts and large space to drive around then pick to voice could be a better solution. However, they are using currently pick to light in Volvo Cars. He also states that they usually kit medium and small size parts. Larger parts are more often sequenced instead of kitting, because it is difficult to kit larger parts.

For successful kitting operations Brynzer thinks that it is very critical to secure the kits are 100% correctly assembled and efficiently performed. Otherwise, the operations would fail.

Efficiency in a production system can be measured as man-hours or quality. Therefore, kitting could improve efficiency in production since a lot of walking time and searching time for the operator is saved, and also number of wrong pickings is reduced. Furthermore, kitting is increasing visibility and helping to create a leaner job environment. He also gives examples of companies like Mazda, Ford, and IKEA that is using and benefiting from kitting.

Brynzer argues that the biggest limitation for kitting is too much material handling that is to handle the parts more than one time which is more costly and also may cause quality problems for some sensitive parts. Therefore, he thinks those parts should not be included in kitting. He also states that kitting could decrease the flexibility for future changes.

Brynzer summarizes his words by stating kitting is neither an easy nor a cheap solution. Therefore it should not be the first solution for a company.

Table 3.1 shows a summary of key learning points from Brynzer.

An efficient picking information system to support picking is very vital.
Kitting operations should be located as close as possible to production line.
It is very critical to secure the kits are 100% correctly assembled and efficiently performed.
Too much material handling is an important limitation for kitting.
Sensitive parts with quality issues should not be included in kits.
Kitting should not be the first solution for a company.

Table 3.1 Key learning points from Henrik Brynzer

Peter Friberg, Volvo Cars Skövde

Peter Friberg is the program manager for central MP&L in Volvo Cars. He was in charge of the kitting operations in Volvo Plant which had been implemented once but then needed to be replaced with other methods due to certain problems. However, Friberg says kitting is discussed once again today because of the space requirements in the plant.

As a start, Friberg states that kitting is their last solution since it is expensive and also consumes too much engineering resources. In Volvo Cars, their first option is to pick the variants readily and directly from the supplier. Second option is to downsize, which requires repacking activities. Third option is batching. Fourth option is called sequenced exposure in which they expose only the high volume parts in the materials façade.

Friberg thinks that their biggest problem was trying to kit the whole engine. Since the plant was new and everything was planned as state of art, they intended to kit the whole engine which didn't work at all. Today he thinks that there is a break-even point at which kitting is most beneficial and after that point it turns out as a failure.

He also mentions that more training was needed for the workers after implementing kitting. Therefore, he emphasizes that having fixed kitting personnel is very important for the success of kitting operations. Otherwise, number of errors increase significantly in each changeover.

Friberg also states that parts like nuts and bolts should not be included in kitting, because it is always possible to drop and lose one part and it causes further problems when they are in kits.

Some major problems occurred in the plant after implementing kitting were:

- Constantly growing kitting area.
- Huge grow in engineering work and resources compared to the situation without kitting.
- Amount of kitting personnel always turned out more than expected.
- Disturbances from automatic store.

- Picking errors were more common than before. There was no time to read the picking list. Workers were checking it only when they were uncertain instead of checking it each time.
- Parts were stacking into each other and got damaged in the kit containers. Some other parts like belts, pipes and harnesses were difficult to pick and place in kits.
- Initial plan was the operator should pick the kits circulating from the assembly but it failed due to many changeovers. The workers didn't remember what to pick and where to place the items.
- Different speed of the workers caused waiting time in the kitting corridors.
- Problems due to one-sidedness. It was more difficult to get and keep the personnel.

Finally, Friberg emphasizes the importance of good training and the support of an electronic system to prevent picking errors. Table 3.2 shows a summary of key learning points from Friberg.

Kitting is never the first solution because it is more expensive than other solutions.
Everything should not be kitted. There is a break-even point somewhere.
Fixed kitting personnel is necessary otherwise the errors increase.
Parts like nuts and bolts should not be included in kitting
Good training and the support of an electronic system are vital.

Table 3.2 Key learning points from Peter Friberg

Sebastian Numler, Johnson Controls Arendal

Sebastian Numler is lead expeditor in Johnson Controls in Arendal and he is working with new module program, getting the parts more ergonomically to the assembly line and also efficiently.

Numler initially states that their main reason for applying kitting in Johnson Controls was the space problems due to the high number of variants. Another important reason for them was to decrease the non value adding time of the workers. They try to keep workers as busy as possible and only with assembly. Everything except assembly that workers are busy with is a non value adding activity.

Numler mentions that currently they have 1-2 kitting personnel who are only busy with kitting but these persons used to work in assembly before the implementation of kitting so in total there are no change in the number of workers.

First focus for Johnson Controls in kitting was to get things up and running. But, the consequence was lower quality in the end product, so next step for them is to work with kitting quality-wise.

Numler thinks that in order to do good kitting with good quality it is important to design new boxes which match all different part types since they put numerous parts in one type of box which was not really designed for kitting. (Volvo blue boxes) So, the parts get scratched in these boxes and quality level decreases.”

Numler adds that kitting brought gains as more effective material flow, decreased picking errors and cycle times. However, there are still things to improve. He defines two conditions for a good kitting which are a large picking area and electronic support.

Numler finalizes by emphasizing the importance of kitting activities for Johnson Controls and he foresees an increase in the usage of kitting and sequencing activities in the future.

Table 3.3 shows a summary of key learning points from Numler.

Main reason for kitting is the problems about space.
It is important to use boxes specially designed for kitting.
A large picking area and electronic support are important for good kitting.
Kitting activities will be increasingly used in the future.

Table 3.3 Key learning points from Sebastian Numler

Lars Medbo, Chalmers University of Technology Göteborg

Lars Medbo is an assistant professor in Logistics and Transportation Department in Chalmers University of Technology and he has long years of experience about production systems design and kitting operations.

Medbo initially mentions about the principles of additive learning and holistic learning to emphasize the learning effects of kitting and how kitting can be used as a work instruction. By the usage of kitting, workers better understand the product as a whole and form a mental picture of it as they do it repeatedly. That turns kitting into a tool that helps workers to learn and assemble correctly. Practices show that it worked very well.

As well as learning, Medbo identifies other tracks in which kitting could be used very effectively to solve problems. They are: space, flexibility, materials handling and quality.

Part size is an important factor for kitting because for larger parts the focus is more on materials handling whereas for small and medium size parts it is more about learning aspects.

Medbo mentions kitting brings huge reductions in non-value adding time of the assembly workers compared to its alternative line stocking. Typically in line stocking 40% of the used time is non-value adding whereas in kitting it decreases to 20%.

There are differences how kitting is recognized in Sweden and Japan. He thinks that kitting is not fully understood in Sweden with all its aspects such as quality, flexibility and cognitive aspects but instead it is considered to solve space problem which is not similar to the case in Japan where these other aspects are included in business cases. Japanese kitting applications were observed to focus mostly on quality and learning issues.

Medbo summarizes the reasons for using kitting as:

- Accuracy, correct components, precision in the configuration of an assembled product

- Using the materials as work instruction
- Complex products can be overviewed and be understood
- Alternative to sequencing of separate components in serial flows
- Alternative to smaller packages in serial flows
- Enabling materials supply and feeding to parallel flow

Medbo finally emphasizes that it is very important to follow up the kits are 100% correctly assembled. Otherwise, there can be problems in the case of a missing or wrong part and it takes long time to solve this problem and may cause a stop in the production.

Table 3.4 shows a summary of key learning points from Medbo.

Kitting can be used to solve problems of space, quality, flexibility, materials handling and learning.
Kitting is a tool that helps workers to learn and assemble correctly.
There are big differences how kitting is recognized in Swedish and Japanese industry.
Kitting is not fully understood in Sweden with all its aspects such as quality, flexibility and cognitive aspects, it is more often considered to solve space problem only.
Kitting brings huge reductions in non-value adding time of the assembly workers.
It is very important to follow up the kits are 100 % correctly assembled.

Table 3.4 Key learning points from Lars Medbo

4. Lean Kitting

In this chapter the concept of lean kitting is presented. The possibilities for applying kitting in a lean production system are further considered by giving an example from literature and another example called SPS from Toyota Production System.

To contribute to this research, it was found very beneficial to discuss to which extent kitting fits to lean philosophies. In the literature, there are researchers like Vujosevic (2008) who mentioned the term lean kitting.

Vujosevic (2008) mentions kitting activities usually starts with an order generated by plant's ERP/MRP system. With this order, production control department first verifies that adequate quantity is available for each part number. If there are shortages, parts are ordered. In general, the kit is not released to the stockroom until parts arrive. After the arrival of short parts, the kit, now complete, is released to the stockroom for picking. The kit is typically sent to the off line setup area within 48 hours. The time it takes to pick all parts depends on *kit size* and *number* and *skill of employees*. (Vujosevic, 2008)

There are some problems observed by Vujosevic (2008) due to the inaccurate nature of ERP when it comes to following on-hand inventory levels as parts flow during kitting. Besides, the system is only accurate about the total quantity of a certain part type but not about the delivery. (for example: a total of 20,000 parts versus 4 deliveries of 5,000 parts) These inaccuracies together with human errors cause kitting problems such as:

- Insufficient quantity of parts.
- Excessive quantity of parts.
- Wrong parts.
- Incomplete kits.
- Insufficient quantity of packages

Then, these problems in kitting lead to increased machine downtime, lead times, and manpower. (Ronen, 1992; Vujosevic, 2008)

Vujosevic (2008) mentions a lean kitting project at a large electronics contract manufacturer's site and the project involved an assembly line that included a new Fuji NXT pick-and-place line. The NXT machine is based on a new concept of modular, scalable, and reconfigurable pick and place machines. This NXT machine had 10 modules. Thus, the same part number may occur on different modules as a result of placement sequence optimization and load balancing. The priority for the project was to eliminate waste on the assembly line by making sure machine downtime due to kitting problems does not happen. Next was to eliminate waste and make the kitting process as lean as possible.

Further goals for the project are explained as:

- Reduce kitting cycle time.
- Reduce manpower.
- Reduce number of partial material packages returned to stockroom.
- Eliminate the issue of insufficient quantity of material packages for parts split between different modules on NXT machine.
- Eliminate the possibility of wrong components being kitted by implementing electrical component test and component verification.

After the implementation of the project, their recommendation was not to eliminate kitting but instead eliminate waste from kitting and make sure it is right the first time so that there is no machine downtime caused by invalid kits.

Their solution can be called as a “Supplier Controlled supermarket Based Kitting” –which is similar to SPS in Toyota- and the following results were noted by Vujosevic (2008) as a result of the project.

- A central stockroom should not be used.
- The ERP system-based component procurement should be abolished.
- A supplier who can supply all types of components should be used.
- On-hand quantity requirement for each component should be established based on the ERP forecasts (weekly consumption), or even better, actual sales.
- Part consumption and attrition is maintained using a manufacturing execution system (MES). The component supplier gets (daily) data from MES on part consumption.
- The supplier restocks parts once a week based on MES supplied data.

The advantages compared the earlier situation are the reduced inventory cost, more accurate inventory counts, reduced manpower, reduced paperwork and purchase order cost. The disadvantage of the new situation is the initial implementation cost. Also, tying all inventory needs to one or a few suppliers may be risky.

In the industry, it has also been reported that Toyota has started using kitting in some of their plants for high volume assembly operations. It is a new kitting process, called Set Pallet System (SPS), implemented in San Antonio plant where they produce Tundra full-size pickup trucks. (leaninstituut.nl)

Before the implementation of SPS, line-side storage racks were used by operators to pick parts as seen in figure 4.1 below. Operators would walk from their assembly station to each rack and pick parts to install.

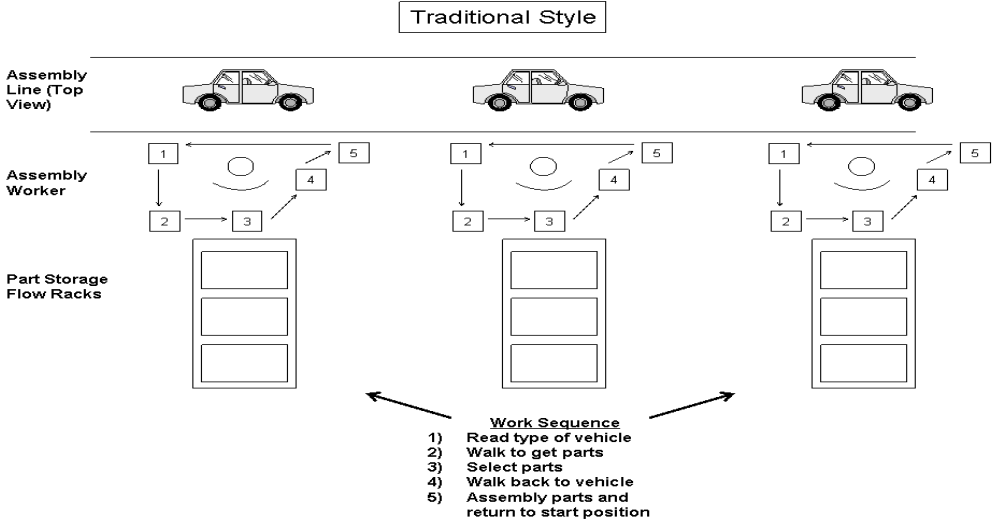


Figure 4.1 Traditional Assembly Line (Toyota New Material Handling System)

SPS introduces kitting personnel that receive a signal with a list of parts to be kitted, pick parts from storage racks, and then deliver pallets of parts to the assembly stations. Assembly operators are not involved in the part picking process any longer. Operator walking is dramatically reduced and parts selection eliminated. Walking and selecting is concentrated on material handlers, freeing assembly operators to concentrate on installation. In figure 4.2 below, operators walk from position A to B during installation, then back to position A. After receiving an electronic signal on what parts to select, material handlers take the parts from line-side bins to a pallet or tray traveling with the car or engine being assembled. Material handlers bring empty trays back to the racks for replenishment at the end of their station positions. (leaninstituut.nl)

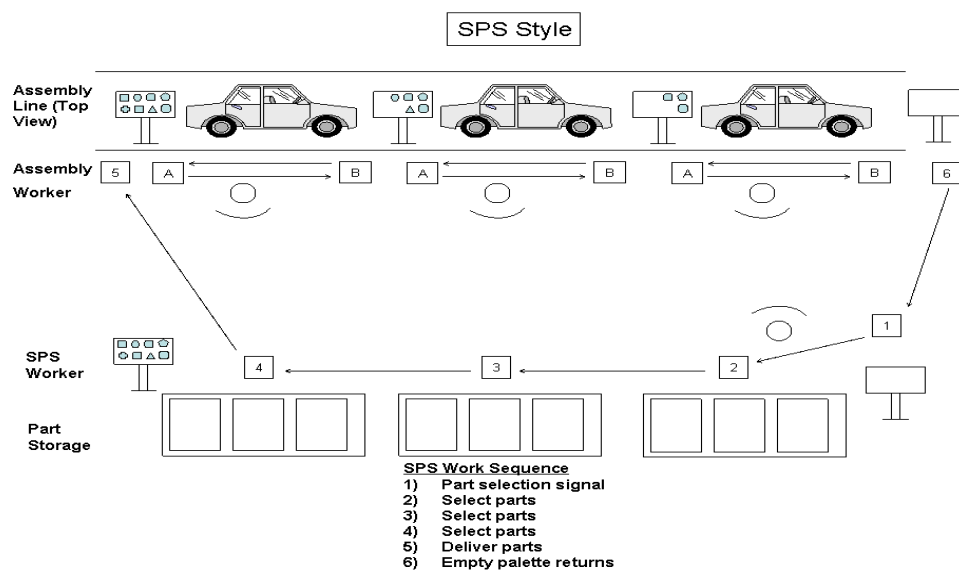


Figure 4.2 Set Pallet System (Toyota New Material Handling System)

According to a Toyota spokesman the advantages of this approach are:

- *More value added time by the operators:* By the cancellation of non-value-adding task of walking a few steps to retrieve parts from flow racks, now operators stay in a very tight zone and focus nearly 100% of their time on the value-added work of installing parts. The switch also eliminates reaching, stretching, and searching for parts by assembly operators. (Value)
- *Cleaner work areas with visual control:* The line become less cluttered, easier to see, easier to walk around, and just feel like a much more open work space. (5S)
- *Fewer part selection errors:* The big advantage of the new material handling system is simplicity and quality improvement through error avoidance. (Poka-yoke)
- *Easier training of assembly operators:* The new arrangement also makes training operators and material handlers easier because the job responsibilities are narrower.

On the other hand, there are two disadvantages which are the increased manpower by adding kitting personnel and adding or subtracting pickers incrementally as takt time changed somewhat harder to do. (leaninstituut.nl)

As mentioned earlier, a fit to the pull production system is also very important for kitting activities to fit in lean production systems. Ding & Balakrishnan (1990) consider part-size, lot-size and kit-size are the most important factors for a good fit to pull production.

Part-size

In industries dealing with heavy and bulky parts, such as metal industry, sizes of the parts are needed to be considered very carefully for kitting. Some large parts which don't fit into kits should be handled separately. In a pull production system, these large parts can be pulled individually while the kitable parts are pulled together as a kit. (Ding & Balakrishnan, 1990)

Lot-size

Another important decision to make for a pull system is whether to have parts production pulled by kits or pulled by parts. A pulled by kit system refers to a system that triggers the production for all the parts of a kit whenever the kit is emptied. A pulled by part system refers to system that provides intermediate storage between the manufacturing facilities and using stations for various kitted parts. Whenever a kit is emptied, it is refilled by retrieving parts from this intermediate storage point.

Briefly, pulled by kit would give one rhythm of replenishment while pulled by part would allow different rhythms for various kitted parts. (Ding & Balakrishnan, 1990)

Kit-size

For a system that works under pull production, storage container sizes should be compatible with kit sizes. Otherwise, if at any moment the number of units in the container of a certain part is less than the kit size, that container is useless for kitting. The determination of the kit size is affected by container size, material handling and WIP. (Ding & Balakrishnan, 1990)

5. Analysis

In this chapter an analysis of the previously mentioned concepts are performed. Kitting activities are analyzed generally under five tracks and furthermore from a lean kitting perspective.

Kitting as a method of materials supply to the assembly line is generally observed as a good solution for the industry whenever there are problems about space, quality, materials handling, flexibility and learning due to high number of variants. However, it is also a demanding and expensive solution. Companies prefer considering it as their last solution due its high amount of cost.

In the industry, kitting is used in combination with other materials supply methods such as line stocking, batching and sequencing. Experiences show that kitting everything is not a good idea. There is a breakeven point where kitting is at its best and after that point more problems occur due to increasing complexity. Furthermore, some certain parts should not be ever included in the kits. These are small parts like nuts and bolts, washers and also certain sensitive parts with quality issues.

There are numerous drawbacks of kitting if performed poorly. Therefore, it is very important to do kitting properly and secured from mistakes. Besides, kits should be simple and be structured in a predetermined and effective way. Kitting performs at its best when it is performed in-house and as close as possible to the assembly line.

Kitting decisions affect the performance of assembly lines significantly according to the previously mentioned areas of *physical design* by changing the material façade dimensions; *work task* by reducing the travelling and searching times for the workers, *information and support* by serving as a work instruction and lowering the learning curves for the workers; *flexibility* by creating free space around the assembly line and *materials planning* by affecting packaging size and amount of parts displayed around the assembly line.

For the purposes of this thesis it was found beneficial to analyze kitting operations under five tracks.

Space

As supported by all researches and professionals from the industry, kitting is used as a very useful solution when there is high number of variants demand a large area around the assembly line.

From a Swedish industry point of view, space problems seem the only and most important reason for applying kitting. All interviewed professionals were agreeing on showing space issues as their main reason. Furthermore, as in the case of Volvo Cars, although they had a past failure caused by too much kitting, today kitting is still a hot topic for them. The reason is simply the space concerns.

However, Medbo thinks there is a misconception of kitting in the Swedish industry and proves his ideas with examples from Japanese industry. He states that the business cases are kitting in Japan are prepared by considering all different aspects of kitting, not only space which is not the case in Sweden since there is a lack of awareness and necessary modules to add them in the business case.

Medbo states that a business case about kitting considering only the space issue but ignoring other issues will cause further problems in the production. As in Johnson Controls case, usage of kitting only to gain some space without really considering quality issues created quality problems for them. Therefore, they had to take quality-wise improvement steps afterwards.

The idea proves itself true in application even by the problems mentioned by other interviewed professionals such as: constantly growing kitting area, huge grow in engineering work, higher amount of kitting personnel, more common picking errors, decreased quality and disturbances from automatic store.

Quality

In the literature almost all researchers mention benefits of kitting from a quality point of view.

Main benefits for quality are the reduction in the number of wrong pickings and wrong assembly by safer use of parts that are similar in appearance. Although, it doesn't seem as the most important reason for applying kitting from the Swedish industry point of view, they all are aware of the quality benefits. Still, no quality issue was shown by them as the main motivation for kitting as in the Japanese examples.

Here, it is important to emphasize that kitting affects quality positively as long as it is secured, done 100% correctly and in proper packaging otherwise it creates some problems in quality.

Therefore, support of an electronic system is vital as mentioned by most researchers. Besides, working with a complete kit is crucial. An incomplete kit would cause poor quality and more rework.

If not secured or applied correctly, kitting could cause many problems. As in Volvo Cars, too much kitting led their number of wrong pickings to increase and quality level to decrease consequently. As in Johnson Controls, when performed in non-designed boxes it may cause lower quality due to the scratching parts. Sensitive parts, if added in kits, may cause quality problems, too.

Therefore, it can be said that kitting may add benefits to quality only if it is applied correctly and properly otherwise it becomes a reason for poor quality.

Materials Handling

As previously mentioned, there are a number of benefits of kitting in materials handling area such as the elimination of searching time, better control over WIP, better parts availability, standardization of the work. These are commonly accepted by most researchers however there are different and contradictive ideas when it comes to the amount of materials handling after applying kitting.

Conceptually, kitting is an order picking operation itself. The figures shown by Piasecki proves that travelling, extracting and searching time for the parts in order picking constitutes an average of 80% of the whole working time. Kitting, as a method of bringing the picking location to the picker, helps to decrease all of these non-value adding times significantly. Well defined methods for order picking as suggested by Tompkins and Avery Way are essential.

In the literature, there are comments on both sides that materials handling could be decreased or increased by kitting. Thinking about sending a collection of parts to the assembly line

instead of individual parts and the elimination of the worker's efforts to locate the correct part kitting can be accepted to decrease the materials handling in the assembly area. However, from a larger point of view including the kitting assembly area, it increases the materials handling activities.

Locating the kitting assembly station as close as possible to the assembly line was mentioned and accepted as a fact by all researchers and professionals. There are various benefits of doing this such as better coordination, being more responsive and getting faster feedback whenever a problem occurs in the assembly line.

Part size is also very important in order picking activities and kitting. Brynzer mentions that for large parts pick to voice systems could be a better solution. In Volvo Cars, they kit small and medium size parts and they use pick to light systems. Medbo states that for small and medium size parts kitting could be used as a work instruction whereas for larger parts focus is more on materials handling.

Brynzer recognizes the biggest limitation of kitting as too much materials handling. Touching the parts more than once is both costly and causes lower quality as Avery Way also mentioned in their perfect order picking method.

Flexibility

There are contradictive ideas in flexibility issue, too. Most researchers think that kitting has numerous benefits in the flexibility area whereas people in the industry were not observed to agree with these researchers.

In the literature, it is mentioned that kitting helps the assembly area to be more flexible and free from left over components therefore leads better visibility and easier control of the flow. Improved control of the flow and better visibility leads easier product changeovers which decrease the lead times.

However, most of the professionals interviewed mentioned that they observed a less flexible production system after the implementation of kitting. Brynzer mentioned that once applied, kitting makes the system less flexible to future changes. These contradictive ideas were also mentioned and supported by Friberg.

To my opinion, these contradictive ideas are sourced by different ways of understanding the term flexibility. As mentioned in second chapter and summarized in Table 2.3 there are different dimensions of flexibility. When different people are talking about flexibility, they focus on different types of flexibility most of the time. Brynzer and Friberg focus more on process flexibility and labor flexibility point of view. On the other hand, researchers who defend kitting creates a more flexible working environment emphasize more on product and volume flexibility.

Learning

In the literature, there are mentioned benefits of kitting such as lowering the learning curves for the workers and helping them to overview and understand a complex product by having the mental picture in their minds.

Medbo explains that using kitting as learning means or as work instruction is somehow neglected in the Swedish context. Swedish companies are generally too much and one-sidedly

focused on the savings about the space don't have too much efforts when it comes to learning aspects. In that sense, there are huge differences compared to Japanese industry where they see kitting as a tool of improving quality and learning aspects.

Learning aspects become more important when it comes to small and medium size parts compared to the larger parts where material handling is more important.

On the other hand, Friberg argued that their experience was workers needed much more training than before after the implementation of kitting. Their initial plan in their plant was the worker should pick the kits circulating from the assembly but the plan failed. The workers didn't remember what to pick and where to place the items due to many changeovers. Finally, they had to decide fixed kitting personnel to avoid these problems.

All professionals from industry agree that well trained workers are essential for good kitting operations.

Lean Kitting

It is quite straightforward that to be able to fit in lean philosophies, an activity should support the organization to eliminate waste, also should go along with pull production system smoothly as well as helping to achieve continuous improvement. Therefore, the general idea behind lean kitting is to eliminate waste on the assembly line continuously to make sure machine downtime due to kitting problems does not happen to create a smooth flow.

As mentioned previously, elimination of the waste is at the core of lean philosophies. If Ohno's list of eight wastes is considered, kitting can be accepted as a gain for:

- *Waste of unnecessary movements* by reducing the travelling, searching and extracting time of the assembly worker significantly.
- *Waste of transporting* by supply of a collection of parts instead of individual.
- *Waste of defects* by preventing the system producing defective parts.

However, kitting could be an extra waste for:

- *Waste of waiting* by different speed of the workers caused waiting time in the kitting corridors as in Volvo Cars case.
- *Waste of over processing* by too much material handling.

Kitting shows features to support the foundation blocks and walls of lean philosophies such as stability, standardization, JIT, jidoka and involvement.

Stability as the one of the foundation blocks of lean philosophies requires 5S which starts with visual management and aims to create a better and cleaner workplace. Kitting supports stability perfectly by creating free space around the assembly line and increasing visibility.

Also as a standardized way of doing things, kitting supports standardization block as well. By this way, kitting reduces variations and opens a gate for continuous improvement. Kitting shows a good fit to JIT and pull production as long as part-sizes, lot-sizes and kit-sizes are carefully taken into consideration. Kitting also fits with Jidoka as it decreases the number of wrong pickings and can be considered as a support to error proofing efforts. Kitting should be

supported by poka-yokes to secure that order picking is done 100% correctly. Finally, kitting helps involvement by creating workers with mental picture of a complex product in their minds.

Therefore, it can be said that lean kitting is possible as long as kits are secured so that they are 100% correct in the first place and there is no machine downtime caused by invalid kits. Additionally, waste should be continuously eliminated from kitting operations and workers should be trained well to get involved with the process.

6. Conclusions

The answers for the research questions are presented in this chapter and followed by recommendations for further research.

The main reason for kitting was observed as space requirements in Swedish industry. Most companies are aware of other benefits such as quality and learning aspects but are not considering them as their most important reason to initiate kitting activities.

Companies are also hesitant to initiate kitting since it is an expensive solution compared to other solutions. In Japanese context, aspects like quality and learning are the key reasons to initiate kitting activities. Space is not their first priority.

The biggest limitation of kitting seems as increased number of materials handling and the uncertainty about the level of kitting. Past experiences made companies more hesitant about kitting implementations.

Kitting was observed to show numerous benefits in all of five tracks if applied properly. Drawbacks of kitting are mostly caused by wrongly prepared kits, kitting too much or unnecessary parts.

It is important to include all five of these aspects in business cases before the implementation of kitting, otherwise kitting activities are likely to cause further problems.

According to the analysis, kitting operations can go along with lean philosophies as long as kits are secured so that they are 100% correct in the first place and there is no machine downtime caused by invalid kits. Additionally, waste should be continuously eliminated from kitting operations and workers should be trained well to get involved with the processes.

6.1 Further Research

I think further research of kitting in the following areas would be beneficial:

- Quantifying kitting with all of its five aspects since there is a lack of modules to quantify all aspects and use them in business cases.
- Kitting of larger parts since the literature is mostly on small and medium sized parts.
- Elimination of waste from kitting activities since it is a never ending process.

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SPACE	QUALITY	MATERIALS HANDLING	FLEXIBILITY	LEARNING
Saving space in the work stations, if the materials were supplied in materials containers, i.e. tote pans, with numerous identical components in the same container, this would have resulted in an enormous plant (Bozer & Mc Ginnis, 1992; Medbo 2003)	Parts could be damaged lying idle in open packages. (Schwind, 1992; Brynzér, 1995)	Reduced material handling, instead of sending single parts, a collection of parts will be sent to the assembly line. (Sellers & Nof, 1986; Ding & Balakrishnan, 1990; Medbo 2003)	The assembly areas could become more flexible and free from leftover components. (Schwind, 1992; Brynzér, 1995)	Kits are easier to learn for assembly workers which lead easier training (lower learning curves) and also reduces the training cost. (Ding & Balakrishnan, 1990; Medbo 2003)
Savings in manufacturing space and a better organized shop floor. (Bozer & Mc Ginnis, 1992; Medbo, 2003)	Safer use of components that are similar in appearance. (Schwind, 1992; Brynzér, 1995)	The elimination of searching time, since all parts are in a single kit. Therefore, increased productivity. (Ding & Balakrishnan, 1990; Medbo, 2003)	Improved control over and better visibility of the flow of components on the shop floor. As a consequence part availability will also better besides product changeover can be easily accomplished. (Conrad & Pucanic, 1986; Sellers & Nof, 1986; Bozer & Mc Ginnis, 1992; Medbo, 2003)	Using the materials as work instruction. (Medbo, 2003)
Inventory costs could be reduced due to integrated storage and assembly. (Sellers & Nof, 1986; Schwind, 1992, Brynzér, 1995)	Components can be presented in sequential or assembly order in special packages that ensure correct assembly. (Schwind, 1992; Brynzér, 1995)	Better control over WIP, the parts of existing kits provide immediate information regarding the WIP level, since each kit consists of a predetermined quantity of parts. (Ding & Balakrishnan, 1990)	It could be ensured that all components are available prior to scheduling work. (Schwind, 1992; Brynzér, 1995)	Complex products can be overviewed and be understood. (Medbo, 2003)
	Kitting ensures that the latest bill of material is used. (Schwind, 1992; Brynzér, 1995)	Control of the number of components to store, replenishment, and the numerous design change orders will be less complicated to administer and handle. (Medbo, 2003)	Less work-in-process at the work stations, and consequently shorter lead times. (Medbo, 2003)	
	High value components can be secured in kitting package. (Schwind, 1992; Brynzér, 1995)	When kits are standardized, this offers an opportunity to implement robotic handling. (Boldrin, 1982; Bozer & Mc Ginnis, 1992)		
	Early identification of low quality components. (Sellers & Nof, 1986; Bozer & Mc Ginnis, 1992; Medbo, 2003)	It would be easy to notice if a component is missing, given that the kit package is properly designed. (Schwind, 1992; Brynzér, 1995)		
	There will be less damage during the transportation process. (Bozer & Mc Ginnis, 1992; Medbo, 2003)			

SPACE	QUALITY	MATERIALS HANDLING	FLEXIBILITY	LEARNING
<p>Kitting is likely to increase in storage space requirement, especially when kits are prepared in advance. (Bozer & McGinnis, 1992)</p>	<p>An increased number of handling occasions increases the probability of damaging the components, therefore not all components are suitable for kitting. (Johansson & Johansson, 2006)</p>	<p>Preparing the kits requires some time and effort which is a non value adding activity, waste. (Bozer & McGinnis, 1992)</p>	<p>Temporary shortage of parts will decrease the overall efficiency of kitting. (Bozer & McGinnis, 1992)</p>	
		<p>When different kits contain common parts, an assignment of available parts to kits needs to be done. (Bozer & McGinnis, 1992)</p>		
		<p>Spare parts might be needed at the assembly line in the case that a part in the kit is wrong or defected, otherwise the production will be disrupted. (Bozer & McGinnis, 1992)</p>		
		<p>Components that may even fail during the assembly process will require special consideration or exceptions. (Bozer & McGinnis, 1992)</p>		
		<p>If parts shortages develop, some kits may get cannibalized. That is, short parts may be removed from some of the existing kits. This may further complicate the shortage and it may lead to problems in parts accountability. (Bozer & McGinnis, 1992)</p>		