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MASTER'S THESIS

Kitting in a High Variation Assembly Line

A case study at Caterpillar BCP-E

Oskar Carlsson
Björn Hensvold

Luleå University of Technology

MSc Programmes in Engineering
Industrial Business Administration
Department of Business Administration and Social Sciences
Division of Industrial Logistics

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Kitting in a high variation assembly line

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OSKAR CARLSSON
BJÖRN HENSVOLD

MASTER OF SCIENCE PROGRAMME
Industrial Engineering and Management

Department of Applied physics and mechanical engineering
Division of Manufacturing systems engineering

Department of Business administration and social sciences
Division of Industrial logistics

Preface

This Master's Thesis is the final part of our MSc. Programme in Industrial Engineering and Management at Luleå University of Technology, Sweden. The work was carried out during four months in autumn 2007 at Caterpillar BCP-E in Leicester, UK.

We would like to use this opportunity to thank the persons supporting us during the project, our mentors at Caterpillar: Paul Fowkes and Rob Sparks and the mentors at Luleå University of Technology: Torbjörn Ilar and Anders Segerstedt.

Finally a special thanks to Bhau Kika for taking care of us the first couple of weeks of our stay in Leicester.

Leicester,
30 November, 2007

Oskar Carlsson

Björn Hensvold

Abstract

A growing number of product variants, which is reality for many assembling and manufacturing companies, often result in more part numbers. These part numbers need to be delivered to the assembly process. Delivering them in the traditional way with continuous supply and lineside stores becomes a problem since the increasing number of parts demands an increase in lineside storage space. An increase in lineside storage space and part numbers creates longer operator walking and searching times at the assembly line. One way to decrease the lineside storage space and operator walking and searching times is to deliver parts in kits. In manufacturing systems, 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". Theory explains a number of benefits and limitations with kitting, however most of the theory is found from research in parallelised assembly systems and assembly with small parts. It is therefore of great interest to investigate if these theories also apply to the situation at Caterpillar BCP-E, Leicester (CAT), with assembly lines with high end product variation. Since most assembly plants are turning to the theories of Lean production it is also of interest to see if kitting is applicable in Lean environments.

The purpose of this study is to analyse the business case and feasibility for CAT to implement a kitting process for delivery of material to lineside Point of Use (POU).

To fulfil the purpose a case study at the engine subassembly area at CAT has been made. Within the case study a quantitative analysis in the form of a mathematical model has been performed. The results of the mathematical model has been analysed in a qualitative way to form the final results and conclusions.

The study shows that kitting can be beneficial in high variation assembly lines. Kitting provides the opportunity to decrease lineside storage, lineside inventory value, lineside replenishments and operator walking times. However kitting increases the number of part handlings, space for kitting and time for kitting. Kitting also provide opportunities of a more intangible nature such as the possibility of increasing shop floor control, end product quality and ease of educating new personnel. The results show that the benefits of a kitting process is very much dependant on the needs of the specific factory. Performing some kind of multi criteria decision making process before implementing a kitting process to find out these specific needs is therefore of importance. In this study an Analytical Hierarchy Process was performed to find out the needs of CAT.

The results show no indication that kitting does not coincide with Lean theories. On the contrary kitting is a way to move waste from one of the most common bottlenecks, the assembly line. In order to not just move the problem, but to facilitate or eliminate it, it is of greatest importance to design the kitting process in an efficient way, both for the logistic and operation functions. Results on how CAT should design their kitting process, if implementing one, are given in this report.

The suggestion for CAT is to implement a kitting pilot at the engine subassembly area to verify the results of this research. When doing this it is suggested that all parts that can be lifted by hand should be included in the kit.

List of abbreviations

The following abbreviations and definitions are used in this report.

ASRS	Automated Storage and Retrieval System
BCP-E	Building Construction Products – Europe
BHL	Backhoe loader
BP	Business Process
CAT	Caterpillar BCP-E, Leicester
Caterpillar	Caterpillar enterprise
CPS	Caterpillar Production System
CWL	Compact wheel loader
EAME	Europe Africa Middle East
FP	Flow Path
JIT	Just in Time
Lineside	“In direct connection to the assembly line”
MRP	Material Requirements Planning
MHE	Mini hydraulic excavator
NNVA	Necessary non-value adding
PDI	Pre Delivery Inspection
POU	Point of Use
SWL	Small wheel loader
VMI	Vendor Managed Inventory
WIP	Work in Progress/Process

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<u>**Appendices**</u>

1 Introduction

In this chapter a background to the upcoming of this thesis is presented. This background leads to the purpose, goals and delimitations of the thesis.

1.1 Background

“I will build a motor car for the great multitude”, Henry Ford proclaimed in announcing the model T in October 1908 (Ford, Henry, 2007). This was the start of a new era in manufacturing, where mass production and assembly lines were in focus. This focus still remains, however the customer demands has changed since Henry Fords famous T model, offered according to the famous quote made by Ford: “Any color as long as it is black”. Customer these days seem to need vehicles customised for their personal needs, not just one standard product. This has forced new principals and theories within production; the most widely used seems to be Japanese and developed from Toyota Production Systems, these principals and theories often goes under the name Lean production.

By producing in a Lean way companies are supposed to reduce waste in their production (Womack, 2003). Originally these theories or methods emerged from the automotive industry, however they are now widely used in all different kinds of industries, the industry of manufacturing earth moving equipment is no exception. Caterpillar is currently implementing the Caterpillar Production System (CPS) throughout their whole manufacturing organisation. The base of CPS comes from Lean and Six Sigma theories and tools.

A growing number of product variants, which is reality for many assembling companies, often result in more part numbers (Johansson, 1991). These parts need to be delivered to the assembly lines somehow and according to Johansson (1991) there are mainly three ways of doing this; continuous supply, batch supply and kitting. The main differences between these are whether all parts are presented to the assembly line at all times and if part number or assembly object sorts the parts.

Caterpillar BCP-E, Leicester, (CAT) is at the moment assembling four product types, namely mini hydraulic excavators (MHE), small wheel loaders (SWL), compact wheel loaders (CWL) and backhoe loaders (BHL). The end product is a turnkey ready machine to be delivered directly to customers and retailers. The machines are assembled in four assembly lines, sequentially assembling machines according to their specifications. The main way of delivering parts to the assembly lines today at CAT is continuous supply, meaning all parts that might come to use are stored in a two-bin kanban system along the assembly lines (lineside). The variation in the end products causes the lineside stores to keep inventory of great amounts of different part numbers, even if the usage of some of them are very low.

To cope with the variation and the wanted takt times at the assembly lines some of the assembling is performed in decentralised subassembly areas. To free space for coming changes in production decision has been made on moving these subassembly areas in connection to the main assembly lines. At the same time, due to customer demands, CAT wants to increase their assembly line capacity. At the BHL assembly line the capacity of daily produced machines needs to increase by almost 100%. Having the subassembly areas moved and increasing assembling capacity demands more space lineside, space that currently not exists.

Besides using big lineside space CAT believes that the existing lineside stores are increasing operator walking and searching times. These times are by CPS and Lean theories defined as waste and are something CAT wants to decrease or eliminate, especially in order to increase their capacity.

To solve the issues with lineside space and motion waste CAT is looking at new ways to deliver material lineside. CAT has acknowledged three ways of doing this: Optimising bin sizes, reducing bin quantities and delivering parts in kits (kitting). The effect in decreasing space and walking distances of the three is explained in figure 1.1, where “parts in standard bins” represents the current situation at CAT.

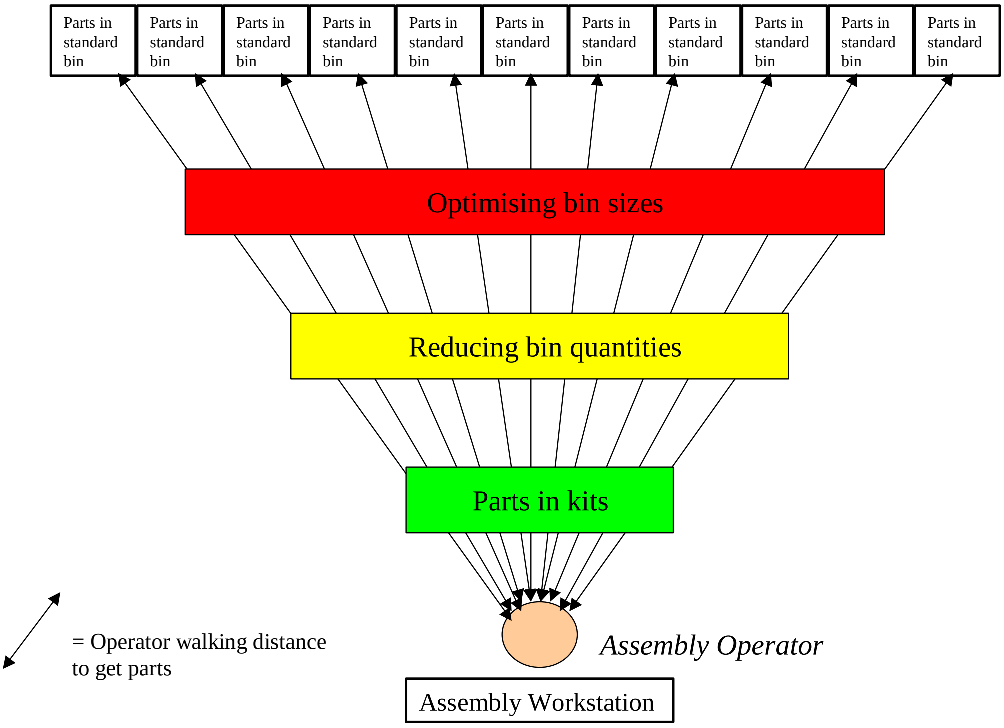

Figure 1.1, Effects of new ways of delivering parts to the assembly line.

Kitting is considered having the most extreme effects of the three; however it also brings a need for work in making the kits. Kitting is a method widely used in manufacturing industries, however several authors (Bozer & McGinnis, 1992; Brynzer, 1995; Ding & Balakrishnan, 1990) acknowledges the fact that it has rarely been described in the literature. When it comes to the type of industry CAT is in, with sequential assembly of relatively big parts in assembly lines, even less theory exist. For the above mentioned reasons it is of great interest for CAT to investigate if kitting is a beneficial and feasible solution for them.

1.2 Purpose

The purpose of this study is to analyse the business case and feasibility for Caterpillar BCP-E, Leicester, to implement a kitting process for delivery of material to lineside Point of Use (POU).

1.3 Goals

The goal of this study is to determine if Caterpillar BCP-E, Leicester could benefit from a kitting process.
If Yes:

- To determine general rules of what type of parts that suits to be kitted, e.g. size, weight and value of parts.

- To determine general rules of the kitting process design.

- To give suggestions for implementation of a kitting process.

1.4 Delimitations

This study will only investigate kitting and compare it to the current situation at CAT, meaning other possible ways of delivering material to the assembly lines will not be investigated.

2 Caterpillar at a glance

This chapter aims to give the reader a little bit more information about the business and the company where the research is performed before the theoretical framework and the methodology is presented. A more extensive description of the company and its business is presented in chapter "5 Present situation".

2.1 The Caterpillar enterprise

Caterpillar Inc. is the world's largest manufacturer of earthmoving machinery, construction and mining equipment, natural gas engines and industrial gas turbines.

Caterpillar is a global organisation with its headquarter located in Peoria, Illinois, USA. The company has nearly 300 operations in over 40 countries and its products are sold in nearly 200 countries. According to the annual report from 2006, the Caterpillar enterprise has nearly 95,000 employees and an annual turnover of around $41.5 billion.

Caterpillar's business is divided in three major business areas:

- Machinery.
- Engines.
- Services.
  -Logistics.
  -Financial Products.
  -Remanufacturing.
  -Rail-Related.

2.1.1 History

Caterpillar products have made an impact on world history. Caterpillar's crawler tractors inspired the first military tanks, which helped end World War I. Caterpillar machines helped build the Hoover Dam, the tunnel under the English Channel, tumble the Berlin Wall and construct cities and neighbourhoods across the United States.

The story of Caterpillar Inc. dates back to the late 19th century, when Daniel Best and Benjamin Holt were experimenting with ways to fulfil the promise that steam tractors held for farming. The Best and Holt families collectively, prior to uniting in 1925, had pioneered track-type tractors and gasoline-powered engines. After the families were united, the company went through many changes and at the end of World War II began growing at a rapid pace. The opening of its first overseas subsidiary in Britain in 1950 marked the beginning of the company's development into a multinational corporation.

By 1981 sales reached more than $9 billion, but shortly after plummeted due to a worldwide economic recession. The company recorded its first loss in 50 years in 1983 and was forced to close plants and lay off workers well into 1984. In 1985 the company started shifting production operations overseas and in 1987 began a $1.8 billion program to modernise its factories. In 1990 Caterpillar decentralised its structure, reorganising into business units responsible for return on assets and customer satisfaction. In the company's effort to expand in 1997 it acquired the U.K.-based Perkins Engines.

With the addition of Germany's MaK Motoren the previous year, Caterpillar becomes the world leader in diesel engine manufacturing.

2.2 Caterpillar BCP-E, Leicester

At the Caterpillar BCP-E (Building Construction Products- Europe) plant in Leicester, four product types are assembled in four different assembly lines in over 60,000 square metres of production facility. The four product types are backhoe loaders, small wheel loaders, compact wheel loaders and mini hydraulic excavators (shown in figure 2.1-2.4 below). For further information of the product range see appendix A. Approximately 1000 employees are working on the factory site in Leicester.

The output of the factory is a turnkey ready machine going straight to retailers and customers in the EAME (Europe, Africa, Middle East) market. The majority of products are assembled according to customer order and specifications, meaning very few machines are assembled without a customer waiting for it. A minority of the machines are assembled to stock, especially during low conjuncture. Due to customer demands and corporate strategy a lot of specifications can be ordered making each machine a unique individual, the products can be ordered in an almost limitless amount of variations.

Figure 2.1, Backhoe loader.

Figure 2.2, Small wheel loader.

Figure 2.3, Compact wheel loader.

Figure 2.4, Mini hydraulic excavator.

3 Theoretical framework

In this chapter the theories of which the thesis is based upon are presented. The chapter starts with a brief presentation of manufacturing theories, continues with a description of materials feeding and ends up in an extensive review of theories on kitting.

3.1 Manufacturing Theory

CAT is in the process of fully implementing Caterpillar Production System (CPS), a production system very similar to Toyota Production System (TPS). The base of CPS comes from the theories of Lean production and Six Sigma. Since the decision of using CPS has already been made, the authors will not question whether Lean production or Six Sigma is the right thing for CAT. However it is important that whatever recommendations this thesis delivers it must go along with CPS in order to get CAT to consider implementing it. With this in mind a short review of the most fundamental Lean and Six Sigma theories will be presented.

3.1.1 Lean Production

According to Krajewski et al. (2007) the essence of Lean is to maximise the value added by each of a company's activities by paring unnecessary resources and delays from them. These unnecessary resources are also known as waste or the Japanese term "muda". Further, Womack (2003) defines waste as "everything that exceeds a minimum of resources that are needed to add value to the product".

Central in the definition of waste is whether an activity is adding value or not. According to Rapp and Heaton (2005), all activities in an organisation can be classified as either value adding or non-value adding (waste). The "value" is determined by whether the activity adds direct value for the customer. Furthermore the non-value adding activities can be subdivided into necessary non-value-adding (NNVA) waste and "pure" waste.

The identification and elimination of waste also makes it easier to focus on value adding activities and become more cost efficient. (Rother & Shook, 1999)

Womack (2003) identifies seven different types of waste:

- Overproduction, "producing more or faster than needed".
- Waiting, "keeping a worker idle".
- Transportation, "moving materials or products excessively".
- Over processing, "doing more than is required".
- Inventory, "excess raw material, work-in-process or finished goods".
- Defects, "repairing errors".
- Motion, "acting without adding value".

Recent years, some researchers have identified an eighth type of waste named "People", defined as "The waste of not using employees' mental, creative, or physical abilities". (Ray et al., 2006).

As shown in figure 3.1 below, all types of waste are inter-dependent, and each type has an influence on the others; and is simultaneously influenced by the others. For example, overproduction is regarded as the most serious waste as it gives rise to many other types of waste (Rawabdeh, 2005).

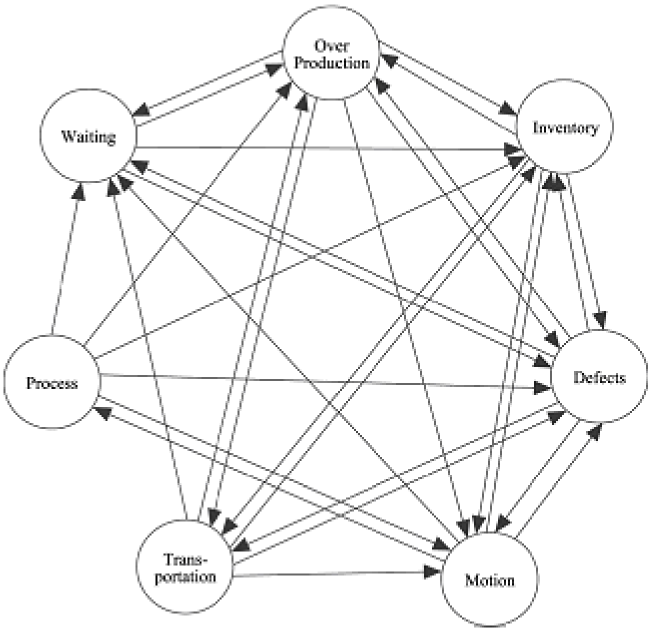

Figure 3.1, Inter-dependence of different types of waste (Source: Rawabdeh, 2005).

Below two of the identified wastes are further explained, namely “excess inventory” and “motion”. These two are by the authors of this thesis believed to be the most affected wastes when changing materials feeding systems.

Excess Inventory waste

According to Krajewski et al. (2007) inventory exists in three aggregate categories that are useful for accounting purposes:

Raw Material is the inventory needed for the production of services or goods. It is considered to be inputs to the transformation processes of the firm.

Work-in-process (WIP) consists of items, such as components or assemblies, needed to produce a final product in manufacturing.

Finished goods are the items sold to the firm’s customers. The finished goods of one firm may actually be the raw materials for another.

Karlsson and Åhlström (1996) state that apart from being wasteful in itself, inventory also hides other problems and prevents their solutions. The effects of reducing inventory therefore go beyond that of reducing capital employed. However, it is not advisable to eliminate inventory mindlessly. Instead, the reasons for the existence of inventory must first be removed.

Figure 3.2 demonstrates how high levels of inventory can hide problems. The water surface represents product and component inventory levels. The rocks represent problems encountered in the fulfilment of products. With the water surface high enough, the boat passes over the rocks because the high level of capacity or inventory covers up problems. As capacity or inventory shrinks, rocks are exposed. Ultimately, the boat will hit a rock if the water surface falls far enough, the problem will occur, forcing the company to deal with it.

Through lean systems, workers, supervisors, engineers and analysts apply methods to demolish the exposed rock. Maintaining low inventories and periodically stressing the system to identify problems is crucial in lean companies. (Krajewski et al., 2007)

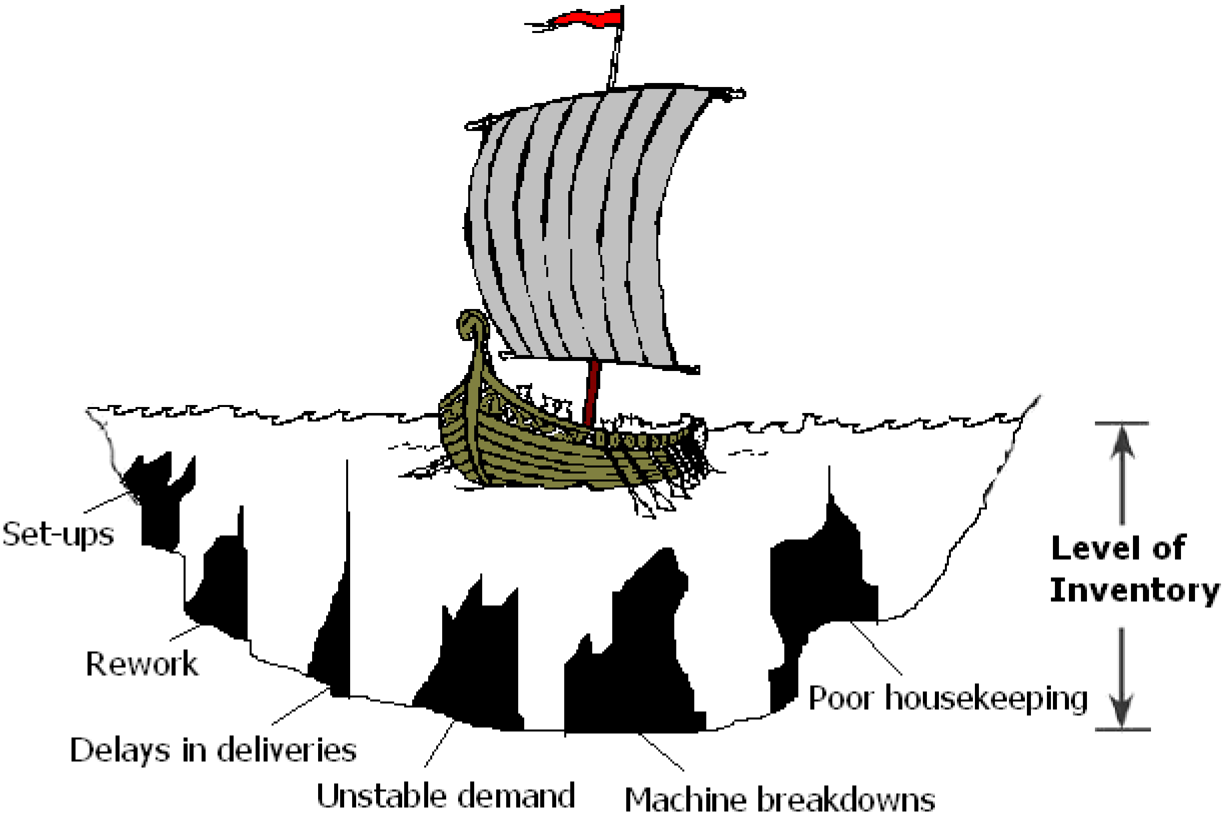

Figure 3.2, Illustration of inventory hiding problems.

Motion Waste
Motion takes time and does not add any value to the customer. Chanesky (2002) defines motion waste as; "Any time someone has to walk to another area, lean over to pick up parts or reach a great distance to get an item, this is wasted motion."

Principles of Lean
In "Lean Thinking" by Womack and Jones (1996), the authors define the following five principles for reducing waste and building lean enterprises:

- **Specify value** from the standpoint of the end customer by product family.
- **Identify the value stream for each product**, eliminating every step and every action and every practice that does not create value.
- **Create continuous flow** by making the remaining value-creating steps occur in a tight and integrated sequence.
- **Let customers pull** value from the next upstream activity.
- **Pursue perfection** through continuous improvement

The first principle focuses on customers' demand and identifies what the processes should contribute in adding value to the customer. The three principles thereafter focus on value adding flows and minimisation of waste while the fifth principle sustains and improves flow.

Altogether the main objective of Lean is to minimise the consumption of resources that add no value to a product or service.

There are a wide variety of tools and methodologies attached to the Lean concept. Below is one of the most common, and for this thesis appropriate, tool presented.

Five S

According to Krajewski et al. (2007) five S (5S) is a methodology for organising, cleaning, developing and sustaining a productive work environment. It represents five related terms, each beginning with an S, that describe workplace practices conducive to visual controls and lean production. The processes are;

- **Sort**
  - To clearly distinguish needed items from unneeded items and eliminate the latter.
- **Straighten**
  - To arrange items so that they can be found quickly by anybody.
- **Shine**
  - Keeping the workshop swept and clean, a "spotless workshop".
- **Standardise**
  - Standardise cleanup activities so that these actions are specific and easy to perform. Create and maintain a safe work environment.
- **Sustain**
  - Make a habit of maintaining established procedures.

All steps are to be done systematically and cannot be done as a stand-alone program to achieve lean systems. 5S is now commonly accepted as an important cornerstone of waste reduction and removal of unneeded tasks, activities and materials. Implementation of 5S practices can lead to lowered costs, improved on-time delivery and productivity, higher product quality and a safe working environment. (Krajewski et al., 2007)

3.1.2 Six Sigma

Six Sigma was developed in 1986 by Motorola Inc. as a metric for measuring defects and improving quality. According to Krajewski et al. (2005), it has since then evolved to being a comprehensive and flexible system for achieving, sustaining, and maximising business success by minimising defects and variability in processes. Further, Manual (2006) states that the principal basis of the Six Sigma methodology is that if one can measure how many defects or failures any business or process has, one can find ways to systematically eliminate them.

Fairbanks (2007) explains that the name Six Sigma originates from the Greek letter sigma (σ) that is used by statisticians to denote the standard deviation or variability of a process. In a process with Six Sigma capability, process variation is reduced to no more than 3.4 defects, per million opportunities. This can be thought of in two ways: a process is correct 99.9964% of the time, or 99.9964% of processes fall within six standard deviations of the mean. A defect can be defined as nonconformity of a product or service to its specifications. It is to be kept in mind that all processes vary, but too much variation is costly.

Krajewski et al. (2005) describe that General Electric, one of the most successful companies in implementing Six Sigma, views Six Sigma as a strategy, a discipline, and a set of tools. It is a strategy because it focuses on what the customer wants, whether the customer is internal or external, and it aims at total customer satisfaction.

Consequently, Six Sigma leads to better business results as measured by market share, revenue, and profits. It is a discipline because it has a formal sequence of steps, called the Six Sigma improvement model, to accomplish the desired improvement in process performance. The goal is to simplify processes and close the gaps between a process's competitive priorities and its competitive capabilities. Finally, it is a set of tools because it makes use of powerful tools such as FMEA, cause-effect charts, and statistical process control.

3.2 Materials feeding

Materials feeding mainly concern what principle to use for feeding the materials to a workstation or an assembly line. Johansson (1991) describes and analyses three different principles of feeding materials to an assembly station, namely continuous supply, batch supply, and kitting. These are shown in figure 3.3, and categorised with regard to:

- Whether a selection of part numbers, or all part numbers, are displayed at the assembly stations; and
- Whether the components are sorted by part numbers or assembly objects.

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

Figure 3.3, Categorisation of materials feeding principles (Source: Johansson 1991).

These three principles can exist simultaneously in one system and for different kinds of parts complement each other. Furthermore, there is a large variety in solutions within each principle and 'pure' systems can hardly be described. (Johansson, 1991)

In a more recent research paper from 2006, by Johansson and Johansson, with the title "Materials supply systems design in product development projects" a fourth principle of materials feeding is identified, namely sequential supply, which is described later in this section.

3.2.1 Continuous supply

Johansson (1991) describes that continuous supply refers to 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. There is no co-ordination of replacements for different part numbers. All part numbers needed for producing every occurring product over a long period are available at the assembly station at every time. Refilling of parts at the assembly stations is often done by storemen, either in station fix bins, or by some kind of two-bin system.

For example, continuous supply is used at CAT, this is done by a two-bin kanban system where the bins are stored along the assembly line; this is referred to in the text as “lineside stocking” or “lineside stores” and is shown in figure 3.4.

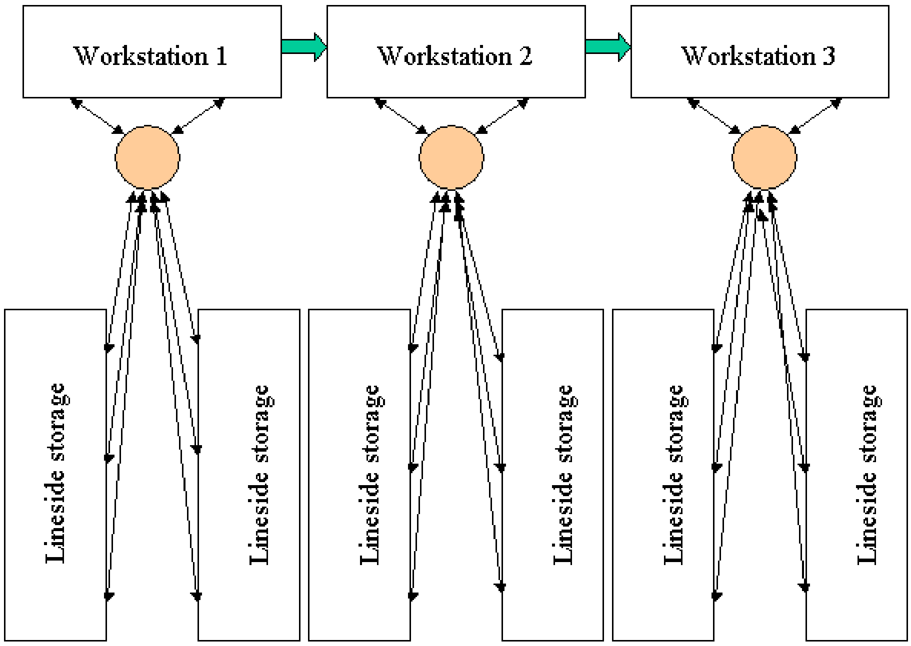

Figure 3.4, Principal outline of lineside stocking system.

3.2.2 Batch supply

Johansson (1991) describes batch supply systems as when material is supplied for a number of specific assembly objects. The batch of materials can be a batch of necessary part numbers, or a batch of these part numbers in the requisite quantities. The first case differs from continuous supply in the sense that fewer part numbers have to be stored at the assembly station and that different part numbers are exposed at different points in time. The remaining material is returned to the store after completion of the batch of assemblies, unless it is to be used in the next batch. This job is eliminated in the latter case, but instead there is a need for counting the parts, which requires technical and administrative systems.

3.2.3 Sequential supply

Johansson and Johansson (2006) state that the explosion of product variants during the last decade in some cases has made continuous supply impossible due to capital cost and lack of space at the assembly stations. Further, if the product is assembled on a serial line where only a few components are assembled at each station, kitting is less advantageous. One way to solve this problem is to use sequential supply. It means that the part numbers needed for a specific number of assembly objects are displayed at the assembly stations, sorted by object.

3.2.4 Kitting

According to Johansson (1991) kitting means that the assembly is supplied with kits of components. The parts are sorted according to the assembly object; this differs from batch supply, where part number sorts parts. Kitting is further described in next paragraph.

3.3 Kitting theory

In manufacturing systems, 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". A more formal definition is described further down in the text.

According to Johansson and Johansson (1990) a kitting process is suitable for assembly systems with parallelised flow, product structures with many part numbers, need for quality assurance and high value components. Ding and Balakrishnan (1990) claims that kitting is most suitable for industries such as the electronics industry, which deals with small parts and performs assembly operations quite often, however they also say that JIT-systems dealing with larger parts also can benefit from kitting. They come to this conclusion after performing a case study at a US tractor plant that has successfully implemented a kitting process.

According to Bozer and McGinnis (1992) there are mainly two types of kitting operations: kit-to-customer and kit-to-manufacturing. The former meaning that you deliver your end product in a kit to your customer. The latter is concerned with pulling the required parts together in kit containers, which are subsequently delivered to the shop floor to support one or more assembly or manufacturing operations. This study is only considering the kit-to-manufacturing kitting operation, also commonly known as kit-to-assembly.

To understand a kitting process some definitions has to be made, Bozer and McGinnis (1992) make the following definitions:

- A component is defined as a fabricated or purchased part that cannot be subdivided into distinct constituent parts. In this thesis a component is also referred to as a part.
- A subassembly is defined as the aggregation of two or more components and/or other subassemblies through an assembly process.
- An end product is defined as the result of a series of assembly operations, which require no further processing in the current facility.
- A kit is defined as a specific collection of components and/or subassemblies that together (i.e. in the same container) support one or more assembly operations for a given product or "shop order".
- The number and types of components required for each kit type is given by the "kit structure".

For example an engine is an end product for an engine plant, but a component in an automobile assembly plant. The engine might be assembled with the gearbox before being assembled in the car, the engine and the gearbox is then a subassembly. The engine might be delivered to the car assembly line together with other parts such as drive shafts and battery; these are delivered to the assembly line in a kit. One engine, one driveshaft and one battery make up that specific kit's kit structure.

3.3.1 Benefits of kitting

The following benefits with kitting have been found in theory; most of the benefits have been recognised by several authors:

1. Saves manufacturing or assembly space. (Agervald, 1980; Bozer & McGinnis, 1992; Medbo, 2003)
2. Reduces assembly operators' walking and searching times. (Agervald, 1980; Johansson, 1991; Schwind, 1992)
3. Kitting can reduce or make better control over WIP at the workstations by storing primary components and subassemblies at a central storage area. (Bozer & McGinnis, 1992; Ding & Balakrishnan, 1990; Ding 1992; Sellers & Nof, 1989)
4. Since the majority of components and subassemblies are not staged at the workstations, it increases the flexibility of the workstation or assembly line; product changeover is accomplished with relative ease. (Bozer & McGinnis, 1992; Schwind, 1992; Sellers & Nof, 1989)
5. Offers better shop floor control by just handling the kit containers through the assembly system instead of every component container. (Bozer & McGinnis, 1992; Ding & Balakrishnan, 1990; Ding, 1992; Medbo, 2003)
6. Reduces or facilitates material delivery to workstations by eliminating the need to supply individual component containers. (Bozer and McGinnis, 1992; Ding & Balakrishnan, 1990; Medbo, 2003)
7. Provides better control and visibility for expensive or perishable components and subassemblies. (Bozer & McGinnis, 1992; Schwind, 1992).
8. Offers potential in increasing product quality, due to the possibility to have quality checks earlier in the value chain and the possibility of reducing the frequency of wrong parts in the end product or missing parts in the end product. (Bozer & McGinnis, 1992; Schwind, 1992; Sellers & Nof, 1989)
9. By reducing search time and designing the kits in a "pedagogic" way, kitting could ease assemble and ease education of new staff. (Agervald, 1980; Ding & Balakrishnan, 1990; Toyotas new material handling system shows TPS's flexibility)
10. Facilitates robotic handling at the workstations by presenting an opportunity to control the exact quantity, position and orientation of individual parts placed in the kit. (Bozer & McGinnis, 1992)
11. In high variety production, kitting can help balancing the line by moving away setup time from the line. (Jiao et al., 2000)

3.3.2 Limitations of kitting

Many of the authors of the benefits above acknowledge the risk that having a poor kitting process might turn the benefits into limitations. For example if the kits have a high rate of missing parts or wrong parts this may lead to reduction in product quality instead of an increase in product quality.

Except for what is stated above the following limitations with kitting have been found in theory:

1. Making the kits (i.e., kit assembly) consumes time and effort with little or no direct value added to the product. (Bozer & McGinnis, 1992)
2. Is likely to increase storage (not lineside) space requirements especially when kits are being prepared in advance. (Agervald, 1980; Bozer & McGinnis, 1992)
3. Demands additional planning to assign on-hand parts to kits, especially when kits are prepared in advance. (Bozer & McGinnis, 1992)

4. Temporary shortage of parts may force the user to kit short; doing so will reduce the overall efficiency of the operation (due to the double handling of kit containers and the additional storage space required by partially assembled kits). (Bozer & McGinnis, 1992)
5. Defective parts that are inadvertently used in certain kits will lead to parts shortages at the workstations. Kits that contain defective parts must be “reassembled”. (Bozer & McGinnis, 1992)
6. Components that may fail during (or as a result of) the assembly process will require special consideration or exceptions (i.e., they may have to be excluded from the kits). One may be forced to provide either a spare piece with each kit or to store component containers at some workstations. (Bozer & McGinnis, 1992)
7. If part shortages develop (due to defective parts or other reasons), some kits may get “cannibalised”. 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. Also, it will almost always lead to double handling – first to remove the short part from existing kits and later to add the part to “cannibalised” kits when a new shipment is received. (Bozer & McGinnis, 1992)
8. Picking parts is a monotonous working process; in the long run with a poorly designed picking process this might lead to injuries and unmotivated personnel. (Agervald, 1980; Christmansson et al., 2002)

Before introducing a kitting process one has to ask the questions: Why do we want to kit? Is there a need for a kitting process? There is a possible need for a kitting process when the advantages written above exceed the limitations written above.

When there is a possible need for a kitting process, how to design the kitting process can be divided into four questions: Where to kit? What to kit? Who kits it? How to kit?

3.3.3 Where to kit?

According to Brynzer and Johansson (1995) the choice of a kitting process design at a high level involves decisions regarding the work organisation and the geographical location of the kitting process. They also say that if kitting on the factory site the kitting process can either be located in a central picking store or in decentralised areas close to the assembly stations, the so-called materials markets (also called satellites). Two examples of how this principle can look like are shown in figures 3.5 and 3.6.

In the article “Is third party logistics in your future” (2000) it is explained that kitting also can be done off the factory site, either by third party logistics suppliers or by suppliers supplying more than one part going into the same product. Since this study is aiming at analysing the effects of a kitting process, the authors believe that investigating third party kitting more extensively will not contribute to solving the purpose and goals of this thesis. With the time limitations given to this project it is also assumed by the authors that there will be no time to investigate third party kitting further.

Having a central picking store means that one can benefit from economies of scale making many different kits in the same area, however there might be a lack in communication due to the geographical location of the kitting area. Having a central picking store also provides the possibility of integrating the kitting area with the main stores, reducing unnecessary materials handling.

The benefits of having decentralised kitting areas close to the assembly line is mainly communication, however there might not be space for such areas and it might be labour intensive due to the difficulty of balancing the workload of making kits.

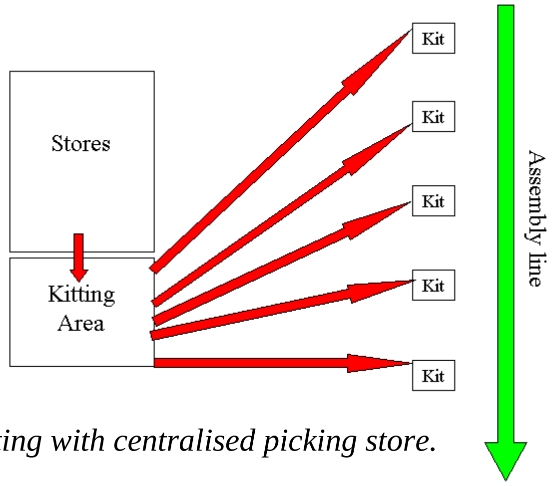

Figure 3.5, Kitting with centralised picking store.

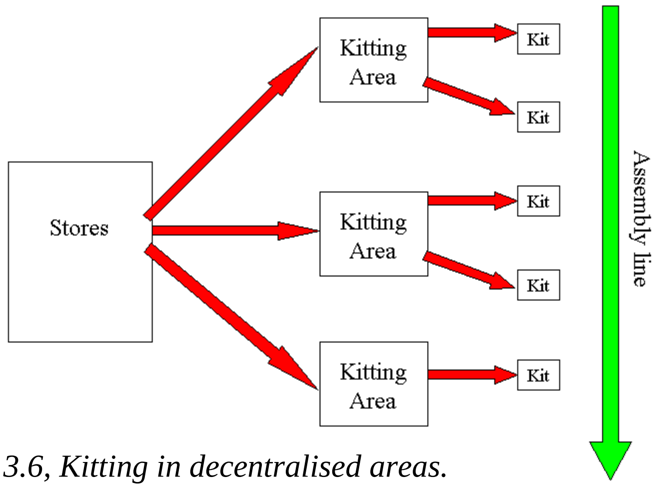

Figure 3.6, Kitting in decentralised areas.

3.3.4 What to kit?

Regardless of the type a kit typically does not contain all the parts required to assemble one unit of the end product. This is sometimes due to the product complexity or product size. Also, certain components such as fasteners, washers, etc. are almost never included in kits; instead such parts are bulk delivered to the shop floor in component containers. (Bozer & McGinnis, 1992)

Ding (1992), investigating kitting in a tractor plant, says that considerations of kitting in a pull system are part sizes, lot sizes and kit sizes. Under the part size consideration, Ding claims there are kittable parts and nonkittable parts due to size restriction; nonkittable parts should be pulled separately when needed. According to Schwind (1992) expensive or high value parts are suitable for kitting since one can have higher damage control and parts can be individually accounted for in some systems.

Bozer and McGinnis (1992) have observed two types of kits: stationary kits and travelling kits, shown in figures 3.7 and 3.8 respectively. A stationary kit is delivered to a workstation and remains there until it is depleted. The product to be assembled moves from one workstation to another independent of the stationary kit(s). A travelling kit is handled along with the product and supports several workstations before it is depleted. There are two types of travelling kits. The first type is a single container where the kit and the product travel in the same container as the product is assembled. With the second type, the product travels in one container (or fixture) while the kit follows the product in parallel in another container. The two travel together from one workstation to another.

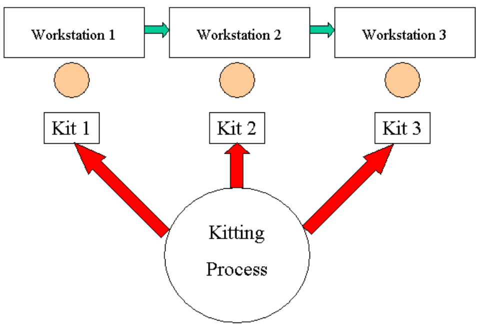

Figure 3.7, Stationary kits.

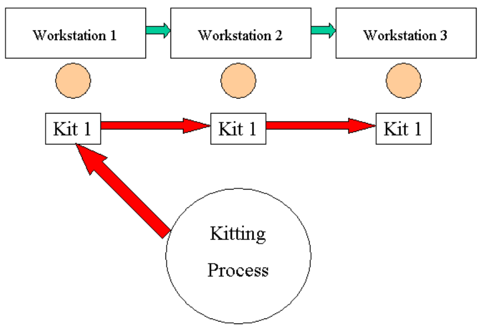

Figure 3.8, Travelling kits.

3.3.5 Who kits it?

Who physically produces the kits is firstly divided into man or machine, e.g. employee or robot. This research will not consider robotic picking and kitting since the authors believe that the variation and size of the parts at CAT makes it unfeasible.

According to Brynzer and Johansson (1995) making the kits can either be done by the assemblers themselves or by a specific category of operators, called pickers. In some cases assemblers produce kits for other assemblers, most often belonging to the same team on the assembly line. They also acknowledge two benefits of integrating the kitting process in the assemblers work. First, there is the idea of obtaining higher picking accuracy when the operator is responsible for the whole job. Second, integration and job enlargement will enhance the overall productivity by reducing balancing problems and giving better possibilities regarding job designs that promote ergonomics and the quality of working life.

The article “Toyotas New Material-Handling System Shows TPS’s Flexibility” acknowledges the benefits of having certain pickers as: Assembly operators now focus nearly 100% of their time on the value-added work of installing parts because they no longer have to perform the nonvalue-adding task of walking a few steps to retrieve parts from flow racks. This system also eliminates reaching, stretching and searching for parts by assembly operators.

3.3.6 How to kit?

How to kit can be divided into three questions: How do we get the right parts in the right kit? How do we get the right kit to the right workstation? How do we design the kits to be as easy as possible to kit and as easy as possible to assemble parts from?

Bozer and McGinnis (1992) define “kit assembly” as an operation where all the components and/or subassemblies required for a particular kit type are physically placed in the appropriate kit container. They also come to the conclusion that kit assembly conceptually is an order picking operation.

According to Brynzer and Johansson (1995) one way of classifying order picking systems is whether the picker is traveling to the picking locations (picker-to-part) or whether the materials are brought to the picker (part-to-picker). Picker-to-part systems are the most commonly used in the industry. Part-to-picker systems are even described by Christmansson et al. (2002) as a principally new way of materials kitting.

Bozer and McGinnis (1992) have observed that in most cases, since several component and/or subassembly containers must be retrieved to assemble a kit, it is fairly common to assemble several kits of the same type simultaneously. That is, once a component or subassembly container is brought to the kit assembly area, one may pick enough pieces from that container to assemble several kits of a given type. After the required parts are retrieved, the component or subassembly container is returned to storage (provided the container is not empty). The number of kits (of the same type) that are assembled simultaneously as described above is by Bozer and McGinnis defined as the “kit batch size”.

The writers’ of this thesis reflection on the above statements is that kitting in batches only makes sense when there is no or little variation in part numbers going into the kits, e.g., parts that can vary between kits can not be picked in batches, unless there happens to be more than one kit in a row containing the same variation of parts. Meaning you could plan your production sequence to be able to make kits in batches even with variation in part numbers.

Brynzer and Johansson (1995) states that in some sense batching also causes a more complex picking, including the design of the picking information, which can have a negative effect on the picking accuracy. A preliminary conclusion from their case studies is that the higher picking efficiency, resulting from these batching policies, is in many cases offset by an increased amount of sorting and administration.

When designing the kitting area it can either be one big area or you can divide it into zones. If you have one big area you pick the whole picking order in one picking tour, this is shown in figure 3.9.

According to Brynzer and Johansson (1995) zone picking divides the storehouse into different picking zones and an order is divided between these zones. Brynzer (1995) explains two types of zone picking: Progressive zoning is processing each order or kit by one zone at a time, when the order or kit has gone through all the zones it is finished, this is shown in figure 3.10. Synchronised zoning is when all the zones are working on the same order or kit at the same time, the parts from each zone is then brought together into the order or kit, this is shown in figure 3.11.

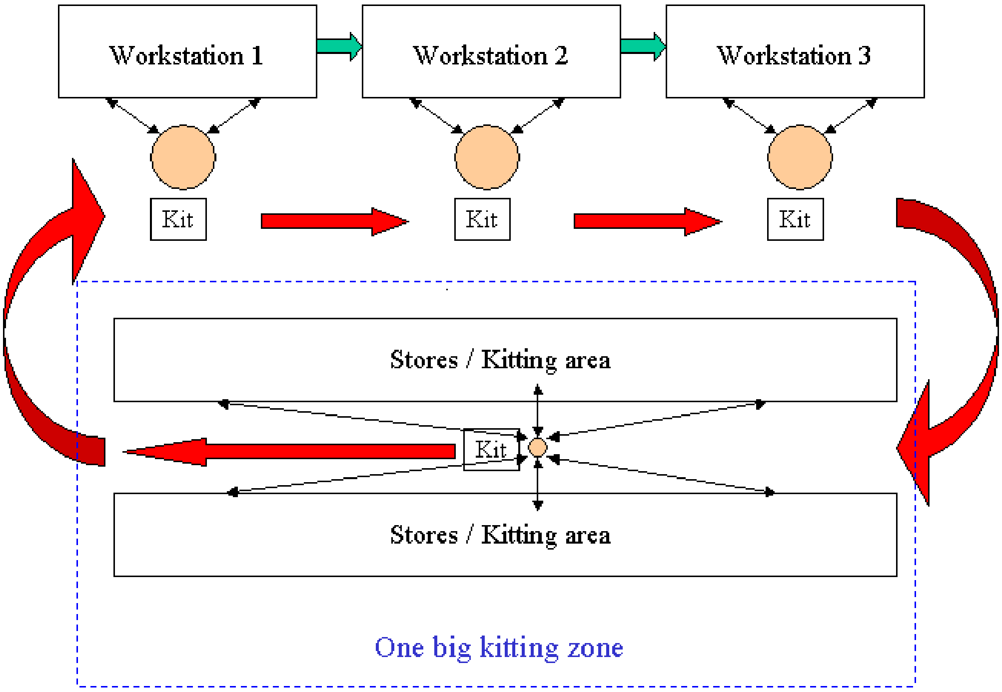

Figure 3.9, Kitting in one big area in combination with travelling kits.

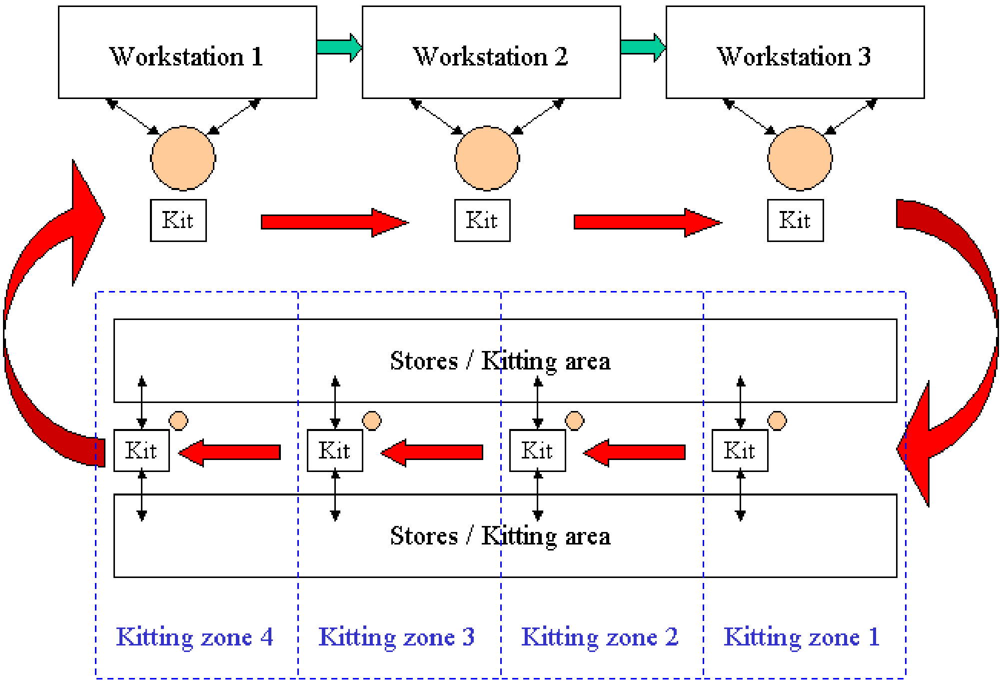

Figure 3.10, Zone picking alternative 1 in combination with travelling kits.

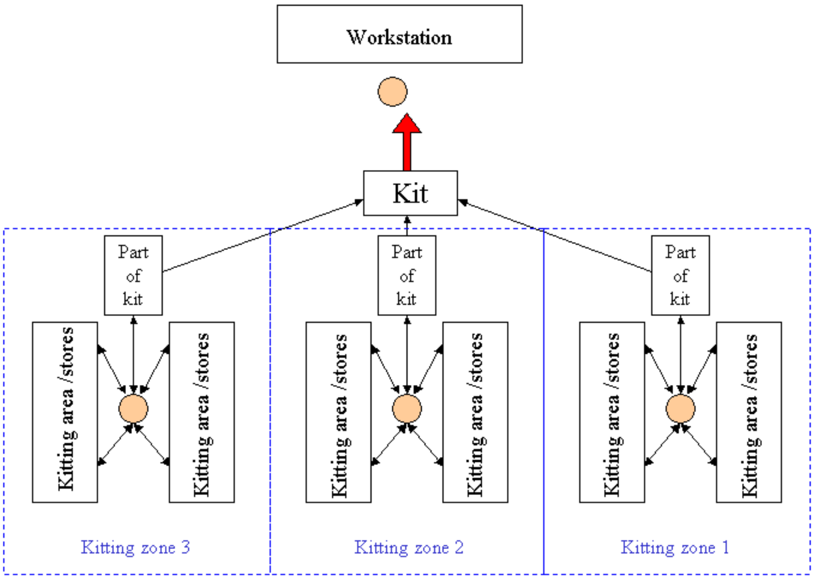

Figure 3.11, Zone picking alternative 2.

According to Brynzer (1995) the picking information design has been shown to be an important factor concerning picking accuracy, picking productivity and how the picking work is perceived. Brynzer and Johansson (1995) have during their case studies observed five main ways to design the information system, in which the picker receives and understands the information regarding which parts to pick for each order. These ways and some benefits and limitations with them are:

- The traditional picking information reaches the picker in the form of a picking list, specifying the identification, numbers, location, etc., of the parts to pick. Usually the picker manually has to tick of the parts in the picking list after picking them. The problem with this system is that it is most often designed for "beginners", making experienced pickers neglecting the picking list, just picking by experience. This causes problems when there are design changes, new part numbers etc. and even if the picker is not using the picking list, time has to be allowed to the picker for reading and identification. However this system's benefit is that the investment is usually quite small since a similar system most often already exists in the warehouse.
- The use of displays at the storage locations showing what to pick. For example a small lamp indicates when a specific component shall be picked and a display shows how many are required, this system is called pick-to-light. In some cases placed next to the display, there is a button for the operator to push when the part has been picked. The kit can't be sent away unless all buttons have been pushed. Picking errors are unusual in this system; however it requires a relatively big investment in hardware and software.
- Each variant of the final product has a number and, when picking, the picker looks for this number on a variant scheme at every storage location. A different approach to this idea is using colours instead of numbers, i.e., the picker receives a colour and then continues to pick parts at every storage location with the same colour. This system requires a dedicated storage area, i.e., every part number has a dedicated location in the storage area. It also requires frequent physical updates when parts are moved, changed or taken away.

- The picking information is displayed on a screen placed in the picking truck telling the picker what, where and how many components shall be picked. This system requires a relatively big investment in hardware and software.
- The picker only receives the end product specification and from that through experience and work sheets knows what parts to pick. This system benefits from its simplicity, but it demands experienced pickers and non-frequent product design changes.

The physical design of the kit container is of great importance when designing a kitting process. Brynzer (1995) means that the kits have to be functional in the picking process as well as in the assembly process. Medbo (2003) comes to the conclusion that assembly work is definitely supported by the way kits are configured. He means that configuring the parts in the kit container according to the order they are to be assembled can substantially decrease assembly cycle times. Brynzer (1995) also acknowledges the importance of designing the kit container so that the picker knows where specific parts go and can easily detect if any parts are missing. This can for example be done by specific pigeonholes or coloured maps. A drawback with these kit containers is their inflexibility since they need changing when parts are changed and they might not be suitable for kits in high product variation assembly. These kit containers also demand customised design and manufacturing which can be costly.

3.3.7 A descriptive model

Based on a number of site visits, Bozer and McGinnis (1992) have developed a conceptual framework and a descriptive model of kitting compared to lineside stocking. In the framework the authors develop definitions, which are intended to serve studies of most kitting operations. The descriptive model can be used to quantify the trade-offs in material handling, space requirements and work-in-process between kitting and line side stocking in an early decision stage. Although the model is based on a number of assumptions the authors of the framework believe it can be quite useful in an early decision stage, they also encourage further development and customisation of their model. The full model is shown in appendix B.

3.4 Conclusions on theory

In this section conclusions and comparisons on theories above are made. The chapter exists to see if there is a need for further research according to the purpose of this study.

3.4.1 Conclusions on kitting theory

Most of the theory found on kitting is from articles in scientific journals. Most of the articles concern kitting of small parts such as electronics assembly or kitting in parallelised production flow. The theory mostly concerns kitting when the decision to have a kitting process is already made, not the decision making in having a kitting process. It also seems like the biggest limitations with kitting is if the kitting process is poorly designed, which can turn most of the benefits into limitations, hence the design of the kitting process is of great importance.

3.4.2 Kitting in a lean environment

On a high level one can say that to implement a kitting process means moving necessary non-value adding activities (NNVA) from the production line upstream to the kitting area. This NNVA mainly consist of motion waste where either the operator at the line or a kitting operator in a kitting area has to walk and pick parts.

If having a kitting area, the whole idea of it, is to produce kits in the most accurate and efficient way as possible. Here the core competence of the employees is to pick parts and assemble kits. It could in many cases mean that the picking of parts in the kitting area is more efficient than is possible at an assembly line that is not just designed to optimise parts picking. Hence a net reduction of motion waste can be achieved.

Even though kitting in other cases just means moving the motion waste upstream, not decreasing the total amount of motion waste, it can be of great benefit. Since many facilities have its bottlenecks near or in the production line, moving away the waste from the bottleneck increases the capacity of the whole facility.

According to theory, using a kitting process can reduce or make better control of WIP at the workstations, the first case meaning removing waste from them. According to lean theories excessive inventory is not just wasteful itself but also hides other problems and prevents their solutions.

In a case study made at a Toyota-plant in Georgetown, USA (Toyota's New Material-Handling System Shows TPS's Flexibility) the author cites a Toyota spokesman stating that after introducing a kitting process at the assembly line it became much more open and clear, enhancing the shop floor control, than the traditional scenario with all material around the line. These effects of introducing a kitting process coincide with the lean waste reduction methodology of 5S. By eliminating non-frequently used inventory and delivering material in well-designed kits a kitting process can facilitate the "sorting" and "straightening" of a workplace.

One foundation stone of Lean production is to strive to achieve a pulling flow of material. For the internal material flow, when having a kitting system it is possible to use an empty kit as a trigger for replenishment. With a kitting system it is possible to hold a lower amount of kits than the amount of bins required when using continuous supply. Having fewer units to manage, and improved visibility, kitting could facilitate achieving an efficient pull system.

An unsuccessful implementation, or even worse, an inadequate use of a kitting system can be very costly. A high degree of inaccurate kits delivered to the line and quality issues and added costs because of the extra part handling are just some of the problems it might lead to.

A correctly used and implemented kitting system can be a very useful tool achieving leaner production. A typical example of where kitting can be beneficial is assemblies with high product variation. On the other hand, using a kitting system on a highly standardised assembly line in some cases might only lead to adding extra physical part handlings i.e. waste, hence not making the production leaner.

After reviewing existing theory within the subject the authors consider it justifiable to continue this research according to the purpose and goals already set up.

4 Methodology and Tools

This chapter intends to describe how the work with this thesis has been performed. This is done by explaining different methods and tools used during the course of action. In this chapter methodology issues are also described to explain obstacles and assumptions along the way.

4.1 Course of action

In figure 4.1 a schematic overview of the course of action is shown.

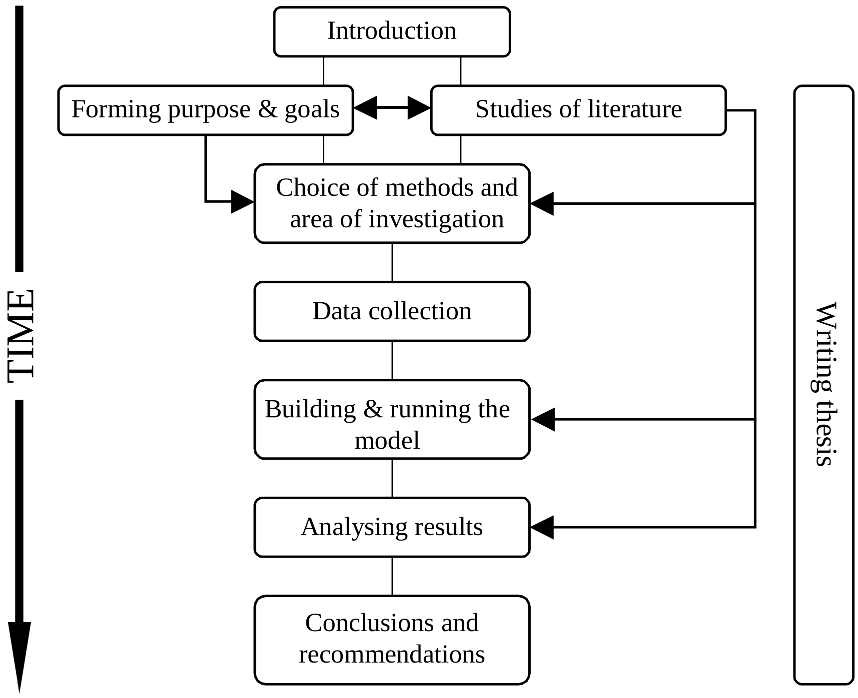

Figure 4.1, Course of action.

The work with this thesis started off with an introduction to the company, the factory site and the BHL-line. After the introduction, searching for theories within the area of research followed. During the search of theories the purpose and goals were formulated together with the mentors at CAT. When the purpose and goals were found the search for a proper research strategy began, the writers' and the mentors' choice was case study. This choice is further explained in paragraph 4.4.

The next task was to decide on which area the case study should be performed. The choice of looking at the BHL-line was made by the company since this is the assembly line with the highest volumes and the biggest lineside storage areas. The manufacturing engineers at CAT are also looking at doubling the capacity of the BHL-line; it was therefore highly interesting investigating how a kitting process would affect efficiency.

After performing different informal interviews with operators, team leaders and supervisors at the shop floor, the engine subassembly area within the BHL-line was chosen to be the area to study. This area was chosen because it is a small production line consisting of five stations, making it in many aspects similar to a whole factory.

If instead choosing a couple of work stations on the mainline it would have been more difficult to get the whole picture and take all aspects into account. Further the decision to move the engine subassembly made it even more interesting to investigate since an eventual implementation of a new materials feeding system is easier to perform if the line can be designed from scratch, instead of changing an existing system. The moving of the engine subassembly is further explained in paragraph 5.7.1.

After choosing the area of investigation the collection of data began. The main source of data was the MRP-system, this data regarded part numbers used at the engine subassembly and was verified by the authors. Since the area of the engine subassembly is to be moved the comparison made in the case study was made from a proposed layout plan for the new subassembly, for this reason walking distance and space-data was taken from this proposal. The data collection procedure is further explained in paragraph 4.5.

After collecting and verifying the data the work of building a model in MS Excel began. The model is based on the descriptive model made by Bozer and McGinnis (1992); however some changes to make it fit to CAT's situation were made. The model functions as a way to compare different scenarios to each other. By scenarios it is meant to kit different parts, e.g. kit all parts, kit valuable parts or kit no parts. During the building of the model some assumptions were made, these were continuously discussed with the mentors at CAT or other CAT employees with specialised knowledge.

The outputs of the model are in several different units and very difficult to compare in terms of monetary values. Some kind of weighting of the outputs or criteria was therefore needed. The choice in this study fell on the multi criteria decision-making tool, AHP. Through pairwise comparison the AHP produces weights for different criteria. The AHP is further explained in paragraph 4.8.1. The reasons for using the AHP were two; it is a widely used tool in the industry and CAT uses it as one of their Six Sigma tools. The actual pairwise comparison took place during a meeting with the authors and three CAT employees, where the employees collectively had to reach consensus in their answers. The result of the AHP combined with the mathematical model presented final scores of the tested scenarios.

The three best scoring scenarios were chosen to be investigated in a more qualitative manner and compared with theory. The results that came out from the analysis lead to conclusions, discussions and suggestions for further research.

After the introduction the authors have continuously been writing on the report. This was done to even the workload and to assure that research was not forgotten but always documented.

4.2 Research Philosophy

There is not a clear distinction between quantitative and qualitative research philosophies, however they have some characteristics. The quantitative research often uses numbers as the central unit of analysis and the qualitative research has a tendency to use words as the central unit of analysis. The qualitative research is more often connected with describing and the quantitative is more often connected to analysis. (Denscombe, 2000)

In this thesis a quantitative philosophy was used to produce scenarios in which a qualitative analysis followed. The choice to start with a quantitative philosophy was mainly due to time limitations, to perform the whole thesis qualitatively would have taken much more time. The scenarios were qualitatively analysed to be able to get a more comprehensive view of the problem, to analyse the options and to discuss the intangible effects.

4.3 Research Approach

Generally, there are two different approaches to research, namely inductive and deductive. Saunders et al. (2000) describes that inductive reasoning applies to situations where specific observations or measurements are made towards developing broader conclusions, generalisations and theories. Opposed to inductive reasoning is deductive reasoning, where one starts thinking about generalisations, and then proceeds toward the specifics of how to prove or implement the generalisations (Saunders et al., 2000).

This research started off by reading theories within relevant subjects, the data from the empirical research was then analysed and compared with the theories. Hence the research approach in this thesis is of deductive art. The choice of using a deductive research approach was because the writers found theory within the area of kitting; however most of the theory was built upon research from other types of production. It is therefore interesting to examine if these theories apply to the type of production investigated in this research.

4.4 Research Strategy

Saunders et al. (2000) state that a research strategy is a general plan of how to answer the purpose of the study. There are four main strategies:

- Experiment
- Survey
- Case study
- Action research

The research strategy in this study is a case study investigating the BHL engine subassembly. According to Ejvegård (2003) the purpose of a case study is to pick a small part of a bigger lapse and try to let the case represent a broader picture.

The downside is that a single case rarely represents the complete reality, meaning that one has to be cautious when deriving conclusions. Another definition by Eriksson and Wiedersheim-Paul (1999) is: "A case study implicates that a few objects is investigated in several aspects."

The nature of the problem in this study is complex and involves a lot of different variables. Researching the whole factory with such a complex problem could not be done with the time limitation of this study. Therefore the chosen research strategy is a case study, picking out a small area in the factory to make deeper research in trying to form conclusions that apply to the whole factory or the whole industry.

4.5 Data Collection Methods

The data collection methods explain how the data in this research has been collected. Where the data collected for the mathematical model comes from is further described in paragraph 6.1.

4.5.1 Primary data

Primary data is data that is collected for the first time, i.e., the data did not exist before the collection (Dahmström, 2000). In this report primary data has been produced on for example shop floor walking distances and space requirements for parts. Primary data for the description of the present situation has been produced by observation and informal interviews.

4.5.2 Secondary data

Secondary data consists of data, which has been collected in another context (Eriksson & Wiedersheim-Paul, 1999). From CAT's MRP system parts data have been collected for the workstations. Furthermore different layout schemes over the factory have been used, of which all must be considered secondary data. The majority of the secondary data collected have been manually verified on the assembly lines and work stations.

4.6 Studies of literature

The theory has mainly been collected through academic databases such as ProQuest, Emerald and Elsevier. The main words being used when searching were; kitting, lean, materials feeding, AHP, order-picking, assembly systems, six sigma and its Swedish analogues. Articles and books from University courses as well as from Caterpillar have also been studied. A licentiate thesis was ordered from Chalmers University of technology and some books were borrowed from the library at Luleå University of Technology.

Because of the fact that the main subject, kitting, is relatively specialised there are no, at least to the authors' knowledge, whole books written on the subject. However kitting is mentioned in several general books on logistics but then just on a very generic level. Therefore the majority of theory on kitting used in this thesis comes from research papers published in scientific journals. The main source for comparing kitting and lineside storage has been Bozer's and McGinnis's article "Kitting versus line stocking: A conceptual framework and a descriptive model". It has also been a useful source to finding other interesting articles.

4.7 Methodology issues

4.7.1 Validity

The validity indicates how well it measures the areas that are to be investigated (Eriksson & Wiedersheim-Paul, 1999).

The choice of case studies as research strategy increases the validity, since it makes it possible to investigate more variables and therefore increases the possibility of researching the significant variables. However a case study might also decrease the validity since the area of investigation might not represent a complete reality. To avoid this happening, the area of investigation was chosen in collaboration with the mentors after performing informal interviews with team leaders and supervisors on the shop floor.

Weekly meetings with the mentors at CAT were held to make sure the writers kept on track using accurate data and researching significant variables.

No assumptions were done without discussions with mentors or other persons within the area of expertise for the assumption. This decreases the risk of having assumptions made on misinterpretations, which increases validity.

4.7.2 Reliability

According to Trochim (2000), reliability has to do with the quality of measurement. In its everyday sense, reliability is the "consistency" or "repeatability" of your measures. Another definition is:"Reliability indicates the accuracy and safety that can be reached with the measuring instrument" (Eriksson & Wiedersheim-Paul, 1999).

All the parts data from the MRP system was double checked to see if parts existed and if they were in use. This increases reliability since it makes sure the investigation was made with accurate data.

A couple of days prior to the AHP meeting mails were sent to the participants to describe the purpose of the meeting and variables. This increases the reliability since the participants were able to prepare themselves prior to the meeting. However two invited participants did not show up on the meeting, this might decrease the reliability since their opinion could have been different to those participating on the meeting.

4.8 Tools

According to theory a lot of the benefits and limitations with kitting are of intangible nature. The benefits and limitations that are of tangible nature are not usually measured in the same units, e.g. monetary, area and time; hence it is very difficult to compare them over each other. In this study it is therefore chosen to use a decision making tool to be able to compare the different outputs of kitting.

4.8.1 Analytical Hierarchy Process

Policy makers at all levels of decision making in organisations use multiple criteria to analyse their complex problems. In the early 1970's Dr. Thomas L Saaty developed the Analytical Hierarchy Process (AHP) which is a problem-solving framework based on the innate human ability to make sound judgments about small problems. Through paired comparison analysis it determines the relative importance of criterion over others.

The AHP is a quantitative technique used to facilitate decisions that involve multiple competing criteria. The method uses multiple criteria rather than relying on a single criterion to make a decision as in, for example cost-benefit analysis.

According to Saaty (1990) the AHP facilitates the decision making by organising perceptions, feelings, judgements and memories into a framework that exhibits the forces that influence a decision. It has been applied in a variety of decisions and planning projects in nearly 20 countries.

AHP is being extensively used in many areas such as flexible manufacturing systems models selection (Hasin & Bohez, 1994), benchmarking logistics performance of the postal industry (Chan et. al 2006) and facility location selection (Lee & Yang, 1997).

Saaty (1990) defines decision making as a process that involves the following steps;

- Structure a problem with a model that shows the problem's key elements and their relationships.
- Elicit judgements that reflect knowledge, feelings, or emotions.
- Represent those judgements with meaningful numbers.

- Use these numbers to calculate the priorities of the elements of the hierarchy.
- Synthesise these results to determine an overall outcome.
- Analyse sensitivity to changes in judgement.

According to Saaty (1990) the AHP meets all of these criteria and is therefore a suitable tool to facilitate decision-making.

How it's done
The problems are decomposed into a hierarchy of criteria and alternatives and thereafter the following three steps are being done:

- **State the objective**
  - E.g. "Select kitting process".
- **Define the criteria**
  - E.g. Space requirements, lineside replenishments, WIP etc.
- **Pick the alternatives**
  - E.g. All parts kitted, just hand weight parts kitted, no parts kitted etc.

This information is then arranged in a hierarchical tree shown in figure 4.2 below.

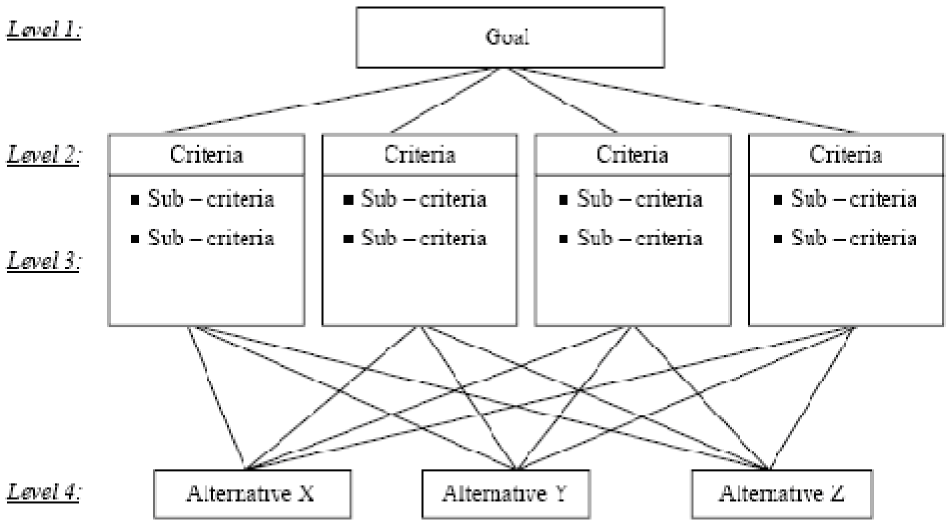

Figure 4.2, Hierarchical tree of an AHP.

Then decision-makers individually express their opinions regarding the relative importance of the criteria and preferences among the alternatives using pairwise comparisons and a 9- point system ranging from 1 (the two choice options are equally preferred) to 9 (one choice option is extremely preferred over the other). Both qualitative and quantitative criteria can be compared using informed judgments to derive weights. The results are thereafter written in matrix form, an example of how it can look like is shown in table 4-1 below.

	WIP	**Lineside repl./day**	**Space reqd.**
WIP	1	1/2	3
Lineside repl./day	2	1	4
Space reqd.	1/3	1/4	1

1 equal 3 moderate 5 strong 7 very strong 9 extreme

Table 4-1, Criterion written in matrix form.

According to Saaty (1990) the best approach to be able to rank the priorities from the matrix is to transform it into an eigenvector through matrix multiplication. This is often being done with computer software such as MS Excel or the today commonly used decision-making software "Expert-choice". In table 4-2 the computed eigenvector for this example is shown.

WIP	0.3196
Lineside repl./day	0.5584
Space reqd.	0.122

Table 4-2, Computed eigenvector.

To be able to compare criteria of different units they are then normalised as shown in the example in table 4-3 below.

				Normalised :	
	Alt. 1	Alt. 2	unit	Alt. 1	Alt. 2
WIP	150	200	£	0.43	0.57
Lineside repl./day	950	700	number	0.58	0.42
Space reqd.	140	100	m^2	0.58	0.42

Table 4-3, Normalisation of the criterion.

Thereafter the normalised criteria are multiplied with the eigenvector to obtain the final weighted results, as shown in table 4-4 below. In this example the most preferred alternative would be the one with the lowest result i.e. alternative 2 with the score of 0.47.

	WIP	**Lineside repl./day**	**Space reqd.**
Alt. 1	0.43	0.58	0.58
Alt. 2	0.57	0.42	0.42

	Eigenvector
WIP	0.3196
Lineside repl./day	0.5584
Space reqd.	0.122

Results

Alt. 1	0.53206
Alt.2	0.46794

Table 4-4, Final stage of the AHP.

In conclusion the output of the AHP is a result or a score for the different alternatives that gives a relatively objective overview of a complex problem with many decision variables.

5 Present Situation

This chapter aims to give an extensive review of the present situation at CAT. It begins with a short description of CPS, it is thereafter explained how CAT divide their ingoing part numbers and how the parts are delivered to the assembly lines. The review then moves on to describe the area of investigation starting with the BHL production to end up in the engine subassembly, which is the area in particular on which the case study has been performed. Finally some acknowledged issues that currently exist at CAT are described.

5.1 Caterpillar Production System

The Caterpillar Production System (CPS) is the common Order to Delivery process being implemented enterprise-wide to achieve the Safety, Quality and Velocity goals for 2010 and beyond. CPS encompasses three sub-systems: Operating, Cultural and Management. These three sub-systems are overlapping each other and unite in one sustainable system, the CPS.

5.1.1 Operating system

The Operating system is focused on waste elimination using Lean and Six Sigma. CPS emphasises on integrating both the Six Sigma and Lean business improvement approaches where Six Sigma is the “unifying framework” whereas Lean provides additional tools to “turbo-charge” improvement efforts. The core values of the operating system are thus entirely based on the well-recognised Lean and Six Sigma frameworks;

- **Chasing waste**; drive for the continuous and relentless elimination of waste in all processes with priority on safety and quality-related wastes. CPS recognises the “standard” 8 types of waste.
- **Pull production**; use Pull replenishment to only build what is needed, when it is needed, in the amount it is needed.
- **Make the value flow**; simplify processes to quickly identify problems and increase process efficiency.
- **Drive standard work**; standardise tasks and utilise common processes as the foundation for Continuous Improvement.
- **Even the load**; balance the workload to level production and reduce process variability.
- **Validate the process;** prove that the processes and technology work before introducing them into production (standardised work sheets).

5.1.2 Cultural system

The Cultural system is focusing on making change possible and improving the way of work.

- **Put safety first** by placing the highest priority on eliminating safety-related waste.
- **Take the customer’s view**; make decisions based on the customer’s view and the long-term corporate strategy.
- **Go, See, Act;** see it first hand to ensure thorough understanding.
- **Stop to fix;** cease production when a problem occurs to correct it in process.
- **Develop people;** identify, attract and develop people and teams.

5.1.3 Management system

The management system is focused in chasing the measurements and management structure to support continuous improvement.

- **Actively listen**; conduct process improvement dialogues at all levels.
  At CAT a team group meeting is held every morning in all areas to review status and daily objectives.
- **Make it visual**; build the visual workplace so no problems are hidden and opportunities can be realised. CPS standard metric boards are in place throughout the factory (see figure 5.1 below). People, Quality, Velocity and Cost metrics calculated using CPS standards are posted so every team member can see and understand current conditions.

Figure 5.1, CPS board.

- **Align the targets**; deploy cascaded metrics and targets across the value chain.
- **Act decisively**; make decisions by consensus and implement with a sense of urgency.

5.2 Business Processes

All parts going into assembly are divided into four different business processes, known as BP1-BP4. Business processes were introduced in 1998 to improve the material flow, create space to consolidate production, drive to pull trigger deliveries and to improve inventory turns. With the great amount of ingoing parts the business processes has given an opportunity to divide parts with similar properties to simplify the decision making process. In this study only parts belonging to BP2 and BP3 will be investigated. This is since theory explains that cheap and small parts such as nuts and bolts, BP4, are usually not considered for kitting. BP1 parts are not investigated since they generally are too big to be kitted. The nature of each business process is explained in table 5-1.

	BP 1	BP 2	BP 3	BP 4
Value	High	High / Medium	Medium / Low	Low
Delivered from Supplier	Sequenced Pull	Pull	Push MRP	Third party VMI
Delivered internal	Sequenced from trailer / paint	Kanban	Kanban	Kanban
Line Location	Single location for commodity	Minimum 2 locations/part no	Minimum 2 locations/part no	Minimum 2 Box System
Line Location capacity	1 shift including trailers	Minimum 1 shift / location	Minimum 1 shift / location	Minimum 1 shift / location
Example BHL	Frame, Boom	Hydraulic hoses	Light fabrications	Bolts, Nuts

Table 5-1, Description of business processes.

5.3 Flow Paths

The flow paths, known as FP1-9, describe the internal logistics flow for parts and are explained in figure 5.2. At the moment seven out of the nine flow paths are in use.

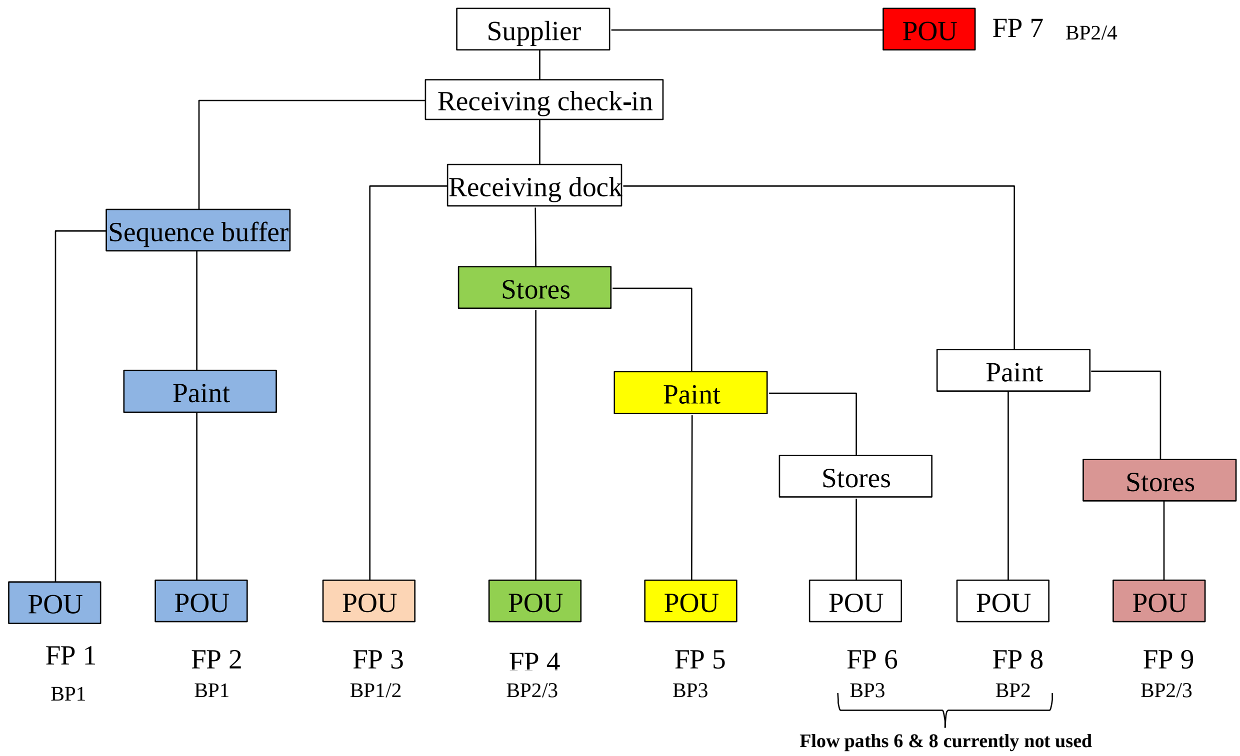

Figure 5.2, Flow paths.

5.4 Materials feeding at CAT

Materials feeding mainly concern what principle to use for feeding material to a workstation or an assembly line. As stated in the theory chapter several principles of materials feeding can exist simultaneously. This is also the case at CAT where three out of the four materials feeding principles are in use, namely continuous supply, sequential supply and kitting. Below is a brief description of how the principles are used.

Continuous supply

The majority of BP2-BP4-parts used at CAT are being delivered lineside using continuous supply. As described in the theory chapter this means the parts are sorted by part number and all part numbers needed for producing every occurring product over a long period are available at the POU at every time. For these parts a two-bin kanban system is used to keep control of the inventory levels.

- BP2-BP3

Specially assigned expeditors are inspecting the lineside stores twice a day, wherever there is an empty bin it means a part has to be replenished. Using a handheld terminal the expeditor scans the barcodes of the empty bins, which produces a picking order to the material handler saying that the part has to be replenished. The replenishment of parts is made by personnel from the logistics department mainly using forklift trucks to transport the bins. In figure 5.3 below a picture of a lineside store is shown.

Figure 5.3, Stores situated lineside with two-bin kanban system.

- BP4

For BP4-parts CAT is using a sort of vendor-managed inventory (VMI). A third party logistics company are managing all inventories of BP4 parts, meaning it is on their responsibility to replenish the parts in the right time in right quantities. BP4-parts, e.g. bolts and nuts, are normally packed in small cardboard boxes that are stored in specially designed storage racks, shown in figure 5.4 below.

Figure 5.4, Storage rack for BP4-parts.

Sequential Supply

Sequential supply refers to the case when part numbers needed for a specific number of assembly objects are displayed at the assembly stations, sorted by object. This principle is used on a majority of the BP1-parts and subassemblies for feeding them lineside. This means the parts are delivered, and stored in the same order they are going to be used. The parts in this category are in general placed on different types of stillages, specially designed to carry one unit of the corresponding part. The stillages are transported lineside either by trailer trains or forklift trucks and placed on rollerbeds, shown in figure 5.5 below.

Figure 5.5, Frames (BP1) waiting on rollerbed lineside.

Kitting

In July 2007 CAT introduced kitting of some of the hydraulic hoses that goes onto the BHLs. This part type comes in a great amount of variants that made the lineside stores very big when supplying them continuously. A kitting area has been set up where a kitting-operator on one shift assembles all kits needed for one days production (two shifts). The hoses are attached to specially designed kit containers, shown in figure 5.6 below. The kitting area is situated near its corresponding workstations enabling the wheel provided containers to be manually moved. The change to kitting the hoses is seen as successful, saving much lineside space with a relatively small effort. In this specific area kitting was almost the only materials feeding solution, it will therefore not be investigated further in this thesis.

Figure 5.6, Hose-kit.

5.5 The Backhoe loader line

The process of building a BHL can roughly be divided into eight phases: Receiving, Stores, Paint, Subassemblies, Main assembly line, End of line process, PDI audit and Finished goods stores. Below a description of each stage is given.

5.5.1 Receiving

All parts from suppliers except those belonging to FP7 (figure 5.2) comes through the receiving check-in. Here the goods are checked in and dropped of by the suppliers to be sorted and sent to its next location according to their FP. The supplier checks in and gets barcode-notes that belong to the material he is supplying. He drops of the material at its designated receiving dock with the barcode-notes attached. When the supplier gets his barcode-notes the material is checked in to the MRP-system used at CAT. At the receiving dock the material is prepared to go into stores, meaning some material has to be decanted into bins in predefined kanban-quantities. However some suppliers deliver the material fitted to go directly to stores without decanting. Three standard bins are being used for parts fitting in them. For parts too big for the standard bins; special pallets and stillages are being used.

5.5.2 Stores

When material leaves the receiving dock to be delivered to stores each of the material handlers scan the barcode with their wireless barcode scanner, the MRP system then knows the material is being transported from receiving to store. Once in store the material handlers scan the material along with the place it is being stored in, the MRP system now knows where the material is being stored. Stores on site are divided into five different areas; Sequenced buffer, Main store, ASRS, Receiving store and POU.

1.The sequenced buffer is a store for parts that are lined up in the order they will be assembled. This storage is only used for BP1 parts going straight to POU or to the paint facility. The parts are given slot numbers telling in what order they go into production. Some parts are delivered from supplier in the right sequence while others have to be rearranged when arriving to the sequence buffer. In figure 5.7 below an example of a sequenced buffer is shown.

Figure 5.7, BHL frames in sequenced buffer waiting for painting.

2. The Main store, shown in figure 5.8 below, is a high rack store situated inside the factory building. It has approximately 2500 storage places for bins and pallets and is managed with manual forklift trucks. From here all material goes straight to POU.

Figure 5.8, Main stores.

3. ASRS means Automated Stores and Retrieval System, which is a system working with robot cranes storing and picking up material automatically (see figure 5.9 below). This store is partly used to supply material to the subassemblies situated along the ASRS. Furthermore the ASRS stores material that goes directly to the POU. With a capacity of storing up to 5200 euro-pallets the ASRS is the storage area with the biggest capacity on site. The ASRS have several pick-up locations and the material is called down manually through computer terminals.

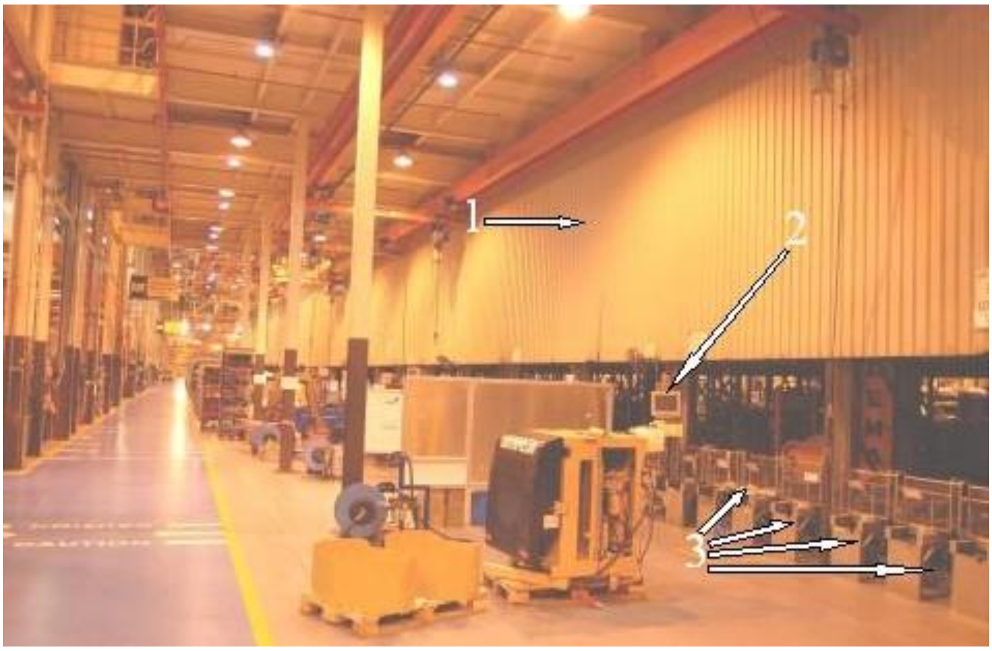

Figure 5.9, Part of the ASRS system. 1. Stores 2. Computer terminal 3. Pick up locations.

4. The Receiving store is right by the receiving dock. Parts stored here are either waiting to be decanted or stored here because of fire restrictions in other stores. The receiving store is the smallest storage area on site.

5. POU (Point of Use), also called lineside stores, are all the stores along the assembly lines. From the POU stores materials are taken by the operators and assembled on to the products. POU is always the last store before assembly, meaning if there is a lack of material here the assembly line stands still. POU stores look different depending of the size of the parts and which business process it belongs to. For example, BP1-parts normally lie on rollerbeds while parts in BP2-3 are stored in standardised bins in kanban-quantities when possible. For further explanation of the business processes, see table 4-1.

Parts in POU are replenished either according to a two-bin kanban system for BP2-BP4 or with a sequential pull-system for BP1. Parts are being delivered to POU by forklift trucks and trailer trains.

5.5.3 Paint

Many parts need to be painted before being assembled. Just outside the main factory building a painting facility is ran by a third party painting company. The parts are being painted either in sequenced slot order for BP1 or in batches for BP2 & BP3. After the painting process the parts are either placed in a buffer (figure 5.10) and thereafter transported to POU or put in kanban-bins and placed in stores, depending on their FPs. From February 1:st 2008 CAT will be running the paint facility themselves.

Figure 5.10, BHL booms and loaders waiting in buffer to be transported to POU.

5.5.4 BHL Subassemblies

To be able to keep takt time and balance on the main assembly line some subassemblies are being made. Typical examples of subassemblies on the BHL-line are engine subassembly and hose-fitting to hydraulic cylinder. Some of the subassembly areas are situated right next to the main assembly line while others are located right next to the ASRS. Subassemblies placed next to the ASRS are mainly those with a relatively high variability where the ASRS is an efficient and high-density store feeding the subassemblies. The subassemblies are made sequentially, meaning each subassembly is uniquely made for a specific BHL; a finished subassembly goes to POU.

To free space for coming changes in production decision has been made on moving the subassembly areas in connection to the main assembly lines.

5.5.5 BHL Main Assembly line

The main assembly line consists of 37 workstations. The line is balanced leading to all stations having the same takt time. At the first station a frame is being loaded onto an electric product mover, shown in figure 5.11, and at the very end of the line (figure 5.12) an almost finished BHL is driven off the line. The electric product mover has fixed positions at every workstation and the operator on each station sets off the movement manually.

The operators pick parts and subassemblies from the POU stores and fit it on the BHL; different workstation has different number of parts, variability in parts, number of operators and number of subassemblies. Many of the workstations perform different quality checks; some stations are set up only to perform quality checks. The assembly work done in the mainline is typically manually performed; the degree of automation is very low. However a considerable amount of specialised tools and equipment such as overhead cranes and special jigs are being used.

Along the assembly line several information boards and displays have been installed. These show the shop floor workers key figures concerning quality, the overall production and safety issues. Each station also holds standardised work sheets telling the operator each step to be performed and how. Because of the big variety of specifications on each BHL, standardised work can differ a lot between each BHL

Figure 5.11, Electric product mover.

Figure 5.12, Part of mainline.

5.5.6 End of line process

Once the BHL is driven off the electric product mover on the mainline it goes into the end of line process. At the first station some of the hydraulic functions e.g. the boom and stick are tested. Then the BHL is driven to the touch-up booth where paint defects are touched up. The next step is to test-drive and test all the functions of the BHL. This step is done outdoors. Once tested the BHL goes indoor again to repair defects that may have been found. Some parts, mainly in the cabin, are fitted and the BHL is made ready for delivery. The reason of fitting these parts this late in the process is because they are in the way if adjustments need to be done.

5.5.7 PDI Audit

PDI, meaning Pre-Delivery Inspection is the last quality check before delivery. This is the last chance of finding any defects or errors before it reaches the customer. A BHL passing the PDI Audit goes directly to the finished goods stores. The BHLs not passing goes to the Special Audit/Hold-station.

5.5.8 Finished goods stores

A parking lot outside the factory functions as the finished goods store where the BHLs are placed waiting for transportation to end customer. Due to the location of the factory site the only way to deliver finished products is by truck, except for the products being delivered to the retailer right next to the factory.

5.6 Variability of the BHL

At the facilities in Leicester six different models of the BHL E-series are being assembled. The BHL E-series was launched in January 2005. The models are: 422E, 428E, 432E, 434E, 442E and 444E. The larger the number the heavier, stronger and more expensive the machine gets. The price range starts at around £30.000 for a minimum equipped 422E and the most expensive 444E costs around £60.000.

The main differences between models are:

- Engine capacity.
- Two or four wheel steering.
- Equal sized wheels or not.
- Front loader design.
- Extendable stick or not.
- Operator ergonomics.
- Cab or canopy.
- Manual or automatic gearbox.

Each model comes with several different equipment packages and on top of that the customer can order a wide range of selectable equipment, see figure 5.13 below. Due to different legislations there are also regional differences between machines, depending on where in the world they will be used.

Figure 5.13, Variability of the BHL. Notice the differences between the machines.

All these options make up a great variation of each and every produced machine. Assembling a BHL is very much comparable with assembling a modern car but the volumes are lower and the end products are bigger.

5.7 The Engine Subassembly

The power trains, each consisting of an engine, gearbox and a hydraulic pump, going in to the BHL main assembly line are preassembled in a subassembly-line consisting of five workstations. The subassembly line has the same takt time as the main assembly line. The production is sequenced according to the order the powertrains are going to be used at the main assembly line. Currently the engine subassembly is situated in the subassembly area next to the ASRS, see Appendix C. The work at the line is mainly done by hand and with the help of pneumatic tools and lifting aids.

Only taking BP1-3 parts into account each power train consists of 43 to 50 parts depending on the model. Due to the product variation a total of 73 part numbers are being used at the subassembly. In figure 5.14 below an overview of the assembly line is shown.

Figure 5.14, Overview of the Engine Subassembly. ASRS , assembly line, stores, from left to right.

At the first station, shown in figure 5.15, the engine and the gearbox are collected from the ASRS, placed on a trolley and attached to each other. The power train remains on this trolley through the assembly line. There are five different gearboxes that go on three types of engines.

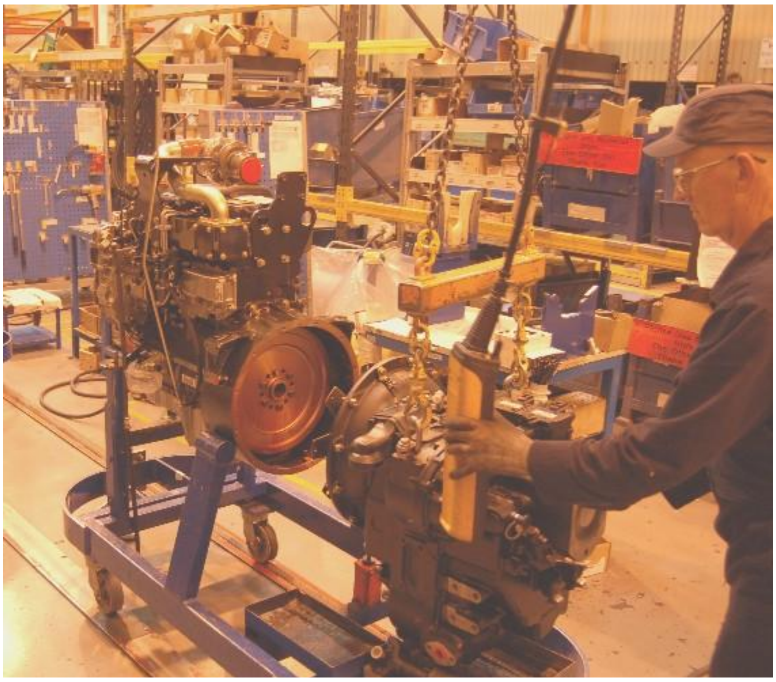

Figure 5.15, Station 1, Gearbox being attached to Engine.

The main part being assembled at the second station is the hydraulic pump that is being attached to the gearbox. Besides the pump some brackets and supports are also fitted to the powertrain.

At the third and fourth station the main work being done is tightening bolts and connecting harnesses. Example of parts that are assembled here are:

- Pulley.
- Radiator fan.
- Electrical harnesses.
- Alternator cable.

Finally, at the fifth station the air cleaner, an AC compressor (if selected) and the muffler are mounted onto the power train.

The finished power train is then lifted off from the trolley and placed on a stillage. A shaft and an oil filter that are to be assembled on the mainline are also put on the stillage. The stillage is placed on a roller bed that also acts as a buffer of maximum two completed power trains.

5.7.1 Moving the Engine subassembly

As mentioned in paragraph 5.5.4 the engine subassembly is about to be moved from its current location near the ASRS to a location closer the mainline. In spring 2007 a consultant was engaged to establish a layout proposal of how the new area for the engine subassembly could look like. This proposal gives a good picture of the possible future state of the engine subassembly.

One of the main issues with moving the engine subassembly is the amount of space needed for parts stored in the ASRS. Since the ASRS is a high-density store, the parts will occupy more space if being stored traditionally by a two-bin system lineside

5.8 Issues at CAT

In this section some of the acknowledged issues linked to materials feeding are presented.

Part shortages

CAT has got some issues regarding their current materials feeding system. The biggest issue at the plant right now is getting parts to POU in time. Every week the main assembly line has to be stopped due to part shortages. These part shortages occur for various reasons, e.g., poor material planning, supplier delays, poor response time when replenishing lineside and poor inventory control. Sometimes the part shortage is not highlighted until the part missing is to be assembled on the product. Sometimes the part shortage is known several days before the assembly line will have to be stopped, but the parts can’t be delivered in time because of the reasons mentioned above.

Poor Kanban-quantities

Another big issue with the lineside storage today is that it is poorly balanced; meaning one part might have two weeks’ worth of inventory lineside while another might only have half a shift’s worth. The poorly balanced inventory leads to excessive storing, which according to Lean theory is waste.

Big lineside stores

CAT is today using the materials feeding system continuous supply for feeding a majority of parts lineside. This means parts have to be stored lineside, no matter if it goes into one machine a month or if it goes into every machine. This fact makes the lineside stores today very space consuming. Which does not coincide with the first S in the theory of 5S, Sort, where you want to remove unneeded items from the work environment. A big lineside inventory also creates long searching and walking time for the assembly operators, this is also considered non-value adding time by lean theories, which is something you want to get rid off. These walking and searching times also make it difficult to balance the assembly line since there is great variation in walking and searching times depending on the end product specifications.

Quality checks

Storing parts lineside forces quality control to be made when assembling the parts, meaning you might think you have a days worth of inventory of a certain part lineside, but when assembling some of the parts might be rejected due to poor quality. This scenario might lead to part shortages lineside since material planning thought these were parts to be used. CAT has a goal that parts quality should be checked by suppliers and by themselves earlier in the process, however quality rejects are not unusual lineside. Quality problems especially seem to occur with painted parts that have been poorly decanted into standard bins.

End quality, wrongly assembled parts

Another quality issue that occurs at CAT today is that parts end up being assembled on the wrong product. This seems to happen when there are part number changes, product changeover or when parts that are assembled very seldom needs to be assembled. Basically this behaviour occurs when operators has been working for so long that they think they know what parts goes on a machine without double checking it. These errors can be very costly since they might not be noticed until much later in the assembly process and the rework gets very time consuming.

Manually managed kanban system

Responsible for the lineside replenishments is an expeditor; the expeditor’s task is to keep control of the lineside inventory levels. This is done by the expeditor physically checking the entire inventory in the morning and before the second shift starts, whenever there is a shortage or an empty kanban bin the expeditor scans the part with his barcode scanner. The scanning creates a pick order at the storage and material handlers replenish the parts. This system has its issues, first there is a lot of inventory for the expeditor to control which sometimes lead to him missing out on parts which creates part shortages. Second the inventory only gets checked twice a day and not continuously. This system creates a “fake” kanban system, where the organisation believes they have a two-bin kanban system, but in real life the empty bins does not create the picking orders in the stores, the expeditor does.

Not following standardised work

Another issue is that the operators at shop floor seem to find their own ways of doing their work, instead of following the standardised work. One example is that they tend to preassemble in batches. For instance, if there are two parts that first have to be attached to each other before being used on the line, the shop floor worker collects all parts he needs on one shift at the same time. Because the process should not be done this way there are no space to store this extra material, it instead ends up under benches or tables spread around the line. The workers at the stations are doing this because they think it simplifies and makes their work more efficient. From their perspective it can surely be the case, but the problem is that they don’t see the whole system, in that sense they are sub optimising. The main problems with this issue are that it makes the shop floor messy and less visual and abuses the inventory system by adding an extra buffer. Further the information in the MRP-system becomes inaccurate, because the system shows there is a shortage but in real life there may be a shift’s worth of inventory lying under a table.

Decanting of parts

Because of the fact that the suppliers don’t deliver parts in the right kanban quantities and in bins fitting the lineside stores; much of the incoming material has to be decanted into the standardised bins already existing in the factory. As described earlier the decanting is mainly done upon arrival to the receiving dock. To handle material does not only take time and cost money, but also adds a quality risk because every time a part is handled there is a possibility to damage it.

6 Building a model

With Bozer's and McGinnis's (1992) model (Appendix B) as a ground a model in MS Excel was built. The model made by Bozer and McGinnis was built for general purposes; however some variables and outputs did not fit into the current situation at CAT. The result of their model aimed to point out the general differences between lineside stocking and kitting, not pointing out what types of parts could benefit the most from a kitting process. The result of the model is a way to quantify the output of a kitting process and to narrow down the number of scenarios onto which a more qualitative investigation should take place.

Secondary data has mainly been retrieved from CAT's MRP system Glovia. The data being used is the most up-to-date that is available, all coming from this year.

A proposed layout of how the line could be designed when it is moving closer to the mainline has also been used to extract input data. This layout was made by an external consultant and represents a good picture of how the engine subassembly probably will look like when it's moved.

6.1 Mathematical model explanation

Indexes in the model are:

- *p* = Part number for part *p*, retrieved from MRP-system Glovia.
- *s* = 1,2,3,4,5 for workstation numbers at the engine subassembly.
- *k* = Kit number, i.e., the specific kit if using more than one type of kit.
- *c* = Case number, engine subassembly = 1.

Data inputs in the model are:

- *PD* = End product demand in number of products per day.
- S_p = Lineside storage space in m^2 required for part number *p* if stored lineside, data measured from proposed layout.
- V_p = Value in £ of part *p*, i.e., purchasing cost from supplier, data retrieved from MRP-system Glovia.
- Q_p = Kanban-quantity in number of parts for part p, data retrieved from MRP-system Glovia.
- U_p = Usage in percent of part *p*, e.g., for parts that go into all products U_p equals 100%, data retrieved from MRP-system Glovia.
- N_p = Number of part *p* that goes into one end product, data retrieved from MRP-system Glovia.
- D_p = Demand in number of parts per day for part *p*, i.e., $D_p = \frac{U_p N_p PD}{100}$
- *W* = Average walking distance in metres for the operator to pick a part from the lineside store, data measured from proposed layout to be 3.6 m.
- *KW* = Average walking distance in metres for the operator to pick a part from a kit, currently estimated to 0,5m.
- TU_p = Type of Usage for part *p*, whether a part is standard, selectable or mandatory, primary data collected from assembly lines.
- BP_p = What Business Process part *p* belongs to.
- FP_p = What Flow Path part *p* belongs to.

- OV = Average walking speed of an operator, currently estimated to 1m/s. For further explanation refer to appendix D.
- AP = Average time in the kitting area to pick a part and place it in a kit, currently estimated to 6s.
- KS = Average speed in the kitting area to move the kit container between different component containers, currently estimated to 0,5m/s.
- WS = Number of workstations, for engine subassembly WS=5.

Decision variables in the model are:

- K_{pk} = If part p is kitted in kit k K_{pk} = 1, if part p is not kitted K_{pk} = 0
- NK_p = If part p is not kitted NK_p = 1, if part p is kitted NK_p = 0,
  i.e., $K_{pk} \neq NK_p$ and NK_p = 1- K_{pk}, meaning a part can't be kitted and stored lineside at the same time.

Calculations in the model are:

- LR_p = How many times part p gets replenished lineside per day, i.e., how many times a part container needs to be replenished lineside every day or how many times a kit needs to be replenished every day divided by the number of parts in the kit.

  $$LR_p = \frac{NK_p D_p}{Q_p} + \frac{K_{pk} PD}{\sum_{p \in k} (K_{pk} N_p)} \qquad (1)$$

  The first term in equation (1) represents the number of lineside replenishments if part p is stored lineside, the second term represents the number of replenishments if part p is kitted.

- SR_p = Stores replenishments per day, i.e., how many times a part p container needs to be replenished in stores every day.

  $$SR_p = \frac{NK_p D_p}{Q_p} + \frac{K_{pk} D_p}{Q_p} \qquad (2)$$

  The first term in equation (2) represents the number of stores replenishments if part p is stored lineside, the second term represents the number of replenishments if part p is kitted. Noticeable is that SR_p is the same value no matter if part p is kitted or stored lineside.

- LS_p = Lineside storage space, i.e., the area part p occupies lineside.

  $$LS_p = NK_p S_p \qquad (3)$$

  Equation (3) states that if part p is stored lineside it occupies S_p m^2 lineside, if part p is kitted it occupies no storage space lineside.

- KS_p = Kitting space, i.e., the area part p occupies in the kitting area.

  $$KS_p = K_{pk} S_p \qquad (4)$$

  Equation (4) states that if part p is kitted it occupies S_p m^2 in the kitting area, if part p is not kitted it occupies no space in the kitting area.

- WT_p = Operator walking time for part *p*, i.e., the time an operator has to walk to collect a part from the lineside store or from a kit and the time for the operator to walk back to assemble the part.

$$WT_p = \left(\frac{2NK_pD_pW}{OV} + \frac{2K_{pk}D_pKW}{OV} \right) \Big/ 60 \qquad (5)$$

The first term in equation (5) represents the walking time to get part *p* from the lineside store, the second term represents the walking time to get part *p* from a kit. The factor 2 in equation (5) comes from the fact that the operator has to walk to get part *p* and has to walk back to assemble part *p*.

- LV_p = Value of inventory of part *p* stored lineside or in a kit not yet assembled to the end product.

$$LV_p = NK_pQ_pV_p + K_{pk}\frac{V_pD_pWS}{2PD} \qquad (6)$$

The first term in equation (6) represents the value of inventory for part p in lineside store, the second term represents the value of part p in kits yet not assembled.

- PH_p = Physical part handling of part *p* per day, i.e., how many times a part physically has to be lifted and moved to a new location (e.g. to go in a kit or to be assembled on the product).

$$PH_p = NK_pD_p + 2K_{pk}D_p \qquad (7)$$

The first term in equation (7) represents the number of times part *p* is handled if it is stored lineside, the second term represents the number of times part *p* is handled if kitted.

- KT_p = Kitting time for part *p* per day, i.e., the time it takes in the kitting area to pick part p and place it in the kit, and move the kit to the next part to be picked.

$$KT_p = \left(\frac{PDK_{pk}S_p}{2KS} + K_{pk}D_pAP \right) \Big/ 60 \qquad (8)$$

The first term in equation (8) represents the time it takes to move the kit container to part *p* or for the kit container to pass by part *p*, the second term represent the time it takes to pick part *p* and put it in the kit. For further explanation, refer to appendix D.

Outputs of the model are:

- TLR_c = Total lineside replenishments per day in case *c*.

$$TLR_c = \sum_{p \in c} LR_p \qquad (9)$$

Equation (9) shows the sum of all lineside replenishments for parts *p* belonging to case *c*.

- TSR_c = Total storage replenishments per day in case *c*.
  $$TSR_c = \sum_{p \in c} SR_p \tag{10}$$
  Equation (10) shows the sum of all storage replenishments for parts *p* belonging to case *c*.

- TLS_c = Total lineside storage space in case *c*.
  $$TLS_c = \sum_{p \in c} LS_p \tag{11}$$
  Equation (11) shows the sum of all lineside storage space for parts *p* belonging to case *c*.

- TKS_c = Total kitting area storage space in case *c*.
  $$TKS_c = \sum_{p \in c} KS_p \tag{12}$$
  Equation (12) shows the sum of all kitting area storage space for parts *p* belonging to case *c*.

- TWT_c = Total walking time for operators to go and get parts in case *c*.
  $$TWT_c = \sum_{p \in c} WT_p \tag{13}$$
  Equation (13) shows the sum of all operator walking times to get parts *p* belonging to case *c*.

- TLV_c = Total value of lineside inventory in case *c*.
  $$TLV_c = \sum_{p \in c} LV_p \tag{14}$$
  Equation (14) shows the sum of the value of all lineside inventories for parts *p* belonging to case *c*.

- TPH_c = Total number of parts handling in case *c*.
  $$TPH_c = \sum_{p \in c} PH_p \tag{15}$$
  Equation (15) shows the sum of all parts handling of parts *p* belonging to case *c*.

- TKT_c = Total kitting time per day in case *c*.
  $$TKT_c = \sum_{p \in c} KT_p \tag{16}$$
  Equation (16) shows the sum of all kitting time of parts *p* belonging to case *c*.
  See appendix D for an explanation of how it was calculated.

6.2 Output of the model

The outputs of the model are a way to compare different scenarios with the help of some key factors. The scenarios are different degrees of kitting, at one end there is no parts kitted and on the other end all parts are kitted. Between these two extremes the user of the model can decide scenarios that seems interesting, e.g., to kit low usage parts or to kit the most expensive parts.

The outputs of the model are:

- **Lineside replenishments per day.**
  How many times a part or kit container needs to be replenished lineside per day. Unit; number of replenishments.
- **Storage replenishments per day.**
  How many times a part or kit container needs to be replenished in the (main) store per day. Unit; number of replenishments.
- **Lineside storage space.**
  The area the parts occupy lineside. Unit; square metres.
- **Assembly operator walking time per day.**
  The time an operator has to walk to collect the parts from the lineside store or from a kit and the time for the operator to walk back to assemble the part. Unit; minutes
- **Kitting time per day.**
  The time it takes in the kitting area to make the kits. Unit; minutes.
- **Physical part handling per day.**
  The number of times a part physically has to be lifted and moved to a new location. Unit; number of part handlings.
- **Lineside inventory value.**
  Value of inventory of the parts stored lineside or in a kit not yet assembled to the end product. Unit; GBP.
- **Kitting space.**
  The area the parts occupy in the kitting area. Unit; square metres.

6.3 Assumptions and weaknesses in the model

The model as such is aimed to quantify the outputs of a kitting process; however just as most mathematical models it is merely a simplification of reality. In this section assumptions and some weaknesses in the model acknowledged by the authors will be presented.

The following assumptions are made in the model:

- An operator walks in an average speed (*OV*) of 1m/s. See appendix D for explanation of how the assumption was made.
- The average time it takes to pick a part from a storage rack and place it on a kit (*AP*) is 6 seconds (appendix D).
- Average speed for moving a kit (*KS*) is 0.5 m/s (appendix D).
- The average distance to walk for an operator to get a part from a kit is 0,5m.
- The end product demand per day (*PD*) is set to the same amount of produced BHLs per day as the factory is aiming to reach in the near future.
- When delivering a kit or a component container lineside the material handler can bring back an empty kit or component container. Saving the time of going twice.
- The area required to store a part in a kitting store equals the area it requires in lineside stores.

- The model does not take into account the fact that kitting one part might move another part closer to the line and therefore reduce the average walking distance for the operator to pick a part.
- When assembling; an operator only picks one part at a time, i.e., if he needs to pick two parts he has to walk two times to the component container.
- The usage data is taken from shipments made in August 2006 until July 2007.
- When calculating the lineside inventory value in kits a uniform consumption is assumed, meaning the average lineside storage value of a kit is half the total part value in the kit.
- The model does not calculate assembly operator picking time since the time it takes to pick a part from a kit and from a lineside storage bin is assumed to be the same.

The model does not take into account the aisle space needed both in lineside stores and a kitting area. When looking at a typical storage area, aisles for transportation consume the majority of the floor space. The model only calculates the space the parts consume on the floor, however there is a space demand to be able to pick and replenish parts as well. Put in the context of the model it means that a reduction of $10m^2$ lineside storage space might in real life also reduce $30m^2$ of aisle space. This example also goes for space in the kitting area, where the total kitting area is much bigger than the actual storage space in the kitting area, which is calculated in the model. The aisle space is not calculated in the model since it varies much with the actual layout of the storage areas.

When calculating the lineside inventory value; the model assumes that there is no kit buffer, meaning every kit is delivered lineside in a "perfect" JIT system. However one can assume that in real life there would be a kit buffer of some size, increasing lineside inventory value with the value of this buffer. This would also affect the lineside storage space since this buffer needs to be somewhere, preferably next to the assembly line. The lineside inventory value for parts stored in the two-bin kanban system is also calculated as in a "perfect" system. Meaning a kanban bin is replenished the moment the last part in the last bin is consumed, however this is not the case in reality, making the average inventory one kanban bin quantity. To conclude; the lineside inventory value is calculated to low both for parts stored lineside and parts stored in kits, whether it is calculated equally low for the two materials feeding system is not known by the authors.

The number of storage replenishments is calculated the same way for both kitted and not kitted parts. To calculate this way demands the assumption that the storage area and the kitting area is the same area, otherwise kitting area replenishments would be necessary and that is not calculated in the model.

The model does not take part size and weight into account. In real life some parts can be picked together due to their relatively small size and weight whereas other parts can only be picked one by one. In the model all parts are picked one by one with no regards to their size. This would affect both operator walking time and kitting time, which could be shorter. If it affects one or the other in different ways is not known by the authors.

6.3.1 Differences to Bozer's and McGinnis's model

To make the model fit into the situation at CAT some changes and additions to Bozer's and McGinnis's (1992) (Appendix B) descriptive model have been done. These changes and additions are listed below:

- Bozer and McGinnis does not count space and time in their model, however they explain that values like this with relative ease could be added to the model. They further encourage the user of the model to customise it for the specific purpose.
- The model in this thesis does not have the same denotations as Bozer's and McGinnis's model.
- The model in this thesis is calculating assembly operator walking time, based on the distance to the parts and an average walking speed of an operator.
- The model in this thesis is calculating kitting time. This kitting time is calculated on the assumption that the kitting area is located very close to the store or is the actual store.
- Bozer's and McGinnis's model considers kitting in batches, the model in this study does not. This is due to the great variation in kits/products, which makes batching very difficult if the assembly sequence is not planned according to the kitting process.
- Bozer and McGinnis name the average value or amount of inventory stored lineside as Work-In-Process, shortened WIP. In this model this is named "Lineside inventory value" in order not to mix up the terms Work-In-Progress and Work-In-Process, which are both shortened as WIP.
- Bozer and McGinnis consider Work-In-Process (Lineside inventory value) in the unit number of components, in this study the Work-In-Process (Lineside inventory value) is in the unit £. This is done since the number of components seems insignificant when lineside storage space is calculated.
- Bozer and McGinnis consider space requirements in the unit number of containers, in this study space requirements is measured in square meters. This is done since all parts are not stored in similar containers.

7 Results and analysis

In this chapter the results are described and analysed both in a quantitative and in a qualitative way. This chapter is intended to form the foundations of the conclusions made in the next chapter.

7.1 Results of the model

In accordance to the goals with this thesis some scenarios were tested in the model. To understand the scenarios some explanations has to be made:

- Only BP2 and BP3 parts were investigated, i.e., “All parts kitted” means all BP2 and BP3 parts within the area of investigation was kitted in the model.
- “Hand weight parts” means parts that according to CAT safety rules can be lifted by hand; generally the standard weight of these parts is maximum 15kg. However this maximum weight can vary depending on how the parts are presented to the operator, a lift from the floor is considered heavier than a lift from waist height.
- “Standard parts” are parts that go onto every engine without any variation.
- “Mandatory parts” are parts that go onto every machine but there are variations in the parts. For example a gearbox is a mandatory part since it has to go on every engine, but there are different kinds of gearboxes.
- “Selectable parts” are parts that can be selected to go on to the engine, but it might just as well not go onto the engine. For example an AC-compressor is a selectable part since it goes on the engine if the customer has ordered an AC, but if the customer has not ordered an AC it does not go onto the engine at all.
- Two scenarios tested are involving the value of the parts, the value limit chosen was £100; this value was chosen since there was a significant gap at £100. The closest to £100 was worth £102, but the next part in terms of value was worth £48.
- The scenario “No parts kitted” means all parts are stored lineside, i.e., the way CAT are delivering parts lineside today.
- In the area of the engine subassembly only parts with FP4, FP7 and FP9 existed, hence only these FPs were investigated in the scenarios.

The scenarios investigated in the model were:

- All parts kitted.
- All mandatory parts kitted.
- All mandatory and selectable parts kitted.
- All selectable parts kitted.
- All hand weight parts kitted.
- All hand weight mandatory and selectable parts kitted.
- All hand weight mandatory parts kitted.
- All hand weight selectable parts kitted.
- All standard parts kitted.
- All parts with value less than £100 kitted.
- All parts with value more than £100 kitted.
- All hand weight BP3 parts kitted.
- All hand weight BP2 parts kitted.
- All hand weight parts with FP7 kitted.
- All hand weight parts with FP4 kitted.
- All hand weight parts with FP9 kitted.

- All hand weight parts with FP9+7 kitted.
- All hand weight parts with FP9+4 kitted.
- All hand weight parts with FP7+4 kitted.
- All non hand weight parts kitted.
- No parts kitted.

In order to show the results of the model in a visual way, charts for every output was made. In figure 7.1-7.7 these charts are shown with the scenarios in which the most interesting and significant results were found when running the model. All values are normalised only showing the relative numbers between the different scenarios.

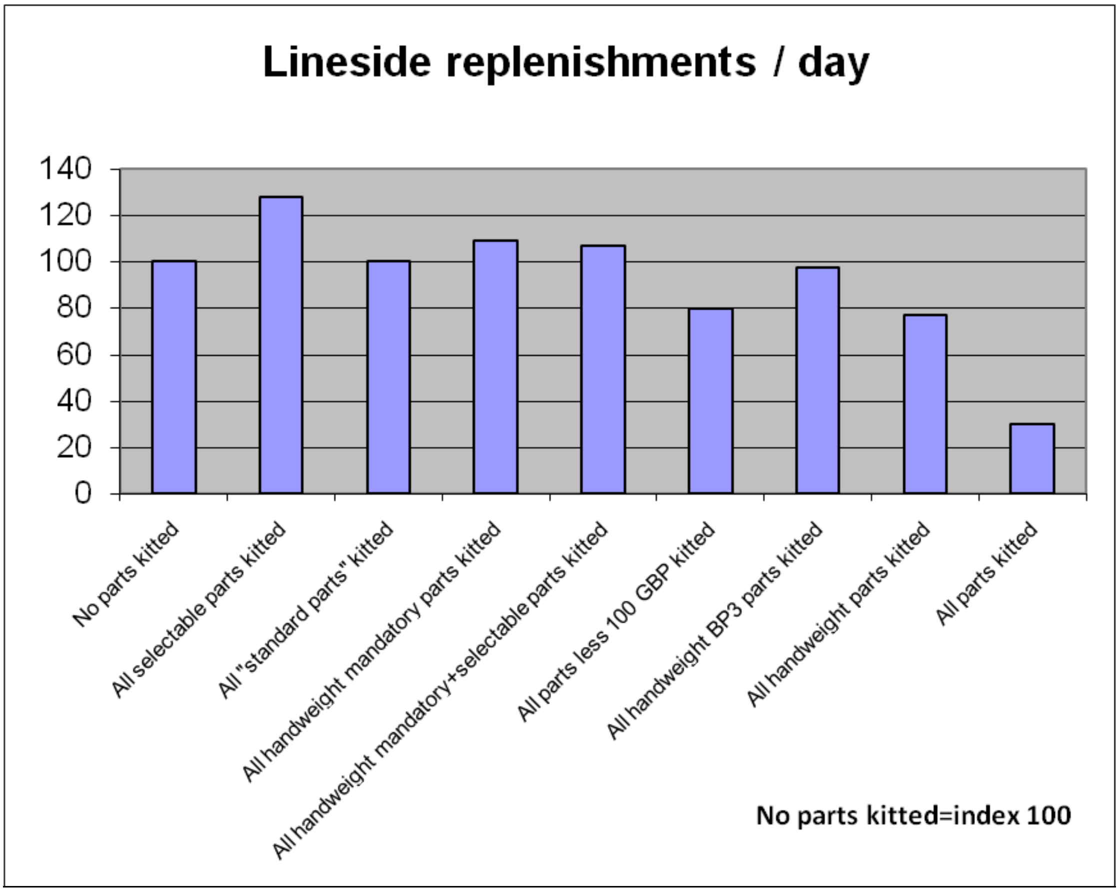

Figure 7.1, Number of lineside replenishments per day.

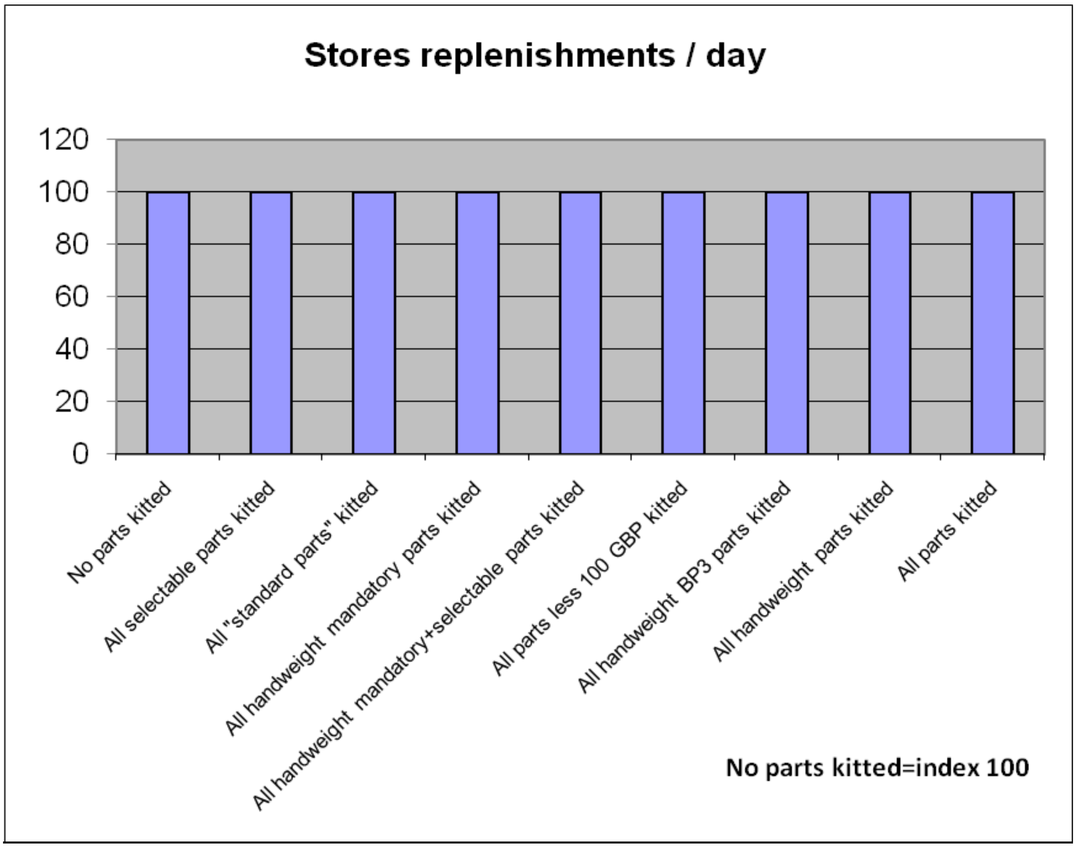

Figure 7.2, Number of stores replenishments per day.

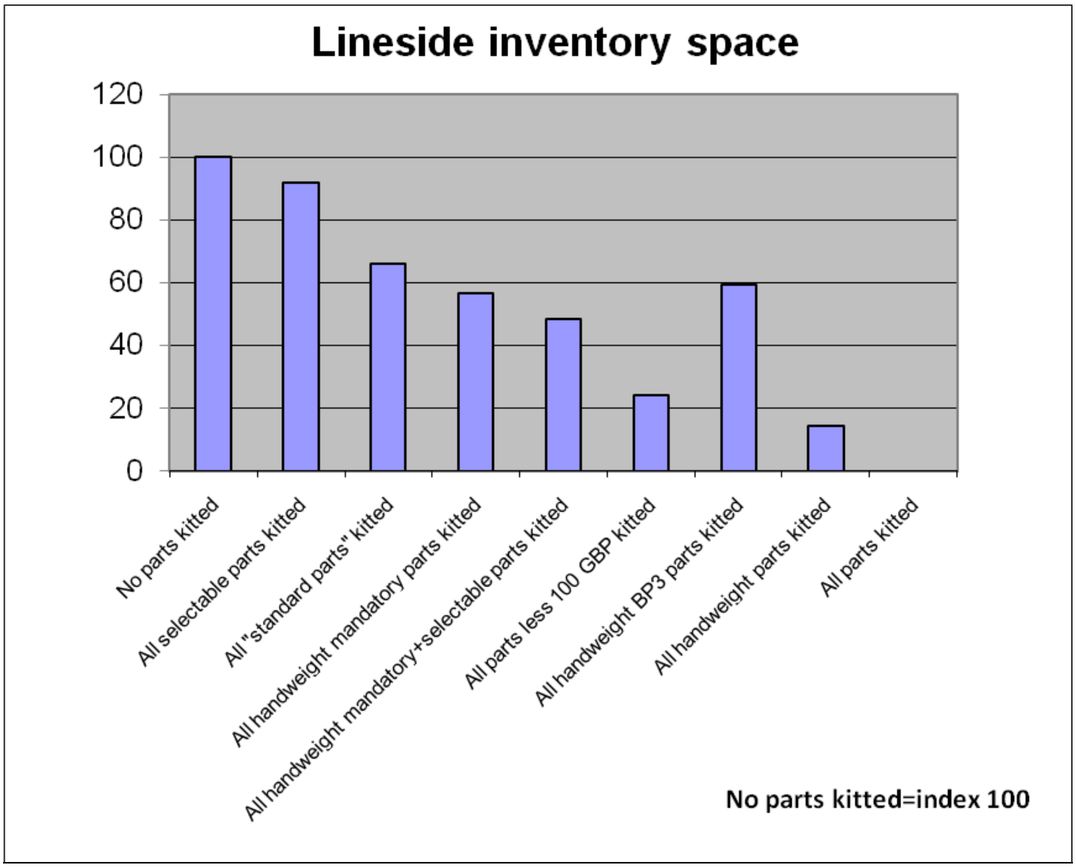

Figure 7.3, Lineside inventory space, in square metres.

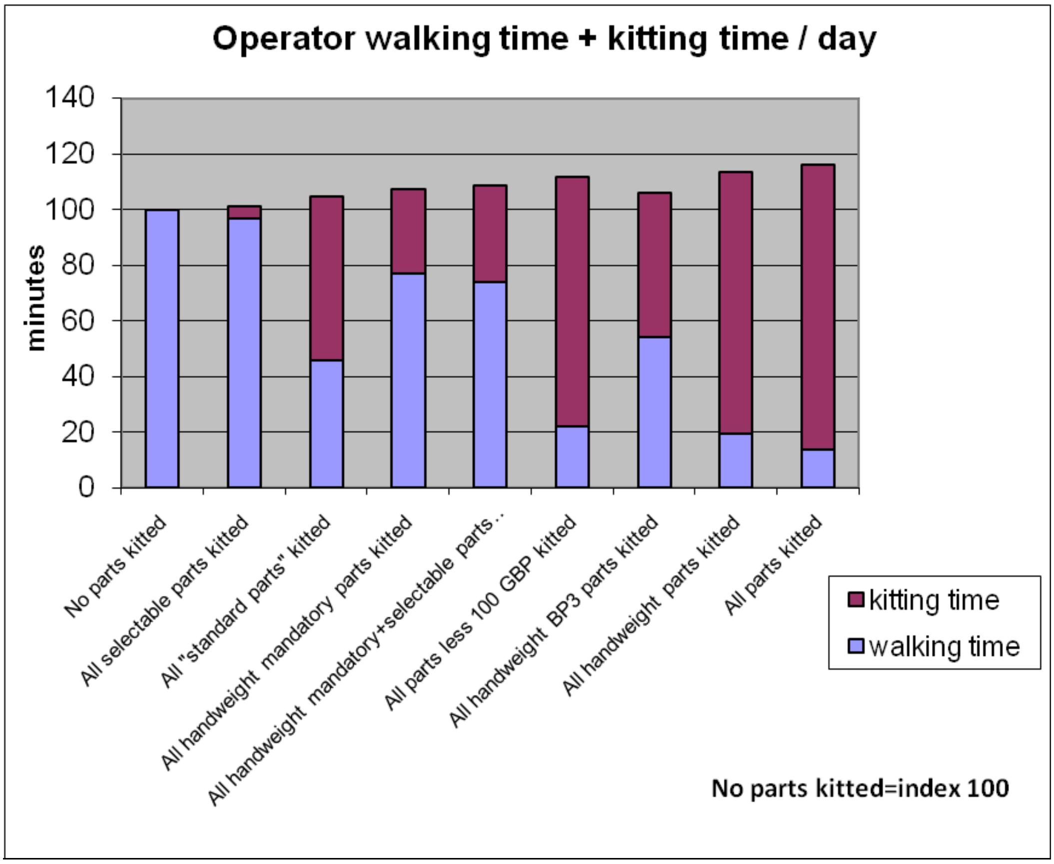

Figure 7.4, Operator walking time and Kitting time per day, both in minutes.

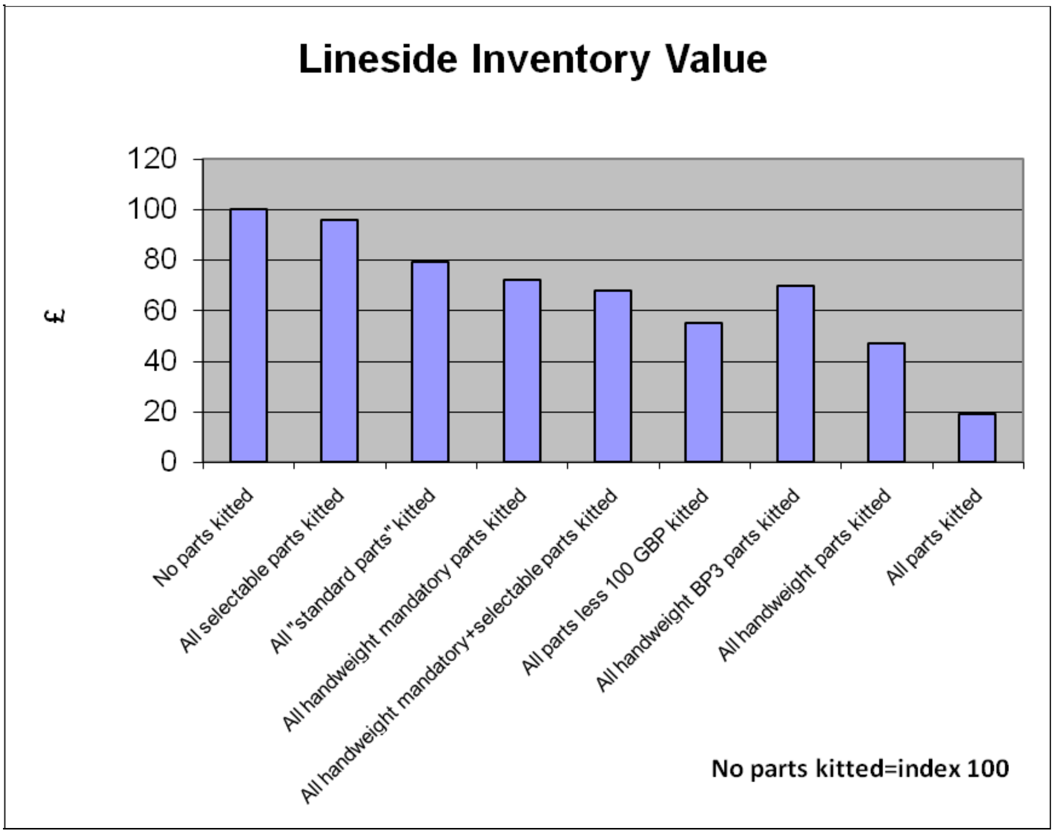

Figure 7.5, Lineside inventory value, in GBP (£).

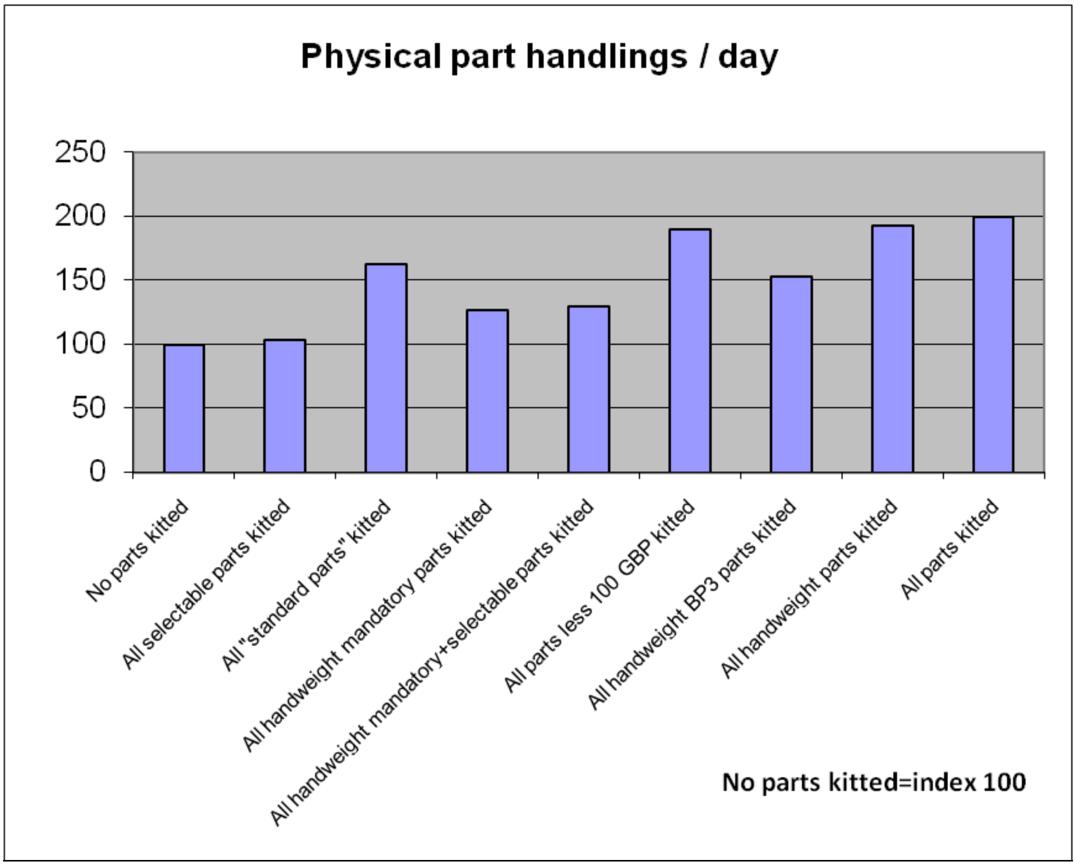

Figure 7.6, Number of physical part handlings per day.

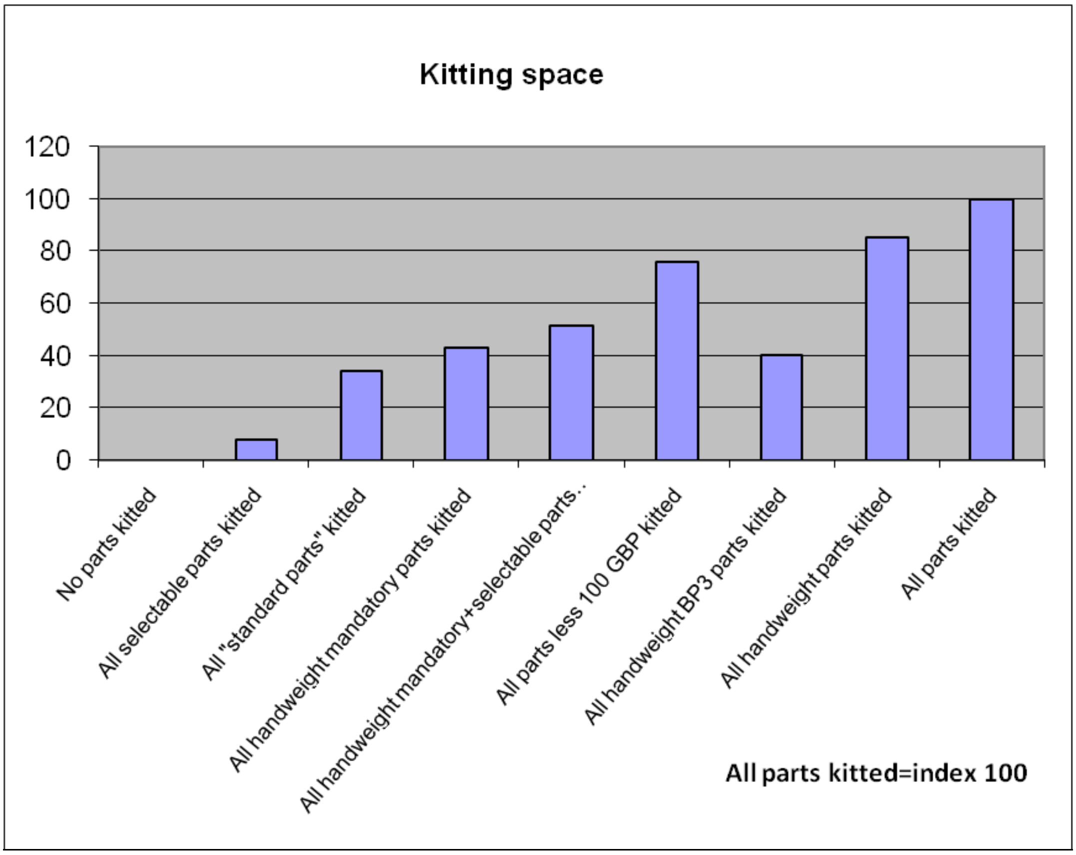

Figure 7.7, Required kitting space.

As shown in figure 7.1-7.7, kitting affects some of the criteria in a positive way (decreasing them), while it affects some in a negative way (increasing them).

Lineside inventory space (Figure 7.3), lineside inventory value (Figure 7.5) and operator walking time (Figure 7.4) are all decreasing with a higher degree of kitting, which act in accordance to benefits of kitting number 1,2 and 8 in the theory chapter (paragraph 3.3.1).

Physical part handling (Figure 7.6), kitting time (Figure 7.4) and kitting space (Figure 7.7) all increases with a higher degree of kitting, which act in accordance to limitations of kitting number 1 and 2 in the theory chapter (paragraph 3.3.2).

Storage replenishments (Figure 7.2) are not affected by the degree of kitting, this is because kitting does not affect the number of parts that is needed for production.

Lineside replenishments (Figure 7.1) increase with a low degree of kitting, but decreases with a high degree of kitting. This behaviour occurs since kits with very few parts creates a lot of transportations lineside in replenishing the kits, but if there are many parts in one kit you do not have to replenish as often per part. In theory it is explained that kitting reduces material delivery to the workstations (benefit of kitting number 5, paragraph 3.3.1), however the model shows that this is only true when having a relatively high number of parts per kit.

When adding the operator walking time and the kitting time, the sum shows a small increase in total time when kitting (Figure 7.4). However the authors believe the accuracy in the assumptions of kitting time (appendix D) is not high enough to prove a small increase like this.

In conclusion; the results of the model coincides with the theories explained earlier, kitting moves away waste from the assembly line, but brings more work to the stores. One can also see from the results that in some criteria there are greater benefits with kitting than others, for example there is a potential of reducing lineside inventory value with more than 80%.
To be able to determine which scenario is the best for CAT, a decision making tool has been used, this is further explained in the next paragraph.

7.2 Results of the AHP

The results in the previous paragraph shows there are both positive and negative effects of kitting. In order to summarise and make a conclusion over which scenarios that are most beneficial one has to weight the criteria regarding their importance. For instance, what is most important for the company, to reduce the operators' walking time or to lower the value held at the stores lineside?

This weighting was performed with an AHP using pairwise comparisons. The AHP method was chosen because it is commonly used in the industry, and according to several sources of theory also very suitable for this type of multi criteria decision-making problems. AHP is also a decision making tool used by CAT according to their Six Sigma principles.

A meeting was held with three CAT-employees where they were asked to complete a number of pairwise comparisons. The group was composed upon recommendation from the mentors and consisted of two persons from the logistics department; the logistics manager and a logistics planning supervisor and one from the operations department; a Advance planning manager.

The participants were first introduced to the case and how an AHP is performed. Thereafter each comparison was discussed to reach consensus and hence produce a mutual answer. The process was performed as described in the methodology chapter with a graded ranking from 1 (equal) to 9 (extreme).

The group was asked to consider the whole factory when answering the pairwise comparisons. The reason for this was to be able to obtain general results for the whole factory and not just the engine subassembly.

After inserting the pairwise comparisons into a matrix and running them in an AHP model, shown in appendix E, built in MS Excel the weights of the criteria comes out as shown in table 7-1 below.

Criterion	Normalised weight
Operator walking time	0.3312
Physical part handling	0.2361
Lineside storage space	0.1853
Lineside replenishments	0.0843
Required kitting space	0.0593
Lineside inventory value	0.0567
Kitting time	0.0471

Table 7-1, Weights obtained from the AHP.

The outcome of the model are to be interpreted as that “Operator walking time” is by far the most important criterion followed by “Physical part handling” and “Lineside storage space”. These three criteria are significantly the most important. On the other end of the rank “kitting time” is considered least important.

To be able to compare criteria that are measured in totally different units, e.g. £ and m^2, they first have to be normalised. That is, when comparing two criterions against each other you compare an increase or decrease. The normalised criteria are thereafter multiplied with the weights obtained from the pairwise comparisons giving the final weighted results for each scenario, shown in table 7-2 below.

Weighted score	Scenario	Number of parts kitted
0.06417227	All parts kitted	73
0.07784547	All hand weight parts kitted	63
0.08238924	All parts less £100 kitted	60
0.11055818	All "standard parts" kitted	28
0.11343336	All hand weight BP3 parts kitted	32
0.1223072	All hand weight mandatory+selectable parts	35
0.1267006	All hand weight mandatory parts kitted	28
0.15062652	All selectable parts kitted	7
0.15196715	No parts kitted	0

Table 7-2, Weighted results of the model.

In figure 7.8 below, the relation between weighted score and number of parts kitted are shown for each scenario. In general the weighted score decreases with number of parts kitted, i.e. the more parts kitted the better result. However this is not entirely true as one can see in area A of the chart; where an increase in number of parts kitted does not mean a decrease in the weighted score. Hence one cannot make the assumption that no matter what; it is always better to kit more parts, the nature of the parts has to be considered as well. In this case it has to do with the fact that although kitting fewer parts, the scenario “all standard parts kitted” creates a bigger decrease in operator walking time, the highest ranked criterion. This is the case since a standard part per definition has 100% usage, and when decreasing the walking time, even if it’s not much, creates a significant decrease on a daily basis.

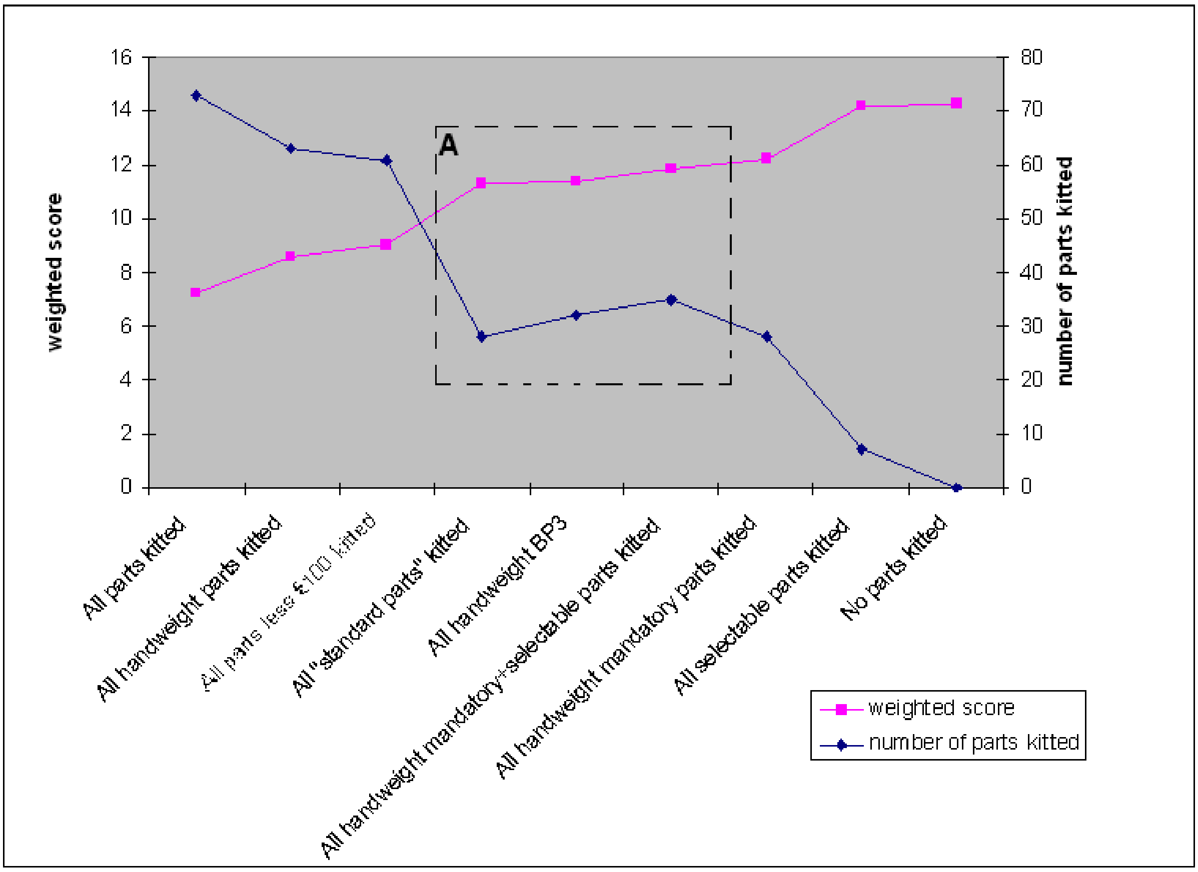

Figure 7.8, Weighted score vs. number of parts kitted.

The three scenarios with the best weighted score are namely: All parts kitted, All hand weight parts kitted and All parts with a value less than £100 kitted. These three scenarios will be further analysed with a more qualitative approach.

The model is just to be seen as a supportive tool to help making decisions on kitting. The scenarios always have to be examined in a qualitative way investigating the intangible aspects and tangible aspects that are not included in the model.

7.2.1 Three scenarios – Qualitative analysis

When choosing different scenarios to examine it is obvious that the extremities, in this case: All or No parts kitted are of interest. The scenario **“All parts kitted”** comes out as the best of them all with a weighted result of 0.063. This scenario saves the most “operator walking time”, the overall highest prioritised criterion and keeps the downsides of kitting, mainly “physical part handling” and “kitting time”, low enough. However there is at least one identified downside with this scenario that is not taken to account in the kitting model, namely the amount of heavy and/or bulky parts that have to be kitted.

The next best scenario **“all hand weight parts kitted”** was initially investigated because of the above mentioned reason, i.e., kitting parts that cannot be handled manually but have to be managed with lifting aids such as overhead cranes makes the kitting process less efficient. To kit a part often means to handle the part one more time. If this extra handling action is too time-consuming and thus expensive, the part might not be beneficial or feasible to kit. This is also seen in theory where for example Ding (1992) claims that there are kittable parts and nonkittable parts due to size restriction: Nonkittable parts should be pulled separately when needed.

When investigating how the heavy parts at the engine subassembly today are handled the writers noticed that even moving them a very short distance to change stillages is very time-consuming.

According to the writers, in this case the benefits of kitting all parts and use one system of materials feeding for all parts does not weigh up the above-mentioned downsides.
In this case it means that 10 part numbers, because of its weight, would not be included in the kitting process, namely the gearboxes, engines and hydraulic pumps. These 10 part numbers could instead of being delivered in the kits, for instance, be delivered to the line in sequenced slot number order and thereafter be connected to corresponding kit. Delivering these parts sequentially would not mean implementing a new type of materials feeding for CAT, in fact this already is the case for parts in FP1 and FP2 e.g. frames and booms.

The third best scenario in the model is **“All parts less than £100”.** In this particular case, at the engine subassembly, hand weight parts and parts with a value less than £100 happens to coincide at a very high degree. Only three part numbers differ, namely two types of torque converters and an AC compressor. One can therefore say that what is written above concerning “all hand weight parts kitted” also applies for this scenario.

Because of above mentioned, and for this case valid, reasons the scenario “all hand weight parts kitted” was chosen to be further investigated.

In the model it is assumed that one travelling kit can be used for all the five workstations in the engine subassembly. After getting the results of the model it was therefore of interest to investigate if the parts actually fit on a kit of a relatively decent size. This was done by collecting all hand weight parts that goes into a typical powertrain, in this case 40 different parts. The parts were laid out on the floor to get an overview and to be able to measure the area they occupy, as shown in figure 7.9. Except for the box containing a muffler the area the parts occupied was measured to be 2.4 m^2.

Figure 7.9, Gathered parts representing a kit.

To be able to conclude whether all these parts could fit into a movable kit-container and to illustrate how a future kit could look like an existing two-sided tool-board was examined and measured. In figure 7.10 below one side of the tool-board is shown. Each side measures 1,4 m^2 which leads to the conclusion that it is realistic and possible to kit all hand weight parts into one travelling kit container.

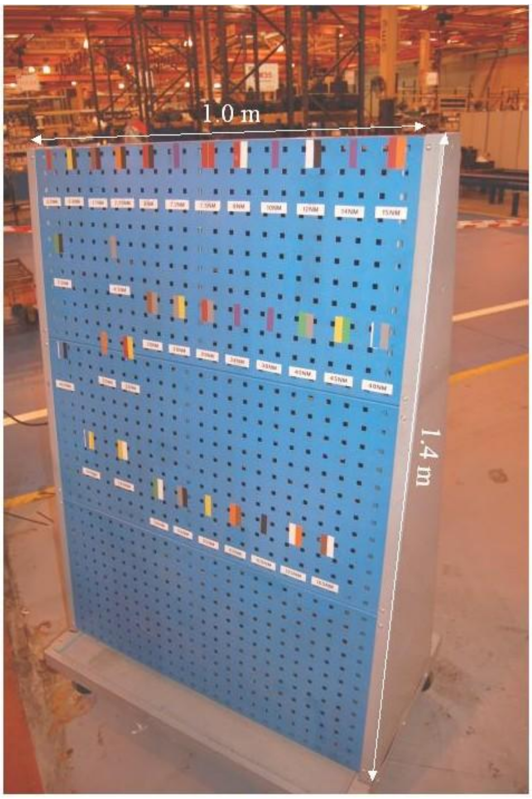

Figure 7.10, Tool-board.

It is shown above that kitting all hand weight parts is the most feasible and beneficial option at the engine subassembly. Comparing this scenario with “No parts kitted”, i.e., lineside stocking, the following results are obtained:

- Lineside replenishments decrease by 20%.
- Stores replenishments are kept the same.
- Required lineside storage space decreases by 80%.
- Operator walking time per day decreases by 80%.
- Lineside inventory value decreases by 50%.
- Physical part handlings per day increases by 100%.
- Required kitting area increases by [1] m^2.
- Required kitting time increases by [1] minutes per day.

Shown below in figure 7.11 is a graph that illustrates this in relative numbers where the values for “no parts kitted” are set to index=100.

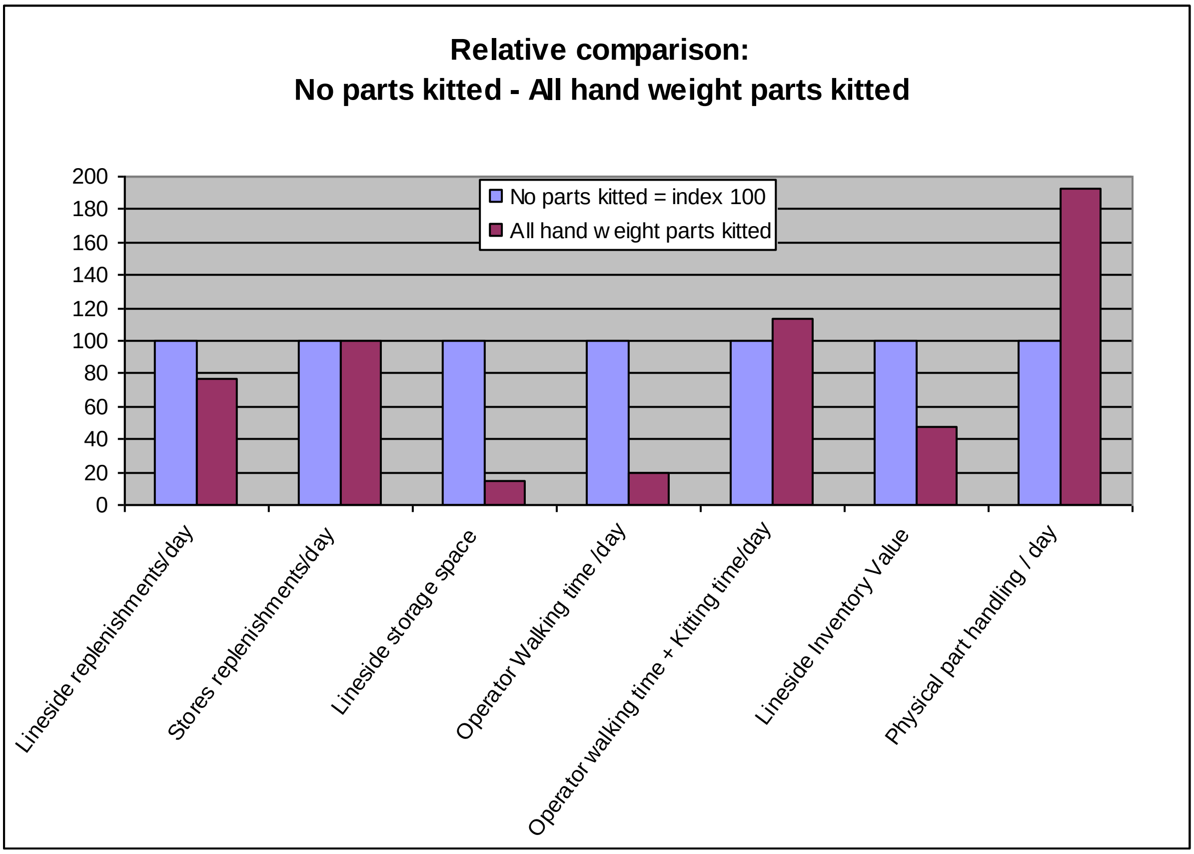

Figure 7.11, Comparison No parts kitted – All hand weight parts kitted.

To sum up, the result of the model combined with a deeper look on the scenarios and an empirical test leads the authors to choose all hand weight parts kitted as the best scenario. This scenario combines the positive aspects of kitting with a relatively low required effort to assemble the kits.

[1] The figures are hidden due to secrecy reasons.

7.3 Intangible effects of kitting

In paragraph 7.1 "Results of the model", it is explained how the model coincides with theory. The model as such only shows quantifiable values; hence it only coincides with some of the kitting theories. However in the theory chapter there are other benefits and limitations of a more intangible nature explained. These theories are not taken into account in the model; nevertheless they are not to be neglected. In this paragraph these theories will be discussed and put into CAT's current situation.

Benefit number 3,7 and 8 (paragraph 3.3.1) explains benefits of kitting as increasing flexibility, quality and ease of education. These benefits occur due to the fact that when one brings in kits with parts that fit on a specific end product you reduce the possibilities of errors in assembly. Having wrong parts fitted to machines is one of the quality issues at CAT today, so according to theory this could be reduced or in best case eliminated by kitting. However to accomplish this, the accuracy in the kitting process must be very high, since operators will rely solely on the parts arriving in a kit being the right parts to fit on the machine. Whenever there are errors in the kit it might become very expensive, at best the assembly operator notices the error and can call for a new part. Worst case scenario is that the machine gets delivered to the customer with the wrong part fitted, however it is more likely that it gets discovered in one of the testing processes. But having it discovered there might still lead to very time consuming rework on the end product. In conclusion these benefits can eliminate or reduce some of the issues CAT faces today, but with a poor kitting process the issues might grow even bigger. If implementing a kitting process it is of greatest importance that the accuracy in the kits is high.

Limitation number 5 (paragraph 3.3.2) explains the problem with defective parts in kits. However benefit number 7 (paragraph 3.3.1) explains that kitting provides an opportunity to have quality checks earlier in the value chain. CAT has some issues with parts quality today, especially with painted parts. The theories above say that if it is possible to perform good quality checks when kitting, you do not get the problem of defective parts in the kit. But if the quality checks when kitting are difficult to perform you might get very time consuming problems since the kits need to be reassembled whenever there is a defective part in the kit. One of the problems with the quality checks is to educate the picking operators in what a quality defect is on a certain part. Since the picking operator does not assemble the part he might not have the same knowledge about the part requirements as an assembly operator who can see what function the part actually has. One way to solve this problem could be to not kit certain part numbers that traditionally has had quality issues. By doing this the assembly operator performs the quality checks on these parts and if defective parts occur he can pick up a new from the kanban bin lineside. The problem described above becomes even more significant if there are certain parts that often get quality defects during or because of the assembly process. Since these parts would pass a quality check when making the kits, but fail when being assembled, they should not be kitted. Instead these parts should be stored lineside in the same way they are stored today.

The issue CAT is facing with part shortages from suppliers might be a problem if implementing a kitting process. This is explained in theory in limitation number 4 and 7 (paragraph 3.3.2), saying that part shortages in kits lead to double handling of parts. However kitting might be a way for CAT to highlight part shortages before the parts are needed on the assembly line. How long before they can highlight the problems depends on the size of the kit buffer they have. For example if there is a kit buffer of one days production the part shortage will be highlighted at least one day before the part needs to be assembled on the end product.

But the bigger kit buffer the more inventory value is tied up, which might take away one of the greatest benefits of kitting; reducing lineside inventory value. In conclusion it is of greatest importance that CAT tries to solve their part shortage issues, since it is a big problem today and would be a big problem if implementing a kitting process.

Sometimes part shortages lineside occur at CAT even though parts are stored somewhere in the facility. This mostly happens due to poor inventory control, the MRP system and the material handlers do not know the exact amount of parts stored at different locations. Benefit number 2, 4 and 6 (paragraph 3.3.1) shows that kitting can increase inventory control, shop floor control and visibility. Kitting also presents an opportunity to increase the traceability of parts, since parts can be traced by the quantity they exist in a kit. Today CAT can’t trace individual parts in the system until they end up in an end product ready to be shipped. The problem this causes is that CAT only knows that they have a part container at a certain location, but the MRP system can’t tell the number of parts in the container. So the number of parts in the container needs to be manually controlled continuously by the expeditor. Kitting presents an opportunity to trace parts one by one or by the quantity of a specific part number in a kit, if this is integrated into the MRP system the role of the expeditor might become unnecessary.

Problem balancing the line is an issue at CAT today. This is mostly caused by the variation in the end product; the working times can change a lot between different specifications at certain workstations. Benefit number 10 (paragraph 3.3.1) explains that kitting can help balancing the line in high variety production. The reason for this is the opportunity to remove setup time (search time) and walk time at the workstations. At CAT kitting might help balancing the line to a certain extent, but today a lot of the differences in work time, caused by variation, come from the actual assembly. Therefore kitting would help CAT balancing the lines better, but it would not eliminate the problem.

The information flow in a kitting process is of great importance. Limitation number 3 (paragraph 3.3.2) claims that kitting demands more planning than if storing parts lineside. By planning it is meant that a kitting process demands to know the sequence of production at the assembly line before making the kits whereas in lineside storing you just need to replenish all parts according to the kanban system. Since most material planning today goes through the MRP system it is also recommendable that the material planning for kitting is integrated to the MRP system. At CAT it might be difficult to integrate these two since the MRP system is working on a part number level and kits would demand another level; a kit level. At this kit level one wants to know exactly what part numbers goes into a specific kit, and to be able to trace this kit through the value chain. A kitting process will also need some kind of intelligent system to inform the picking operator what parts goes into a specific kit. To form solutions in how to trace kits, inform pickers and plan the making of the kits are some of the most difficult and possibly expensive tasks when implementing a kitting process. It might even lead to total restructure of the existing MRP system; however solutions with external systems are also possible.

CAT is using standardised work throughout the factory. It means that all operations are standardised and described in a standardised work sheet. The operators are supposed to always follow it with no exceptions. When using a kitting process, for those part kitted no more parts than needed for each operation is available to the operator. This would eliminate the problem, mentioned before, with the shop floor workers not following standardised work and buffering excess inventory.

If deciding to implement a kitting process there is a possibility to design the stores in the kitting area to store more types of packages, and hence decrease the need for decanting. The greater flexibility of the stores' design in the case of kitting is mainly because of the fact that there are more constraints on lineside stores regarding space. If using a kitting process, one has the opportunity to reduce the need of decanting material on the cost of a bigger storage area. However, this isn't taken into account in the model when calculating the "kitting space". If choosing to design the kitting area to store more types of packages some of the kitting time calculated in the model might just be work moved from the decanting area.

In conclusion one can say that kitting can present many intangible benefits for CAT, however most of these are dependent on a carefully planned kitting process. In the next paragraph theory of designing a kitting process compared with the situation at CAT will be discussed.

7.4 Designing the kitting process

According to theory, decisions regarding a kitting process on a high level involve work organisation and geographical location (paragraph 3.3.3). Theory describes three main ways of doing this: central picking store, decentralised picking areas (satellites) and third party kitting. The latter will not be considered in this study. At CAT today space close to assembly lines in the factory is a critical limitation, hence decentralised picking areas will be difficult to implement, since one of its drawbacks is space consumption. Therefore kitting in a central picking store would be more suitable. Having a central picking store also provides the opportunity to integrate the kitting area with the stores, meaning CAT would only have one storage area where they store parts in big quantities. This would increase the control of inventory significantly since CAT only need to know how many parts they store in one physical place. Compared to the system used today where they need to control inventory levels at stores and POU kitting would only demand inventory control in the stores. Additionally kitting provides an opportunity to decrease the total amount of inventory in the factory. To decrease the total amount of inventory the central stores need to store the same amount of parts with a kitting process as they store today, but the kit buffer needs to be smaller than the lineside stores are today. This is explained in figure 7.12.

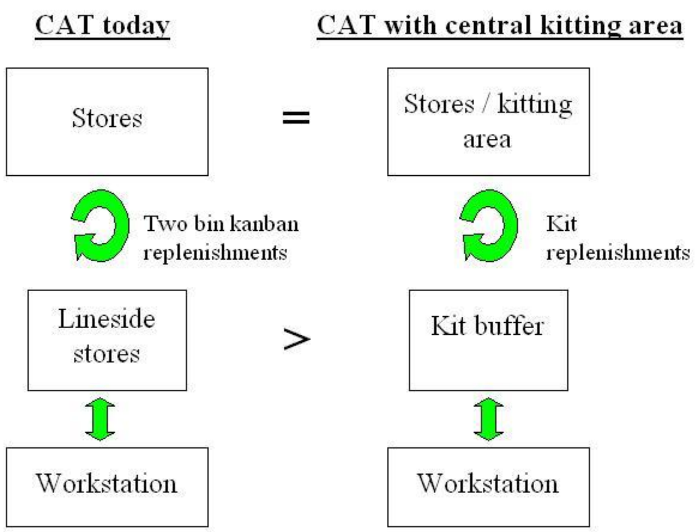

Figure 7.12, Effects on inventory if implementing a kitting area.

When it comes to what parts to put in a kit the answer is explained earlier in the results of the model (paragraph 7.2.1). But as explained in theory (paragraph 3.3.4) there are two types of kits: travelling kits and stationary kits. A benefit of a travelling kit is that it reduces the number of lineside replenishments compared to stationary kits. A limitation with travelling kits is that it possibly contains a lot of parts, which makes it difficult to assemble it according to takt time. Stationary kits on the other hand might not contain that many parts so it is easier to assemble it according to takt time, but it demands more lineside replenishments. From the result of the AHP (paragraph 7.2) it is shown that CAT value the number lineside replenishments higher than kitting time, hence travelling kits is more suitable for CAT at this moment. There are however limitations in how big a travelling kit can be. For example having a travelling kit for all parts at the BHL mainline would be almost impossible since it would be too big and unmovable. Accordingly the limit of how big a kit can be should be decided by the size and weight of it, it has to be able to be transported lineside and to move along with the end product along the assembly line. This might lead to a workstation with many ingoing parts ends up with a stationary kit, but other workstations can share a travelling kit. At an assembly line it might for example end up in 6 travelling kits serving 27 workstations, this example is shown in figure 7.13 combined with a central kitting area.

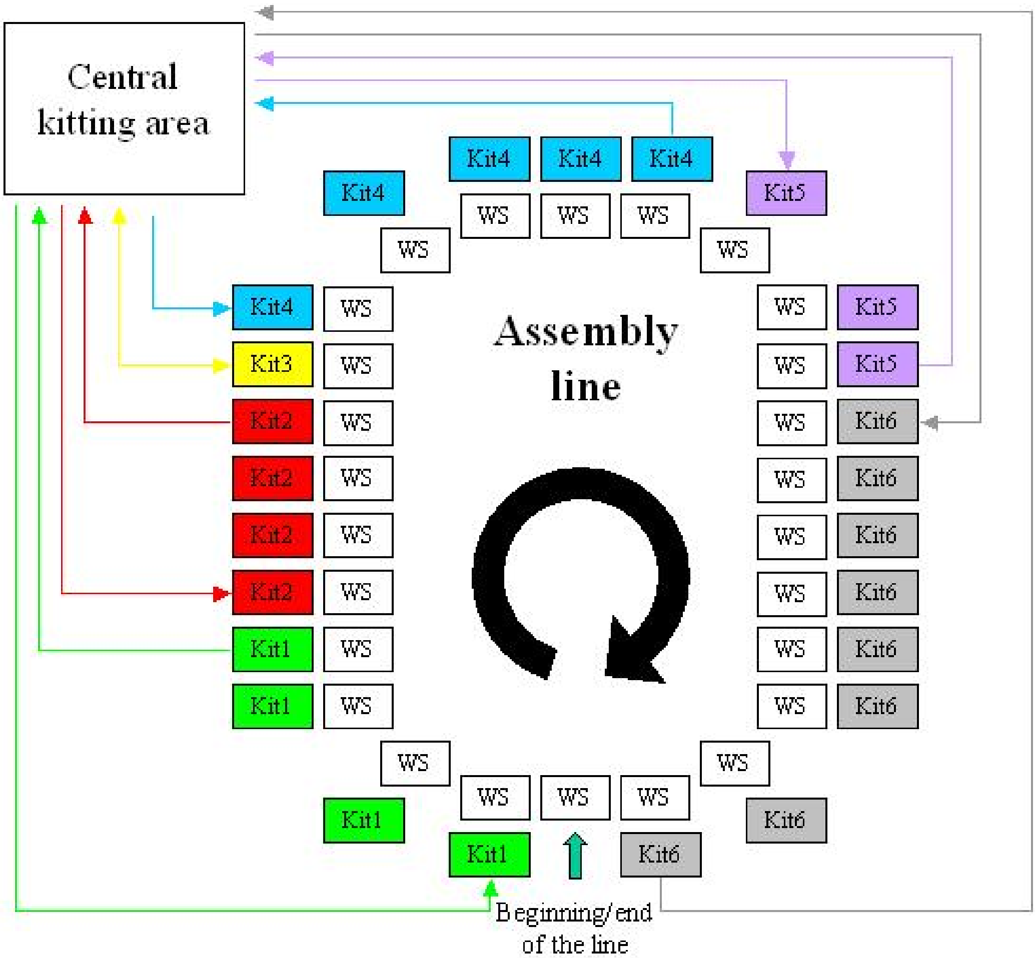

Figure 7.13, Example of a kit flow.

According to theory (paragraph 3.3.5), who physically is making the kits can be divided into: assembler or picker. At CAT this would translate to operator or material handler, belonging to operations or logistics departments respectively. Since CAT is striving to improve the capacity of its assembly lines, having the assembler making his own kits can be excluded. Having designated pickers is the solution for CAT, whether these organisationally belong to the operations or logistics department can be discussed. Having the pickers belong to the logistics department makes sense since that would create a clear line between logistics and operations; meaning parts belong to logistics until the kits are delivered lineside, from then they belong to operations. If the pickers belong to operations, parts would belong to logistics whilst in the stores, but when being picked out to fit into a kit parts belong to operations, when the kits get delivered lineside by material handlers parts once again belong to logistics. When delivered lineside parts become operations responsibility again. So if having the pickers under the logistics department the belonging of parts is much clearer, also it provides the logistics department with a clear definition of their end product: a ready to assemble kit delivered to their “internal customer” lineside.

When designing the kit area, theory explains a number of different methods (paragraph 3.3.6). It seems these methods are suitable for different situations. If kitting is not performed in big scale at the factory it seems that kitting in one big area is the best way to do it, since it demands relatively low labour. If kitting is made in bigger scale and you need several pickers and have a high variety of different kits, zone kitting is more efficient, especially to keep takt time. For CAT this means that if implementing kitting in small scale one design might be the best, if changing and kitting in bigger scale they might have to change the design of the kitting process as well. The same applies for how to design the picking information. In theory a number of different ways to design picking information is described (paragraph 3.3.6). If one wants high accuracy and speed the systems are more expensive in terms of investment cost. Meaning if kitting is performed in a small scale at the factory CAT might not want to make a big investment in pick-to-light systems. However if CAT implements kitting in a big scale some kind of investment in an electronic picking system is suitable. Important if investing in some kind of electronic picking system is that this system needs to be compatible with the existing MRP system.

The design of the kit containers will be of great importance if implementing a kitting process. Theory (paragraph 3.3.6) says that the design has to be suitable both for picking and assembly. Meaning to design the kit containers so the parts appear in the order they are to be assembled, but at the same time designing the kit so the picker knows where each part goes. At CAT a lot of parts have almost the same appearance, for example there might be five different hoses looking almost identical going into one workstation. Due to this identical-part-appearance it is of greatest importance that the kits are designed so the assembly operator knows where each part goes. This can be done by for example labelling each space on the kit container or using different colour codes.

7.5 Implementing the kitting process

As written in earlier paragraphs the results show that a kitting process at CAT provides beneficial opportunities. Results are also given on how to design the kitting process and what parts to kit. However there are no results on how to operationally implement a kitting process. In this paragraph suggestions of how to implement a kitting process at the factory site will be presented.

Implementing a sustainable kitting process takes a great effort. If done in big scale both substantial financial effort and organisational effort is needed. This study is so far very theoretic; not much testing has been done. So to verify the results of this study the suggestion for CAT is to implement a kitting “pilot”. Meaning kitting in relatively small scale for a specific time and then evaluate the results.

The area of the engine subassembly has been the area of investigation in this case study. Interesting with this area is that decision has been made to move the engine subassembly from its current position to be in connection with the mainline. The job of moving this area would primarily consist of moving the lineside stores and designing how they should be placed. As explained earlier a layout proposal has been made on the new engine subassembly area. Moving the actual assembly line would not demand the work of moving the entire lineside inventory. Since the existing trolleys are movable and the tools used are mainly pneumatic screwdrivers and manual tools; moving these demands relatively small efforts.

Since the engine subassembly is inevitably moving our suggestion is to make the kitting pilot on this area. Meaning CAT would move the assembly line, the BP4 storage racks, racks for storing non hand weight parts and the assembly tools. This would enable the assembly line to produce engines as long as parts are supplied to them, i.e. in kits. The old area would when having these things moved act as the kitting area. Without making any big changes all the parts are already prepared to be stored there, and instead of having the assembly trolleys going down the line the kits would be going down the line. Another big benefit of having the pilot at the engine subassembly is that it is such a small line; so most of the assembly operators know how to operate all the workstations and are familiar with all the different parts. This fact makes it possible to assign one of the existing assembly operators as picking operator, making the kits. Since this picking operator has the experience and knowledge of all the parts, the demand for advanced picking information decreases.

When it comes to the information received by the picking operator it could be the top-line numbers for each end product on which the kit is made for. In the MRP system the top line numbers belonging to each part number can easily be looked up. When knowing this, each part number’s location in the kitting area could be labelled with its corresponding top line numbers. The operator then compares the top line numbers of the kit he is making with numbers on the shelf, if it matches it is a part to pick for that specific kit. Obviously this procedure only needs to be done for the mandatory and selectable parts, the standard parts go into every kit anyway. This method very much resembles the third way of designing the information system, described in theory in paragraph 3.3.6.

The actual kit containers could be designed like the tool-boards already existing in the factory (figure 6.10). Places for each part, with hooks or shelves fixing them to the board, should be designated. These designated places needs to be labelled with part numbers and preferably some kind of colour code. Since the tool boards are on wheels they can be delivered lineside either by hand or by trailer trains. Further these tool boards are standardised products, and can be flexible in terms of where to put the parts, the investment for these is lower than having a customised kit container designed.

Figure 7.14 and 7.15 shows the principal differences from the current situation to having the pilot implemented.

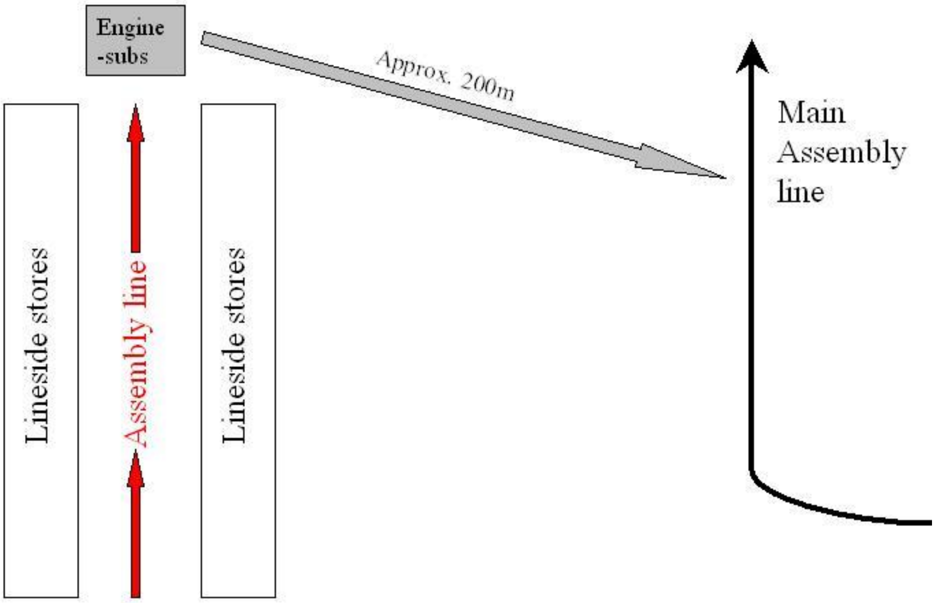

Figure 7.14, Current situation at the engine subassembly line.

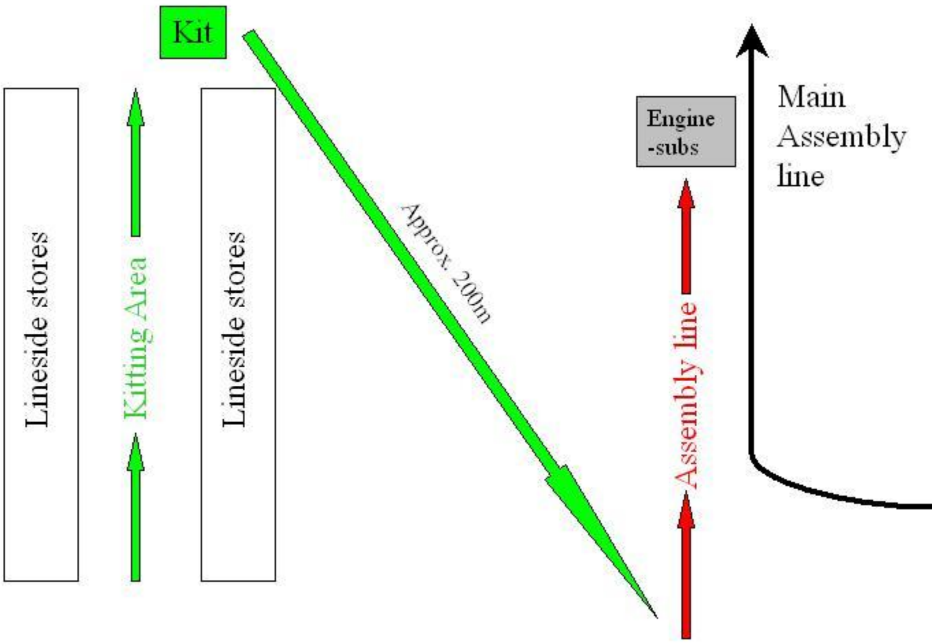

Figure 7.15, Changes made to the current situation when implementing the pilot.

When implementing this pilot a specific time frame for the pilot needs to be decided. The suggestion for CAT is to have this time frame between one and two months of running time. This would mean making between approximately 600 and 1200 kits. This time is suggested because it is believed that the process has time to stabilise during such a time period, if the pilot is run for a week there is hardly any time to learn the process.

Once the pilot has been running for the time frame set up for it, it is time for evaluation. The following areas of interest should be evaluated:

- Kitting time: Analyse time studies in making the kits, how well does the model coincide with reality?
- Information flow: How did the information flow? Did everyone in the kitting process get accurate information on time? Is there a need to improve the information flow?
- Assembly times: How did the kitting process affect the assembly? Did walk and search times decrease? Did the kitting process increase the capacity at the engine subassembly? Does the line need balancing due to the kitting process?
- Kit accuracy: What is the frequency of having missing, wrong or defective parts in the kits?
- Continuous improvements: What improvements can be made to the kitting process?

Having these areas evaluated should help in the decision making in fully implementing a kitting process or not.

The suggestions in this paragraph are a way for CAT to test a new kitting process, without large investments. The suggestions are specific for CAT and can’t be assumed to be general for any implementation of a kitting process. How to implement a kitting process is, to the writers’ knowledge, not described in theory. So the suggestions in this paragraph are based on the knowledge the writers has gained during the work of making this thesis. However this is a low financial risk suggestion, which can provide CAT with the relevant answers they need to continue their work with a kitting process.

8 Conclusions and Discussion

In this chapter conclusions are made from the results in the previous chapter. The discussion aims to discuss and criticise the methodology and results, it also gives the authors a chance to present their own opinions that has been formed while making this thesis. Finally suggestions of further research are presented.

8.1 Conclusions

The results presented in the previous chapter shows that kitting can be beneficial for CAT. The result of the model coincides with theory, which is mainly based upon research performed on parallelised assembly systems and small parts assembly. The main factor why kitting is suitable in line production and not just parallelised assembly systems is due to the high variation in end products. This variation demands a lot of lineside space to store all part numbers, this space creates walking and searching times for operators. Decreasing walking times and lineside space are two of the biggest motives to kit. Therefore kitting is beneficial in high variation assembly lines. It is also shown that the quantifiable results from the model might not be the most important incitements to implement a kitting process, but the intangible effects might be just as important. Kitting provides opportunities to increase shop floor control, increase end product quality and ease the education of new personnel.

When determining what parts should be kitted the results show that all parts that can be carried by hand is potentially suitable for kitting. Parts that can’t be carried by hand is not suitable for kitting since it demands more time and additional lifting equipment to handle them one extra time, which a kitting process in most cases demand. The factors that determine if parts can be carried by hand are size and weight. Therefore size and weight of the parts are what determines if they are suitable for kitting. The results also show that the suitability of parts getting kitted is not dependent on their BP, FP or value. However in the specific area of investigation there seems to be a correlation between high value and high weight of the parts, but ultimately it is the high weight of the parts that determine that it is not suitable for kitting.

The results also show that one should be very cautious in kitting parts with quality issues. If a part arriving in a kit has a quality defect and has to be scrapped; the process of getting a new part to the assembly line takes more effort than if there would be lineside stores of this particular part. However these quality defects should be highlighted during quality checks when making the kits. Parts that might get quality defects during or because of assembly actions are extra sensitive, hence these parts should not be kitted.

The results show that if implementing a kitting process; CAT should use the following methods:

- Kitting in a central kitting area, preferably this area is integrated with the stores creating one stock-keeping unit.
- As far as possible using travelling kits instead of stationary kits, the limitation is the size and weight of the kit; kits need to be movable.
- When making the kits CAT should use specific picking operators, these picking operators should belong to the logistics department.

- When designing how to make the kits CAT needs to consider how big their kitting process is going to be. If implementing a big kitting system (lots of parts kitted in several different kits on several of the assembly lines) CAT should consider investing in new labour and technology. If just implementing kitting in the most critical areas, investments can be lower and systems simpler.
- CAT needs to consider how to integrate the information flow in a kitting process with the existing information flow at the factory site.
- When designing the kit containers it is important that the assembly operator and the picking operator know what part goes where.

To implement a kitting process, the suggestion for CAT is to start a kitting pilot at the engine subassembly. This suggestion comes from the fact that the engine subassembly area is inevitably moving, and therefore the investment of testing kitting on this area is relatively low. The suggestion to make a pilot before implementing in full scale is a way to verify the results of this study and to see if CAT organisationally has the capability of implementing a kitting process.

8.2 Discussion

When researching the area of kitting to manufacturing many interesting aspects have been found both through theory and results. When talking about kitting on a high level one might say that it is just about moving away necessary non value adding processes from the assembly line to somewhere else. If these necessary non value adding processes can be made more efficiently somewhere else you have gained a benefit from kitting. In less formal words this means that if you can search, find and pick parts more efficient in a kitting area than on the assembly lines you should do that. However this research and some of the theories show that this might not be the most important benefit of kitting, but the opportunities kitting provide if performed in the right way is where it gets really interesting. Kitting provides the opportunity to increase product quality, ease inventory control and reduce total inventory. The word to stress in the former sentence is: **opportunity**. Kitting does not automatically bring the benefits described in this research, it provides an opportunity to bring them, but without an organisational effort kitting might just lead to the opposite. Kitting demands a great deal from an organisation, especially when it comes to information. Without accurate information, accurate kits can’t be done. Without accurate kits assembly can’t be done without end product quality defects. With end product quality defects you end up with dissatisfied customers and in the long run without any business. Whether CAT has the ability to put in the organisational effort kitting demands is difficult for us to decide, hence our implementation suggestion is to put up a pilot in small scale.

Taking the step to implement a kitting process means putting effort into it, continuous improvements might become more important than ever. Expecting to design a perfect kitting process when implementing it for the first time is a utopia. Implementing a kitting process that works and then perform improvements where it is needed should be the way to do it, all according to existing lean and six sigma theories, all processes can be improved.

In this research we have tried to investigate if kitting goes along with Lean theories. Our results show that kitting should coincide with Lean, however opponents might say that kitting just moves the problem from one place to another. Even if so, kitting removes problems from a common bottleneck, the assembly line, to less crucial parts of the production.

When it has been moved one have the opportunity to concentrate in making the kitting process as efficient as possible, since this becomes the core task of the kitting area. According to the authors this goes along with Lean theories.

With the methods used in this thesis it is shown that kitting presents both benefits and drawbacks. Whether kitting is beneficial for an organisation or not is therefore dependent on what needs the specific organisation has. In CAT's case the AHP clearly shows that CAT is in need of reducing lineside space and operator walking time, which makes kitting as a method of materials feeding very suitable. However another company or organisation might value physical part handling and kitting time higher, which would lead to a totally different result than the one this report has presented on CAT. In other words one can say that kitting is beneficial for organisations that consider operator walking time, lineside space and lineside inventory value as very important criteria. Hence kitting is not suitable for all organisations within similar industries. Using an AHP or some other multi criteria decision-making tool is therefore important for any company thinking about implementing a kitting process.

The mathematical model built in this study is by no means perfect; one can question some of the assumptions made and the results given. Nevertheless it provides a descriptive picture of the possible changes a kitting process might give, both benefits and drawbacks. By making the model the pros and cons of kitting has been shown in quantitative values, but as can be read in this report our final results and conclusions are not solely based on the results of the model, a qualitative analysis has been made as well. When starting this study there was a perception that the result of it would end up in monetary values, however during the work we realised that it would be far too much work within the time limitations given to put value on all different criteria. One can also question the possibility of comparing space (square metres) and time (minutes) in monetary values, since there are so many aspects involved in translating them to £ or $. Even if setting these values could be done in a good way, to set monetary values on the intangible effects of kitting would be even more difficult. Therefore our result is presented in a more qualitative approach; nevertheless it is our belief that CAT will benefit economically from a kitting process, if performed correctly.

The time limitations in this study have forced it to be a case study on one specific area of investigation. If given more time the first thing we would do with this time is to investigate other areas within CAT or other similar companies. The goal of researching other areas would be to verify the model and to verify the engine subassembly as a representative area for the rest of the factory.

8.3 Further research

Finally the authors make some recommendations for further research within the area in general and for CAT in particular.

8.3.1 Further research within the area in general

Since most of the literature found in the area of kitting to manufacturing is aimed at either production in parallelised assembly systems or production with small parts (mainly electronics) we think further investigations should be done in industries with larger parts. Especially since these industries by nature should have a space issue lineside, and as explained earlier one of the greatest advantages of kitting is reducing lineside storage space.

Testing the model built in this thesis in similar production environments would also be of interest to verify, criticise or finding needs of improvement of the model. Investigating existing kitting processes and compare it to the model would also be a way to do this.
Investigating industry best practise would also be of great interest since this research has not performed any benchmarking except for written sources.

8.3.2 Further research for CAT

For CAT it is of greatest interest to investigate third party kitting. Third party kitting would mean that CAT could entirely focus on their core competency, which is assembling. Third party kitting companies might also already have the necessary systems, equipment and experience to perform a kitting process for CAT with a relatively small investment.

CAT should also investigate the possibility of having their suppliers deliver parts in kits. In some cases one supplier is delivering different parts, could these parts be delivered in kits instead of the way it is delivered today? Could the painting process be done in kits? Today some parts are being painted in batches; these parts are then being decanted into kanban quantities in standard bins. Could these parts be divided by the assembly object they will be assembled to before painting and then get delivered lineside in kits? Since CAT is taking over the painting facility January 1, 2008, this would be a possibility to adjust the paint process to fit CAT better.

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Participants on the AHP meeting

Sarah Baynton	Logistics planning supervisor, Logistics department
Paul Fowkes	Advance planning manager, Operations department
Rob Sparks	Logistics manager, Logistics department

Appendix A

Product range at Caterpillar BCP-E, Leicester.

Backhoe Loaders

MODEL	NET POWER	OPERATING WEIGHT
422E	56 kW	7210 kg
422E	67 kW	7210 kg
428E	67 kW	7570 kg
428E	73 kW	7570 kg
432E	73 kW	7780 kg
434E	73 kW	8370 kg
442E	73 kW	7940 kg
444E	73 kW	8810 kg

Mini Hydraulic Excavators

MODEL	NET POWER	OPERATING WEIGHT
301.6C	13.5 kW	1730 kg
301.8C	13.5 kW	1790 kg
302.5C	18.6 kW	2870 kg
303.5C CR	29 kW	3575 kg
303C CR	29 kW	3575 kg
304C CR	31 kW	4635 kg
305C CR	35 kW	5035 kg
307C	41 kW	7210 kg
308C CR	41 kW	8040 kg

Compact Wheel Loaders

MODEL	NET POWER	OPERATING WEIGHT
904B	39 kW	4450 kg
906H	51 kW	5630 kg
907H	51 kW	5810 kg
908H	58 kW	6465 kg
914G	72 kW	7950 kg
IT14G	72 kW	8450 kg

Small Wheel Loaders

MODEL	NET POWER	OPERATING WEIGHT
924G	97 kW	11340 kg
924Gz	97 kW	10850 kg
928Gz	107 kW	12310 kg
930G	111 kW	13029 kg

Appendix B

Bozer's and McGinnis's Descriptive model

Bozer & McGinnis presents a descriptive model concerned with identifying the material trade-offs between kitting and line stocking. The model focuses on container handling, floor space requirements, and average Work-In-Process.

Nomenclature

s	denote the SKU number for a component, subassembly, or end product
p_s	denote the number of pieces of SKU s stored in a component container
m_s	denote the number of pieces of SKU s used in one unit of the end product
w	denote the workstation type
π_w	denote the number of parallel (i.e., identical) workstations of type w
a_w	denote the floor space required by workstation w (not including space required for staging component or kit containers)
D	denote the number of end products produced in an 8 h day
$\overline{W}$	denote the average WIP expressed as the average number of partially assembled products in the system
Φ_w	denote the set of SKU numbers used at workstation w
α_{sw}	denote the number of component containers of SKU s staged at each workstation of type w
F	denote the floor space required to stage a component container at a workstation
k	denote the kit type *k*
p_{sk}	denote the number of pieces of SKU s used in kit type *k*
d_k	denote the number of kits of type *k* needed to produce one unit of the end product
b_k	denote the batch size for kit type *k;* i.e., the (integer) number of type *k* kits assembled when a component container is retrieved
q_k	denote the (integer) number of kit con*tainers* per batch for kit type k
n_k	denote the number of kits per kit container for kit type k
S_k	denote the set of SKU numbers assigned to kit type *k*
Ω'_w	denote the set of all *stationary* kit types staged at workstation type w.
β'_{kw}	denote the number of stationary kit containers of type $k \in \Omega'_w$ staged at each workstation of type w
Ω''	denote the set of *traveling* kit types that travel along with the product
β''_k	denote the number of traveling kit containers of type $k \in \Omega''$ that travel along with the product,
f	denote the floor space required to stage a stationary kit container at a workstation
c_w	is the total number of component containers to be supplied to all the workstations of type w per 8 h day under line stocking
R	is the number of component containers that must be stored or retrieved per day to support production; *R* is expressed in number of "operations" per day where one operation is a container retrieval or container storage
V	is the number of kit or component containers per day that flow from the

storage/kit assembly area to all the workstations

A_w is the floor space required by all the workstations of type w (including the space required by component and kit containers)

A is the total floor space required by all the workstations (not including aisle space and other clearances)

h_w is the average WIP level at workstation w in number of component pieces

H is the average WIP level for all the workstations in number of component pieces

Definitions:

A "stock keeping unit" (i.e. SKU number) is used to designate any item that is stored and/or handled in the facility; the item can be a component, a subassembly, or an end product.

Assumptions;

(1) There is a *single* component container type and a *single* kit container type. It is also assumed that there is only one type of end product assembled. Of course, the model can be extended to multiple container types and multiple end products by adding the appropriate subscripts.

(2) With line stocking, each workstation that uses SKUs is supplied with a component container of SKUs. That is, workstations do not share component containers. (Although in some applications container sharing might be possible or desirable, in most assembly operations each workstation is supplied with its own component containers.)

(3) $p_s >> b_k p_{sk}$ for all *s* and *k.* That is, the number of pieces in a component container of SKU s is considerably larger than the number of pieces of SKU s pulled from the component container each time it is retrieved to assemble a batch of kit type *k.*

(4) The model only considers the flow of component (or *stationary* kit) containers from the storage (or kit assembly) area to the workstations. That is, it does not address the flow of the product itself (and the associated *traveling* kits, if any) since it is assumed that product flow is not affected by how the workstations are supplied by components.

(5) In computing V, empty component container return is not considered. If the empty component containers are not stackable, one can multiply our results by two to account for their return to the storage area. The same assumption applies to empty kit containers.

(6) WIP is divided into two categories: WIP due to component (or stationary kit) containers, and WIP due to partially assembled products. Although the average number of partially assembled products in the system is used, i.e., $\overline{W}$, to compute the WIP due to traveling kits, the focus is primarily on the former category of WIP because it is likely to vary dramatically between line stocking and kitting. Unless kitting has a significant impact on the mean or the distribution of the workstation cycle times, $\overline{W}$ will not vary considerably between line stocking and kitting.

(6) For line stocking it is assumed that a new component container is delivered only when the current one is near depleted. (This assumption is supported by the just-in-time principle.) It is also assumed that, once it is delivered to the shop floor, the contents of a component container are consumed uniformly over time. The same assumptions apply to stationary kit containers.

(7) The contents of a traveling kit container decrease uniformly over time as the corresponding product travels through the shop.

Based on the above assumptions, below expressions are derived to estimate container handling, floor space requirements, and average WIP under line stocking and kitting.

Component container storage and retrieval

The first expression presents the rate at which component containers must be stored and retrieved under line stocking. With line stocking, each component container must be retrieved from storage and dispatched to the appropriate workstation. Hence, the total number of component containers per day to be supplied to all the workstations of type *w*, that is, c_w, can be obtained from the following expression:

$$c_w = \sum_{s \in \Phi_w} (Dm_s) / p_s \qquad \textbf{(1)}$$

Note that, in Eq. (I), we show all the containers retrieved for all the workstations of a particular type; we do not indicate the containers retrieved for individual workstations since each workstation of the same type uses the same number of containers, by definition. In the long term, since each component container that is retrieved must be eventually replenished (i.e., stored), the number of component containers which must be stored or retrieved per day, that is, *R* is given by

$$R = 2\sum_{w} c_w \qquad \textbf{(2)}$$

operations /day for systems with line stocking. If kitting is used, the rate at which component containers are retrieved depends on several factors. Recall that $|S_k|$ denotes the number of SKU types assigned to kit type *k* and b_k , denotes the kit batch size (i.e., the number of kits assembled from a component container each time it is retrieved).

Hence, to assemble one kit of type *k*, we would need to retrieve $|S_k|$ component containers. However, we may assemble more than one kit (of the same type) once we retrieve the appropriate component container. Since we need d_k kits per end product, to assemble a total of b_k kits per container retrieval, we would need to retrieve a component container $(Dd_k)/b_k$ times per day. Note that this expression is also equal to the number of batches of kits assembled per day, by definition. (Of course, b_k, must be integer divisible by n_k since the number of kit containers assembled per batch, q_k, is an integer number.) Hence, with kitting, the rate at which component containers must be stored or retrieved, that is, *R* is given by

$$R = \left(2\sum_k \frac{Dd_k}{b_k} + |S_k| \right) + \sum_w c_w \qquad \textbf{(3)}$$

where the first term is multiplied by two since every component container which is retrieved while assembling a kit must, by definition, be stored back in the storage system after the required parts are pulled from the container.

The second term in Eq. (3) represents the rate at which the containers must be stored in the system as part of the replenishment cycle. Note that, due to the second term, Eq. (3) yields the approximate number of operations performed per day. In reality, following kit assembly, since an empty container will not be placed back in storage, some of the replenishment operations can be “interleaved” with the retrieval operations.

Component and kit container flow

In comparing line stocking with kitting, we are also concerned with the amount of container flow generated by the two alternatives.

(Recall that we will not address the product flow and the flow associated with traveling kits, if any.) With line stocking, all the component containers retrieved from the storage area are dispatched to the appropriate workstation.

Hence, the number of (component) containers per day that flow from the storage area to all the workstations, V, is given by the following expression:

$$V = \sum_w c_w \qquad \textbf{(4)}$$

where c_w is given by Eq. (1).

If kitting is used, the number of (stationary) kit containers per day that flow from the storage/kit assembly area to all the workstations is given by the following expression:

$$V = \sum_w \sum_{k \in \Omega'_w} \frac{Dd_k}{n_k} \qquad \textbf{(5)}$$

Recall that, in computing V, we do not consider empty component (or kit) container return

Shop floor space requirements

Consider first line stocking. Recall that each workstation of type w needs enough space to accommodate α_{sw} component containers for each type of SKU used. Thus,

$$A_w = \pi_w \left(a_w + F \sum_{s \in \Phi_w} \alpha_{sw} \right) \qquad \textbf{(6)}$$

$$A = \sum_{w} A_w \quad \textbf{(7)}$$

where *A*, is the total floor space required by all the workstations of type u' and A represents the total floor space required for the shop. The above floor space requirement does not include an aisle space allowance since it would not be likely to change between line stocking and kitting.

Consider next kitting. Since a workstation needs enough space to accommodate β'_{kw} containers of (stationary) kit type *k*, we have

$$A_w = \pi_w \left(a_w + f \sum_{k \in \Omega'_w} \beta'_{kw} \right) \quad \textbf{(8)}$$

The total floor space required by the workstations, A, is still given by Eq. (7). If a workstation uses only traveling kits, i.e., no (stationary) kits are staged at the workstation, then we will set $f = 0$ to obtain $A_w = \pi_w a_w$ for that particular workstation type.

Work in Process

The WIP due to component (or stationary kit) containers is mostly determined by the replenishment method used to supply the workstations. Given our just-in-time assumption for container deliveries, and a uniform consumption of components, with line stocking the average WIP at the workstations and the total average WIP in the system (measured in number of pieces) are given by

$$h_w = \pi_w \sum_{s \in \Phi_w} \frac{1}{2} \alpha_{sw} p_s \quad \textbf{(9)}$$

$$H = \sum_{w} h_w \quad \textbf{(10)}$$

If kitting is used, the average WIP due to *stationary* kits, measured in number of pieces, can be obtained from the following expressions:

$$h_w = \frac{1}{2} \pi_w \sum_{k \in \Omega'_w} \beta'_{kw} n_k \sum_{s \in S_k} p_{sk} \quad \textbf{(11)}$$

$$H = \sum_{w} h_w \quad \textbf{(12)}$$

Since traveling kits move along with the product, the WIP due to traveling kits is not straightforward to determine. That is, the number of traveling kits in the system is a function of the number of partially assembled products in the system. Furthermore, as the product moves through the assembly operations, more components in the corresponding traveling kit become part of the product. The following approach, however, is likely to yield a reasonable approximation of WIP due to traveling kits.

The number of pieces of SKU s in one kit container for kit type k is equal to $n_k p_{sk}$ and the total number of pieces in a kit container for kit type k is equal to $n_k \sum_{s \in S_k} p_{sk}$. Hence, as one unit of the product approaches the first workstation, the total number of pieces in the corresponding- traveling kits is equal to $\sum_{k \in \Omega''} \beta''_k n_k \sum_{s \in S_k} p_{sk}$

The average WIP in pieces, H, depends on how the components in a traveling kit are consumed as they travel through the shop. (It also depends on the delay encountered in traveling from one workstation to another; note that $\overline{W}$ captures this delay.)

Given our uniform consumption assumption, we have

$$H = \frac{1}{2}\overline{W}\left(\sum_{k \in \Omega''} \beta''_k n_k \sum_{s \in S_k} p_{sk}\right) \qquad \textbf{(13)}$$

Note that some traveling kits may be consumed before the others. This may violate our “uniform consumption” assumption. However, if all the traveling pieces are viewed collectively, and if the delay from one workstation to another is distributed uniformly across the system, it seems reasonable to assume that the total piece count decreases uniformly. Also note that, if most or all the traveling kits are consumed *before* the product reaches the last workstation, our approach will overestimate the average WIP due to traveling kits. However, one can adjust the value of $\overline{W}$ by determining the last workstation where the traveling kit was used. The average number of partially assembled products between the first workstation and this last workstation would be the appropriate value to use for $\overline{W}$.

Appendix C

Schematic overview of CAT BCP-E, Leicester

Schematic overview of CAT BCP-E, Leicester

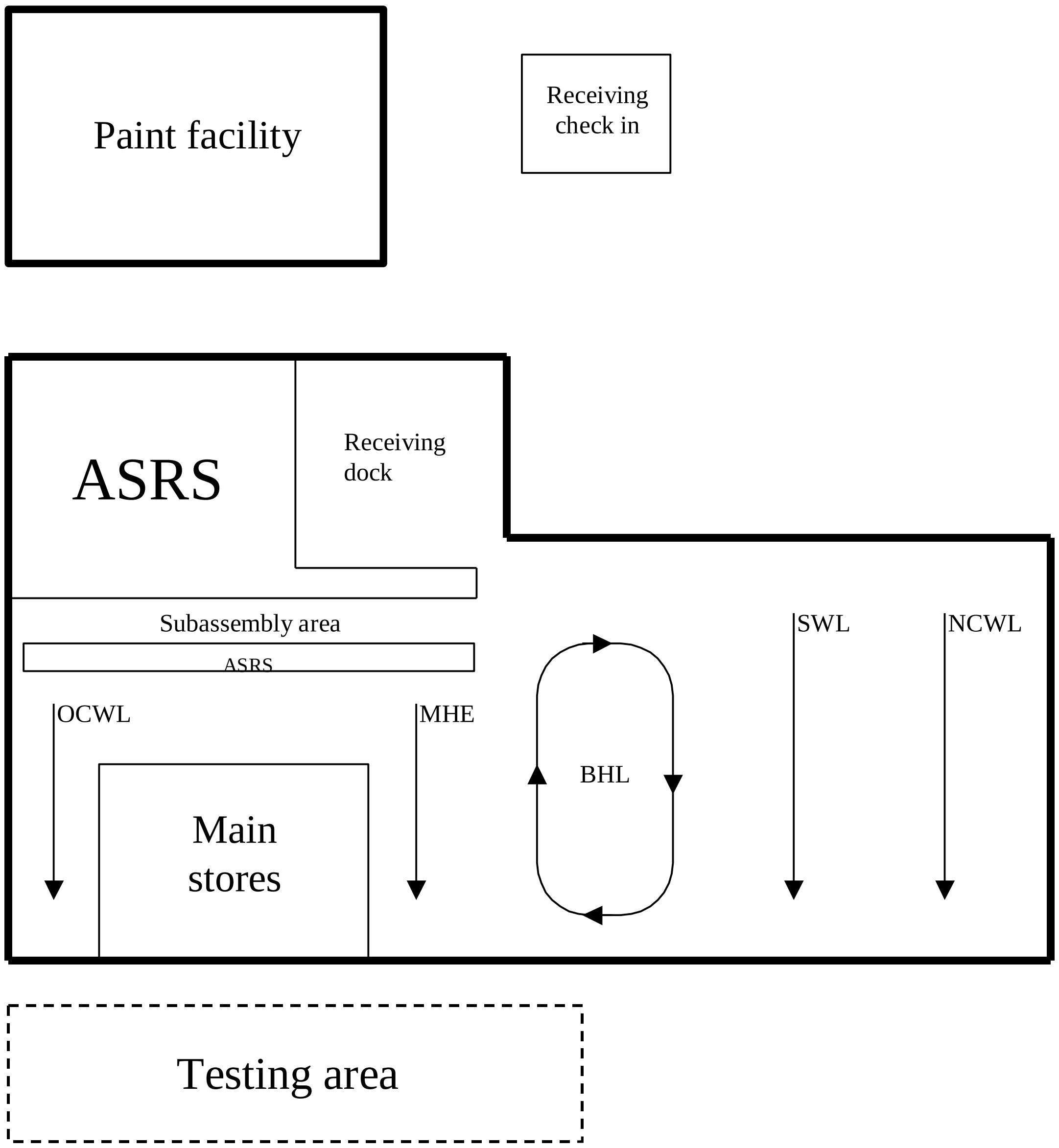
BHL = Backhoe Loader mainline

MHE = Mini Hydraulic Excavator mainline

NCWL = New Compact Wheel Loader mainline

OCWL = Old Compact Wheel Loader mainline

SWL = Small Wheel Loader mainline

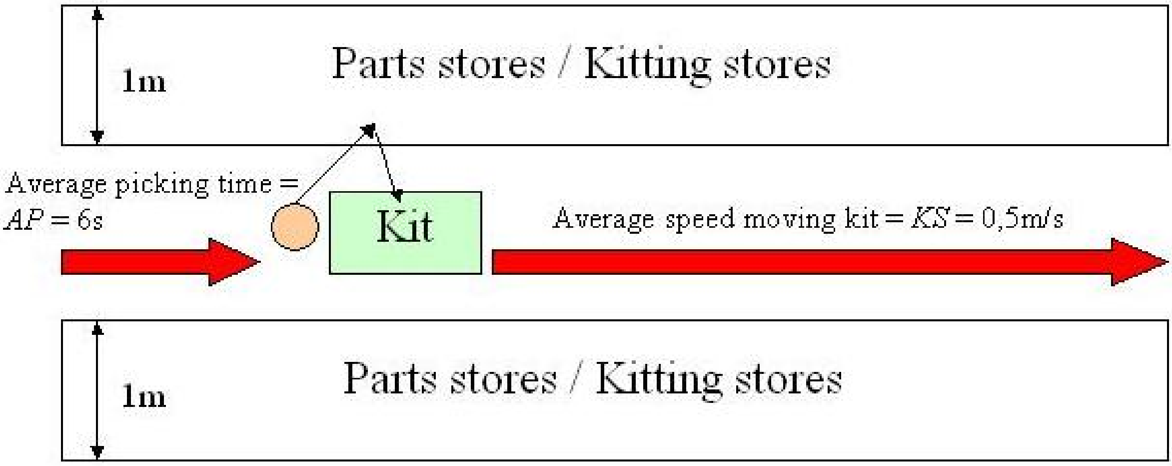


Appendix D

Explanation of Assumptions in the model

Kitting time

A simple model of a possible kitting area was drawn. It consists of two storage racks and a walking aisle between them. It is a picker-to-part system where the picking operator walks with the kit along the aisle and picks the applicable parts from both sides of the aisle as shown in the figure below. When reaching the end of the stores the kit is thus completed.



The time it takes to assemble one kit was divided into two terms, first the travelling speed of the kit and second the time it takes to pick each part. That is, if one picks few parts but still have a long way to walk, the kitting time per part is higher than it would if one had to pick more parts.

To obtain reasonably accurate values of AP (average picking time) and KS (Average speed moving kit) an imaginary kitting area was set up in the factory. The two authors simulated assembling a kit in a comfortable pace that would be possible to keep a whole working day. The procedure was repeated a couple of times with different approaches such as walk slow – pick fast and vice versa. Altogether this lead to an assumption of an average picking time of 6 seconds per part and the average speed moving the kit of 0.5 m/s.

Walking speed

Through empirical tests, where the authors walked and timed each other, and discussion with engineers specialised in operations timing an average walking speed of 1 meter per second was assumed. When assuming the walking speed it has been kept in mind that the pace has to be realistic for a shop floor worker to maintain a whole working day.

Appendix E
AHP model spreadsheet

Original matrix	Lineside replenishments/ day	Reqd. kitting space	Lineside space	Walking time / day	Lineside inventory value	Physical part handling / day	Kitting time/day
Lineside replenishments/day	1.00	5.00	0.20	0.14	0.33	0.20	5.00
Reqd. kitting space	0.20	1.00	0.14	0.20	1.00	0.33	5.00
Lineside space	5.00	7.00	1.00	0.20	5.00	0.33	5.00
Walking time / day	7.00	5.00	5.00	1.00	7.00	1.00	5.00
Lineside inventory value	3.00	1.00	0.20	0.14	1.00	0.20	0.33
Physical part handling / day	5.00	3.00	3.00	1.00	5.00	1.00	3.00
Kitting time/day	0.20	0.20	0.20	0.20	3.00	0.33	1.00

Matrix square 1	Lineside replenishments/ day	Reqd. kitting space	Lineside space	Walking time / day	Lineside inventory value	Physical part handling / day	Kitting time/day	Sum	Eigenvector
Lineside replenishments/day	7.0	14.0	3.5	2.6	23.7	4.0	37.4	92.2	**0.0858**
Stores replenishments/day	8.2	7.0	3.5	1.9	20.8	2.8	14.0	58.4	**0.0543**
Lineside space	30.5	47.0	7.0	4.6	36.7	6.9	73.7	206.3	**0.1919**
Walking time / day	67.0	91.0	17.5	7.0	66.3	9.8	100.3	359.0	**0.3338**
Lineside inventory value	9.3	19.8	2.5	1.2	7.0	1.7	23.0	64.4	**0.0599**
Physical part handling / day	48.2	62.6	14.0	5.2	45.7	7.0	67.7	250.4	**0.2329**
Kitting time/day	13.5	7.8	3.1	1.3	10.3	1.6	7.0	44.6	**0.0415**
							Total	1075.3	**1.0000**

Matrix square 2

	Lineside replenishments/ day	Reqd. kitting space	Lineside space	Walking time / day	Lineside inventory value	Physical part handling / day	Kitting time/day	Sum	Eigenvector
Lineside replenishments/day	1360.9	1606.2	374.4	176.5	1493.1	245.5	2052.2	7308.7	**0.0840**
Stores replenishments/day	870.4	1204.1	247.1	122.3	1017.2	173.0	1626.5	5260.6	**0.0605**
Lineside space	2783.0	3232.2	816.2	407.5	3592.6	577.2	4598.3	16006.9	**0.1840**
Walking time / day	4658.3	5746.6	1413.0	736.9	6539.1	1057.1	8668.3	28819.3	**0.3312**
Lineside inventory value	840.4	919.6	252.6	128.5	1167.4	183.1	1366.8	4858.4	**0.0558**
Physical part handling / day	3301.8	4119.8	1000.0	524.0	4646.5	752.9	6238.1	20583.1	**0.2365**
Kitting time/day	606.3	865.8	189.0	102.8	898.8	149.7	1366.0	4178.6	**0.0480**
							Total	87015.5	**1.0000**

Matrix square 3

	Lineside replenishments/ day	Reqd. kitting space	Lineside space	Walking time / day	Lineside inventory value	Physical part handling / day	Kitting time/day	Sum	Eigenvector
Lineside replenishments/day	8423829.1	10505673.4	2471845.2	1250804.6	10893389.1	1780093.1	15032429.5	50358064.0	**0.0843**
Stores replenishments/day	5901885.8	7405497.0	1735133.6	880266.9	7664784.0	1253832.3	10631897.6	35473297.1	**0.0594**
Lineside space	18483028.8	23004602.5	5436136.3	2756306.7	24048734.9	3924958.1	33045645.9	110699413.1	**0.1853**
Walking time / day	32947681.6	41077309.1	9705518.5	4929409.1	43032789.0	7023214.5	59164602.6	197880524.3	**0.3312**
Lineside inventory value	5660049.2	7023417.8	1665896.8	844948.8	7380190.9	1203278.2	10100752.6	33878534.3	**0.0567**
Physical part handling / day	23476218.3	29283490.9	6916252.5	3513341.7	30669493.1	5005949.9	42186193.3	141050939.7	**0.2361**
Kitting time/day	4661667.7	5844361.8	1375419.0	700114.0	6110211.7	998229.1	8441462.2	28131465.6	**0.0471**
							Total	597472238.2	**1.0000**

Matrix square 4

	Lineside replenishments/ day	Reqd. kitting space	Lineside space	Walking time / day	Lineside inventory value	Physical part handling / day	Kitting time/day	Sum	Eigenvector
Lineside replenishments/day	3.9E+14	4.9E+14	1.2E+14	5.9E+13	5.1E+14	8.4E+13	7.1E+14	2.4E+15	**0.0843**
Stores replenishments/day	2.8E+14	3.5E+14	8.1E+13	4.1E+13	3.6E+14	5.9E+13	5.0E+14	1.7E+15	**0.0593**
Lineside space	8.7E+14	1.1E+15	2.5E+14	1.3E+14	1.1E+15	1.8E+14	1.6E+15	5.2E+15	**0.1853**
Walking time / day	1.5E+15	1.9E+15	4.5E+14	2.3E+14	2.0E+15	3.3E+14	2.8E+15	9.3E+15	**0.3312**
Lineside inventory value	2.6E+14	3.3E+14	7.8E+13	4.0E+13	3.5E+14	5.6E+13	4.8E+14	1.6E+15	**0.0567**
Physical part handling / day	1.1E+15	1.4E+15	3.2E+14	1.6E+14	1.4E+15	2.3E+14	2.0E+15	6.6E+15	**0.2361**
Kitting time/day	2.2E+14	2.7E+14	6.5E+13	3.3E+13	2.9E+14	4.7E+13	3.9E+14	1.3E+15	**0.0471**
							Total	2.8E+16	**1.0000**

Final result of the AHP, in decreasing order of importance.

Criterion	**Normalised weight**
Operator walking time	0.3312
Physical part handling	0.2361
Lineside storage space	0.1853
Lineside replenishments	0.0843
Required kitting space	0.0593
Lineside inventory value	0.0567
Kitting time	0.0471