Maximization of Product Flow

Master's Thesis in Operations Management at Xaar plc 2004

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Preface

This thesis was carried out during the autumn semester of 2004 at XaarJet AB in Stockholm. The master’s thesis is the final test of my schooling in engineering and operations management. It was not an easy task, but on the other hand exceptionally rewarding. I would like to thank for the extensive help received from my two supervisors, Professor Anders Segerstedt of the Division of Industrial Logistics at Luleå University of Technology and Michael Lindholm of the logistics department at XaarJet AB.

In addition to my supervisors I also would like to thank for all the help I have received from staff at XaarJet, the very helpful staff at the Luleå University of technology library and of course my lovely family.

Järfälla, a crisp and clear December evening, 2004

Jonatan Persson
Abstract

Xaar is a high-tech corporation that develops industrial inkjet technology and manufactures print heads. The production process is complex and requires special manufacturing techniques and environments. Yields are low, the product flow uneven and the market demand is high. This thesis investigates how Xaar can maximise the product flow through the production plant in Järfälla, Sweden. The thesis uses traditional methods for problem solving and computer simulations for evaluation.

The purpose of the thesis is to maximize the product flow at the Xaar Järfälla plant.

The results point that Xaar shall emphasize on;

- Accept the washing operations 30, 60, 75 and 320 as theoretical bottlenecks
- Continuously monitor flow and bottlenecks with computer screens connected to the manufacturing information system
- Visualise bottlenecks using special eye-catching signs
- Focus physical work at bottlenecks to maximise the running time
- Level production using bottlenecks to set the pace
- Use pull driven production with buffers
- Utilise machinery efficiently and manufacture to stock
- Use more scorecards to monitor variables that can improve the total quality
- Increase the staff competence by rotating staff
- Create task groups for maintenance, yields and bottleneck capacity improvement
- Formulate a manufacturing strategy
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1. Introduction

In this chapter the background along with the purpose of the thesis at Xaar Järfälla is presented.
1.1 Background
Xaar is a middle-sized corporation developing and manufacturing inkjet print heads for industrial printers. The business started in the beginning of the 1990s in Cambridge, UK. The core of the business was based on a series of patents of printing technology. A few years later the company acquired a manufacturing facility in Järfälla, Sweden. Xaar has launched a number of products since then and in recent years the production has more than doubled at the same time as the workforce has been reduced and more products introduced. The production process is complex with many stages where micrometer precision, particle free compartments and ESD-safe equipment are required. The production yields have been increased from low levels to more moderate on most products. The low yields together with almost 20 different product types have made buffering difficult creating a hectic production environment. The product flow is uneven where occasional dry-outs and work load peaks come and go. This makes it difficult to use the production plant efficiently and the plant has been struggling to meet production objectives.

1.2 Purpose
The purpose of the thesis is to

Maximise the product flow at Xaar Järfälla production plant

1.3 Restrictions
- Material and components are assumed to be available in stock
- The production flow must be maximized with consideration to the relation between cost and income, for example work during nights and weekends must be minimized
- No investments are assumed to be made in order to fulfill the purposes of the study
- Only focus activities within the production plant, excluding distribution and demand forecasting
2. Method

This chapter gives an idea of how the research problem of the thesis has been defined and carried out.
2 – Method

2.1 Method discussion

In this thesis, the method used is based on Zikmund (2000) and his described seven steps of research. The idea is to present the problems to be investigated based on the theoretical reference and the thesis’ purpose. In order to fulfill the purpose of the study, there is one basic research problem that needs to be straightened out for the Xaar plant:

- How can the product flow be controlled?

In order to be able to answer the research problem a number of research questions are discussed.

1. What is the Xaar production strategy?
2. What variables affects the product flow?
3. How does the physical flow look in the production facility?
4. What are the characteristics of the production yield?
5. Which capacity do different operations possess?
6. What operations restrict the production capacity?

The research questions form the base for the empirical study carried out at Xaar production plant. The empirical study has the character of both being quantitative and qualitative. The empirical study consists of physical measurements of lead times and desktop research to obtain data from the Xaar production information system. Xaar ISO documentation has helped develop the flow and information charts, combined with interviews. Also a reference study at Ericsson has been made, to get an input on bottle neck visualization methods. The results will be presented in the results chapter. As a part of the method, a computer simulation model of the production process is to be made, to verify the suggestions. Simulation results are nevertheless not more than results of the simulation, and will be taken as such. The idea of the thesis is to keep a simple approach to these investigations to make repeatability and confirmation for a third part easy. The aim is also to enable Xaar to easily perform necessary analysis in the future.

This thesis uses empirical studies of the production process. Measurement of quantitative data such as processing times and inventory has been made to give a statistical tool for analyzing the production process. Qualitative information has also been gathered to give an idea of staff attitudes, knowledge of the company and technical competence.

The theoretical reference stands as a foundation for the analysis of the production facility. The analysis and conclusions are all motivated by relevant theory. Also suggestions on improvements have been verified using computer simulations. The Extend software was used for simulating. The simulation results are statistically secured by a sensitivity analysis. A simulation model has been created by the means presented in chapter 5.10.
3. Company and production facility orientation

This chapter describes Xaar plc, its current product line-up, the technology used and the production process.


3.1 Xaar plc

Xaar is a technology based company, specialised in development and exploitation of unique ink jet technology. The Xaar business is based on important patented technology in the areas of multiple jet, piezo drop-on-demand ink jet processes and product specific inks. The Xaar technology can be used in making near-photographic quality prints for office, industrial or consumer applications.

The Xaar head office is located in Cambridge, UK, and the main production facility in Järfälla, Sweden. Xaar has sales and support offices around the world to provide service and sales opportunities on important markets such as India and China. There are also technical support offices located in Europe, the United States and the Far East. See fig 3.1.

Since 1990, Xaar has been in the business of, and developing new technology of digital printing. Xaar has over 650 registered patents and applications relating to ink jet technology. The collection of patents can be used and tailored to individual customer needs. Xaar also provides engineering support staff, assisting partners and OEM customers. The company aims to provide solutions which fit specific customer needs and to be able to deliver quickly.

Xaar plc contains three divisions: Xaar Technology, XaarJet and Xaar Digital. Xaar Technology licenses technology to major global corporations for high volume consumer and office applications. Xaar Technology has more multi-disciplinary approach to development, being active with a number of departments including design and development, process engineering, ink chemistry, mechanical engineering, electrical engineering, lifetime & reliability testing and manufacturing.

Xaar licence companies for both ink and print head production. Xaar has nine print head licensees, including Brother, Konica Minolta, Sharp and Dai Nippon Screen.

Xaar's established markets include industrial marking (case coding, barcodes, product marking and labelling), wide format graphics (producing posters, banners and signs), and primary packaging and printing on CD's and plastic cards. See fig. 3.2.
Xaar has two manufacturing sites. One is located in Cambridge, UK and a second, larger facility in Järfälla, Sweden. The UK facility is foremost used for prototype manufacturing and pre-production testing.

Xaar Digital has formed strategic alliances for the development of page-wide print heads with global leaders in print head manufacture, ink production and digital printing systems.

Xaar is working with world-class partners on the page wide print head programme. Under the terms of a collaboration agreement signed between Xaar and Kyocera, Kyocera will undertake the manufacture of the page wide print head on behalf of Xaar. Kyocera is a world leader in the manufacture of precision ceramic-based products for the electronics industry.

The page wide print head will be supplied by Xaar to OEMs with a range of inks, according to the OEM’s target application. Xaar is working with its ink licensee Avecia on this project and has also signed a joint development agreement with Dupont Ink Jet Inks. Xaar is now working with two of the world’s leading manufacturers of inks for ink jet printers.

Agfa - Gevaert N.V., one of the world's leading photographic and imaging companies was the first OEM to sign a partnership agreement with Xaar for this project. (www.xaar.se)

3.2 The technology

The Xaar products printing process uses PZT (piezo inkjet technology) technology. The PZT involves a ceramic material that deforms when an electric field is applied to it. This deformation is made in order to eject the ink from the print head in a controlled and repeatable manner. Each pixel on the substrate is either covered with ink or not. This is called binary printing. This method is used in a range of industrial printing applications. This includes industrial coding and marking, as printing is versatile and can be made on many different materials using many different inks.

One of Xaar’s patents concerns the digital drop on demand technology (DOD). This technology works when several ink chambers are located closely to each other. These chambers contain the ink to be ejected on the substrate and by simply letting the chamber walls move from side to side, a pumping movement is created. This movement is created by applying an electric voltage to the electrodes on the chamber walls. The walls therefore deform and the increased pressure ejects ink through the nozzle at the end of the channel. See figure 3.3.
Xaar has a different technology called drop on demand greyscale ink jet. The greyscale ink jet technology is similar to the binary ink jet, but can fire drops of different sizes. This ability makes up to 16 levels of greyscale. This technology achieves extremely high apparent print resolutions. See figure 3.4.

Bubble jet (Thermal) is another drop on demand technology which utilises heated ink that creates steam bubbles. The ink bubble creates a local high pressure which makes the ink eject onto the substrate. Bubble jet is primarily used in desktop printing applications.

Continuous ink jet uses a different method where the all print head nozzles eject ink. Every drop is given an electrical charge which determines which drops reach the substrate, and which are deflected back into the system. These printers are usually very fast, but not very exact. See fig. 3.5.
3.3 The products

The range of applications for which XaarJet products can be used includes:

- Addressing — personalisation for direct mail
- Plastic cards and tags — printing variable data and graphics
- Primary packaging — printing direct onto containers for fast moving consumer goods
- Secondary packaging — on-line carton coding
- Labelling — on demand self adhesive labels
- Wide format graphics — high speed printing of posters and point of sale advertising
- Grand format graphics — high speed banner and billboard printing
- Point of sale printers — high speed receipt printers
- High speed office printers — replacing traditional impact line printers
- CD printing — printing variable data and graphics
- Photographic printing — for photo shop processing
- Medical applications — reagent jetting
- Ceramic printing — wall and floor tiles

One of the products in the line up is the Xaar Leopard. It is a new product, being a greyscale quality print head for packaging and industrial markets. The print head is being manufactured in low volumes in the UK factory. See fig 3.6.
The XJ64 and XJ128 binary print heads are older products in the line up. The XJ128 is the product that Xaar manufactures the highest volumes of. It is available in several different versions. The most common is a 200dpi version, but it is also available in a 360dpi version. The XJ64 has a printing width of 9mm and 64 ink channels and the XJ128 a printing width of 17mm with 128 channels. These print heads are designed for the industrial market and have a proven track record in the wide format graphics and coding and marking markets. The XJ128 is a popular entry level piezo inkjet 'drop-on-demand' product. See fig. 3.7.

The XJ126 is a newer product in the same range as the XJ128. It is more reliable, more versatile and faster. The XJ126 is capable of working with a broad range of liquids across a wide range of applications. It can therefore be used for many static and scanning uses. It has new features of adjustable electronics, along with its bigger brother – the XJ500. There are different versions of the XJ126 as well, such as the aqueous capable print head, XJ126R. The XJ126R is also available in non-aqueous versions capable of printing with oil, solvent and UV curable inks. The XJ126R has the fastest linear speed within the Xaar product range. The XJ126 is also available in a 200DPI and a 360DPI version.

The XJ500 print head has 500 ink channels. It is a new product with self-contained interface electronic. It is aimed to be a high performer in industrial areas. The XJ500 print heads are available in both binary and greyscale and have a printing width of 70mm. The binary
versions have a print resolution of 180dpi or 360dpi and the greyscale print head provides 360dpi printing with 8 levels of drop size. This print head can be customized in various ways to fit specific customer needs.

**3.4 The production process from a technical perspective**

The wafer production is the first part of the production process, where the ceramic wafers are made. The ceramic wafers hold the ink channels, and the electrodes which are the core of the Xaar printing technology.

![Diagram of the production process](image)

**3.4.1 Front end production**

As described by figure 3.8 the front end production contains the wafer production area. The first operation of the front end production is the sawing operation, where the actual channels are sawn in the surface of the ceramic wafers. High performance sawing machines creates channels only 0.9 µm deep and 0.5 µm wide. Depending on the type of product the number of channels varies from 64 (XJ64) to 500 (XJ500) per wafer. A comparably large number of eight sawing machines work in parallel for this task. Every machine is fitted with a wafer fixture and a very thin and precise sawing blade. The tolerance of this operation is very small. The following metallization operation produces the electrodes on the channel walls. This operation uses a physical vapor deposition process (PVD) to put a thin layer of aluminum on the sawn wafer walls. The aluminum layer itself functions as an electrode. The operation process takes place in a vacuum, making the operation time relative long as the metallization process container has to evacuate the air. The wafers are cleaned with plasma and the aluminum is vaporized and applied to produce the tin layer.

The aluminum layer is not only put on the walls, but in the upper side of the wafer. The next operation grinds this layer off of the wafer, leaving aluminum only inside the channel walls.

After the aluminum has been removed, the passivation operation creates a protective passivation layer of silicon-nitride (Si3N4) on the wafer. The passivation layer protects the
aluminum electrodes from the ink, and also to protect the ink from material dissolved from the wafer. The used method is a plasma enhanced chemical vapor deposition process (PECVD).

In parallel to the wafer production, a wafer cover is made. As the channels are sawn out of the upper side on a wafer, the cover is simply put on top of the wafer creating a material with channel holes. See fig. 3.9.

As the finished wafer is glued together with a lid, the wafers are diced into actual actuators, 18 or 6 actuators from each wafer - depending on product type. At this stage the product is a piece of ceramic material, with channel tunnels in the middle. The top has an inlet for ink, and the channels are open to the front. The back side has leaps of aluminum functioning as connectors for the print head electronics controlling the electrodes.

The print head nozzle is basically a thin plastic film, with microscopic holes made to fit the wafer channels. The plastic film is constructed by hand with different layers for different nozzles. The film is then processed in the laser ablation operations, where a laser is used to burn holes, and cut out the nozzles from the film. The nozzle film is placed over the short side of the wafer, covering all the channels but from one single nozzle hole per channel. See fig 3.10.
3.4.2 Back end production

As described by figure 3.10 the back end production area is the assembly and testing part of the production process. The first operation of the back end production part is assembly of the actuator on a print head platform. The described metallization and passivation processes along with several cleaning operations are carried out in specific dust free production areas. In the actuator assembly the actuator is mounted onto the print head base platform via a plastic inserter to keep it in place. This is a manual operation carried out by Xaar workers using hand tools and various glue machines.

The microchips are connected to the aluminum connectors on the actuator using thin wires. This is a complicated process requiring both the actuator material surface and the electronics to perfectly clean and aligned. The connectors are later protected from dirt and vibrations by a thin layer of silicone.

The entire print head is then sealed with a plastic cap which makes it resistant to ink and dust.

Along the assembly line, microchips are mounted on the platform. Many operations are mechanized to minimize human contact with the products. Other operations are difficult to mechanize with the current product designs, requiring extensive hand work.

The fill and fire operation is a test measuring the accuracy of the printer head. It is comparable to a live fire of the actuators. The printer head is mounted in a testing device, and then operated to print a test liquid. A computer measures the liquid drop velocity and direction. The accuracy of the print head is measured to keep it within given tolerance levels. This is the first point of the production where a print head’s entire function can be tested. After this step, the print heads are packed and shipped. See fig 3.11.
There are several steps of testing and inspection along the production line. All information is put into a custom built computer system called Shopfloor.
4. Theoretical reference

The purpose of this chapter is to gather relevant theory that helps to understand the production process at Xaar and give insight to how its behaviour can be described. The theoretical reference goes in to theory on production economics on a general and a strategic level. It discusses the work of planning and production management. It also describes theory concerning methods for physical management of production
4.1 Processes

In order to have a tool for analysing the production environment, a relevant definition of process has been identified. Ljungberg (1998) means that process mapping and modelling can be used for several purposes, namely;

- Support quality certification
- To identify process bottlenecks
- As an integrative tool
- Prioritise improvements
- As a communication tool

There are many definitions of a process. Harrington (1991) defines a process as any activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer. Ljungberg (1998) has a somewhat different view as he means that a process is a repetitively used network of in order linked activities that use information and resources to transform ‘object in’ to ‘object out’, from identification to satisfaction of the customers needs. Further Ljungberg (1998) characterizes a process as having different kinds of inputs, outputs and means of communication. A process starts and is triggered by its input, an object entering the process. The object might be of physical character or it might not. As this object enters the process, value can be added to it. The value adding transformation of the process is the result of the internal activity. The process needs resources in order to perform the activity. Examples of resources are staff, equipment and machinery. For a process to function properly information is also needed. Information should not be mistaken for object in or object out when these two latter have the characteristics of information. The information of a process is only a facilitator where as the object in is a trigger. The process output is the object out. See fig. 4.1. (Ljungberg & Larsson 2001)

![Diagram of a process]

**The core characteristics of a process**

- **Information**
- **Object input**
- **Object output**
- **Transformation**
- **Resources**

**Interpretation of Ljungberg (1998)**

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Fig. 4.1 – Process definition
With this said on the process definition, the next chapters will show theory with a clearer operations management character.

4.2 Lean systems and Just-in-time

Lean manufacturing is a concept that embodies many parts of an organisation. It is the strive to create an efficient manufacturing process using a perspective of the whole system. Just-in-time (JIT) is a philosophy within the frame of Lean systems. Krajewski & Ritzman (2002)

The demand at different manufacturing stages in a production system is often dependent. Dependent not only on one other, but also on many other stages. This is the result of complex production processes with different product paths and products. The idea of JIT is to make every stage precisely manufacture what is needed in the following stage. In a JIT system cycle stocks and lot sizes are minimized. The demand of the following stage is not completely deterministic as variations in capacity are normal. Therefore safety buffers may be needed. Usually buffers are kept at the end or at the beginning of a production line, but can also be used in between production stages. Generally buffers are made by using conservative lead times in planning. Although needed, buffers should be avoided as much as possible to minimize the material inventory. Magee, Copacino & Rosenfield (1985)

Although production philosophies are very popular today, they are still only philosophies that need to be implemented into a corporation through its strategies.

4.3 Strategies

In order to understand the nature and purpose of strategies, the chapter is handily introduced with a definition. Magee et Al (1985) states that the primary goal of logistics systems is to support the strategic goals of the corporation in the best manner possible. He further means that the design of the logistics system must commence with an understanding of corporate goals and strategies. Manufacturing should not be made ad hoc, but very deliberately. Hill (2000) presents four different levels of corporate strategy. The first one is the industrial level strategy. This strategy concerns wide issues such as investment incentives, employment and government policies. The next one is the corporate level strategy which decides how the company can compete and grow on the market. The priorities between different sectors of the corporation are also stated in this strategy. Below the corporate strategy there is the business level strategy where a company decides how different business units within the corporation relate to one another. Often this concerns how these businesses compete, if they compete. Last is the functional level strategy. Here each function will need to develop its own strategy to reach out to the given market on the given means of competition. Hence the development of this strategy needs to be carried out with coordination both with coexisting corporate functions and the corporate and business strategy. For example, the production strategy needs to be in line with the development strategy and the overlaying corporate strategy in order to jointly take on the requirements put on the company from the market. See fig. 4.2.
The corporate strategy states what operating advantages the processes must possess to outperform its competitors. These are called competitive priorities. Krajewski et al (2002) defines a set of competitive priorities:

1. Low-cost operations
2. High performance design
3. Consistent quality
4. Fast delivery time
5. On-time delivery
6. Development speed
7. Customisation
8. Volume flexibility

Krajewski et al (2002) state further that no firm can reach excellence in all the competitive priorities listed, but have to choose on what premises to compete.

Fig. 4.2 – Corporate strategy
Example of cooperation and contradiction of efficiency variables

\[
\begin{array}{cccccc}
\text{Low capital binding} & - & - & - & - & - \\
\text{High precision of delivery} & + & - & + & + & - \\
\text{Short delivery time} & - & + & - & - & - \\
\text{High resource flexibility} & - & - & - & - & - \\
\text{High product mix flexibility} & - & + & + & - & - \\
\text{Great delivery flexibility} & - & + & + & - & + \\
\end{array}
\]

Interpretation of Mattsson (1999)

Hence it should be clear what a company’s competitive priorities are, given by its strategies. This is very well illustrated by Mattsson (1999) where for example high resource flexibility does not coexist with product mix flexibility. See figure 4.3. Naturally a company has to focus. Ljungberg et al (2001) mean that all parts of an organisation need to aim towards the same goal. They state five factors for business success, namely:

- Cost
- Income
- Capital binding
- Human capital
- Time

The first one is cost. Ljungberg et al (2001) mean that economic issues sooner or later have the most conclusive role. Everything does not have to measure in terms of monetary value, but all actions in a corporation will have economic consequence. Income is the second factor. Ljungberg et al (2001) mean that there are two ways of making money. That is either through low costs or high income. They say income and cost will always be connected. See figure 4.4. Companies making money on low costs have problems competing with quality, service and time. A company with good service, quality products and short developing/production lead times has to have higher income. Capital binding is the third factor. Small inventories may give good results to a company in terms of better quality and service, lower costs and higher productivity. Human capital is also an important factor. An often-neglected asset is a company’s staff. Time is the last factor. Successful firms focus time. Shorter lead times actually give higher quality and less storage. These factors together make it important to focus on the whole, focus the customer and focus the employee.
There are obviously many levels of strategies. The strategy that outmost affects the area this thesis concerns is the manufacturing strategy.

### 4.4 Manufacturing strategy

As stated, functional strategies are more close to the everyday production. Krajewski et al (2002) describe two planning strategies. The first is the **chase strategy**. The firm matches the demand during the planning horizon by varying either the work-force level or the output rate. This strategy has the advantage of little inventory investment but suffers from expenses in adjusting the workforce. The second is the **level strategy** and means a constant workforce level or output rate is maintained during the planning horizon. This strategy builds inventory during the low season, or goes down in staff capacity during the same period. No matter the functional strategy, a company can decide whether to manufacture to order, to stock or assemble to order. Krajewski et al (2002) describe these as the following points:

- Make-to-stock strategy is a strategy where products are held in stock for immediate delivery.
- Assemble-to-order strategy is a strategy where customized products are manufactured from a few assemblies and components after customer orders.
- Make-to-order strategy incorporates customized products, in low volumes.

In the work of developing and implementing a strategy there needs to be a certain level of commitment. Hill (2000) defines a number of points that should be completed:

1. Define corporate objectives
2. Determine marketing strategies to meet these objectives
3. Assess how different products qualify in their respective markets and win orders against competitors
4. Establish the appropriate process to manufacture these products (process choice)
5. Provide the manufacturing infrastructure to support production

Depending on what manufacturing strategy chosen, the production process will develop different characters. Perhaps the greatest sign of a production process health and underlying strategy is the number of products that is located in the production facility at a given point in time. These products are referred to as inventory and also called *work in process* or just WIP.
4.5 Inventory
There are different types of inventory in a manufacturing process. Anupindi (1999) describes five common types;

- Theoretical inventory
- Cycle inventory
- Seasonal inventory
- Safety inventory
- Speculative inventory

The theoretical inventory is essential for maintaining throughput. This measure is a theoretical value of the minimum inventory required to keep a material flow running. It is obtained by multiplying the throughput and the theoretical flow time of the process. The cycle inventory exploits economies of scale. That is when set up costs are high, large quantities are preferred over small in specific manufacturing operations. Anupindi (1999)

Magee (1968) describes this cycle inventory as something that occurs when more is produced than immediately needed. This happens when batched items are processed production, as operations usually cannot process more than a part of the batch simultaneously. See figure 4.5. Anupindi (1999) further describes that seasonal inventory smoothens capacity requirements, rather than adjusting the production capacity. The safety inventory provides stock out protection, enabling operations to continue despite occasional shortages of supply. Speculative inventory profits from price speculations. (Anupindi 1999)

Buffers are often used in the industry. Buffers can be put between operations, between manufacturer and customer or between manufacturer and supplier. The basic response to reducing its levels is reducing uncertainty in supply and demand. Ensuring reliable suppliers and stable demand patterns in production largely eliminates the need for safety inventories. Anupindi (1999)

A general method for controlling material is the order point system. An order point is an inventory level that triggers the order for refill. Magee (1968) and Segerstedt (1999) define the order point as;

\[ Op = \text{Demand during the lead time} + \text{safety stock} \]

The basic model defines inventory levels with a reference quantity, the order point. As soon as the inventory level falls below the order point new material is gathered. (Magee 1969) See figure 4.6.
The safety stock is in practice achieved by manufacturing more than needed, to fill a buffer. This is the definition of a pull system, where the inventory of the downstream operation decides the production pace and chooses the produced item. Figure 4.7 illustrates the pull system where every operation communicates with its supplying operation. In a push system every operation works isolated, and processes whatever is available. Mattsson (1999)

![Order point system and the corresponding inventory level](image)

Fig. 4.6 – Inventory and order point

Manufacturing using the push strategy

![Manufacturing using the push strategy](image)

Manufacturing using the pull strategy

![Manufacturing using the pull strategy](image)

Fig. 4.7 – Push versus pull strategy

The safety stock needs to be large enough to help out in most situations. However it is not possible to buffer for every variation in lead time. Krajewski et al (2002) mean that the size of the safety stock shall be;

\[
\text{Safety stock} = Z \times \sigma
\]
The safety stock is calculated by multiplying the standard deviation $\sigma$ of the need with a constant $Z$ representing the cycle service level. For example, a $Z = 0$ gives a zero safety stock, and stock out will occur at 50% of the time. See figure 4.8.

![Calculating safety stock from the normal probability distribution](image)

Anupindi (1999) means that theoretical inventory can be reduced by:

- Reducing critical activity times
- Eliminating non-value adding activities
- Moving work from critical to non critical activities
- Redesigning the process to replace sequential processing with parallel processing

Anupindi (1999) defines average cycle inventory as

$$Q^* = \frac{2}{\sqrt{\frac{2 \times S \times R}{H}}}$$

where $S$ is the order cost, $R$ is the and $H$ is the cost of holding one unit in store for a year.

The best lever for reducing the cycle inventory is reducing the fixed order cost $S$, which reduces the optimal batch size and average cycle inventory. Reducing fixed set-up or ordering cost can be achieved by simplifying ordering and by making resources flexible. This way set-ups or changeovers between production runs can be implemented quickly and easily. Excessive cycle inventories resulting from forward buying can be reduced by negotiating everyday low prices with suppliers instead of seeking short time trade promotions. (Anupindi 1999)
Seasonal inventory is a result from temporal fluctuations in outflows, coupled with the high costs of adjusting capacity to meet fluctuations. Using pricing and incentives to promote more stable demand patterns can reduce this inventory. Increasing resource volume flexibility so that resources can produce at various flow rates to match demand fluctuations will also make it less expensive to adjust seasonal inventory levels. Similarly, using flexible resources to produce counter cyclical products makes it possible to level the load without building up inventory. Anupindi (1999)

It is not very common that the production circumstances are fortunate enough to avoid queues completely. When queues occur there needs to be a clear way of prioritize. Segerstedt (1999) mentions a few rules for prioritizing;

- Earliest date for planned operation finish
- Earliest ship date for the order
- First in first out, FIFO
- Shortest operation time first
- Least order slack
- Operations with same tools first
- Earliest finish date for following operation

There are different methods of producing. There is one method that is used to deliberately control WIP and production flow; it is a Japanese method called Kanban.

### 4.6 Kanban

Kanban is a method for creating a “pull” demand between manufacturing operations. The Kanban system incorporates standardised containers for transportation of material. There are an exact number of Kanban containers for each material flow. Each container can only contain one type of material and only a specific amount of material. Each operation works only to fill empty Kanban containers waiting to be filled. The operation next in the production chain literally picks up containers to fill their own need from the operation before. This creates a “pull” characteristic to the production chain as no operation produces anything that is not apparently needed in another operation. (Segerstedt 1999)

The Kanban system containers are calculated as the following;

\[
k = \frac{(\text{average demand during the lead time} + \text{safety stock})/(\text{container size})}{d \times (w + p) \times \frac{1+\alpha}{c}}
\]

k = number of containers
d = anticipated demand of the product
w = average queue time through the production process (parts of production day)
p = average production time per container (parts of production day)
c = number of units in each container
\( \alpha \) = policy factor that reflects the efficiency of the operation

(Segerstedt 1999)
Although Kanban, and of course other methods, gives a very controlled environment there is a need to make measurements of relevant performance indicators.

4.7 Performance measures

In order to keep informed of certain production variables, a company can measure its own processes. Tangen (2002) suggests that performance measures must be derived from strategic objectives to ensure that employee behaviour is consistent with corporate goals. Further he says that timely, relevant and accurate feedback from both a long term and a short term perspective must be provided and that they should be undertaken in ways that are easily understood by those whose performance is being evaluated. He also states that the performance measures should be accomplished by a limited number of performance measures that consist of both financial and non-financial measures. Mattsson (1999) defines several dimensions of efficiency that may be used for measuring performance;

- Capital binding
- Capacity usage, the extent to which available capacity is used to value increasing activity
- Number of storage cycles without lack
- Part of demand fed directly from storage
- Number of products without quantity in storage
- Part of items delivered directly from storage
- Part of deliveries delayed as a percentage of total deliveries
- Delivery dependability
- Number of customer orders without remarks from customer as a percentage of totally delivered number of orders
- Delivery times with the help of planning information
- Capital binding, absolute figures
- Inventory turnover
- Storage cover time
- Cross-functional workforce

According to Magee (1968) the cost of capital is the minimum prospect rate of yield that a proposed investment in real assets must offer to be just worthwhile undertaking from the standpoint of the current owner of the firm. He also means that the cost of capital is very difficult to calculate in a company, but that it ranges between five and 15 percent depending on the capital market.

Performance measurements need to be fed back to the production system in an appropriate way. The production planning function generally controls the production environment and has great possibilities to do exactly this.

4.8 Planning

The purpose of planning production is to

- Make sure there is sufficient supply of components and materials
- Make sure that inventory is sufficient, but not oversized and economically expensive.
The main production plan is in general a manufacturing plan generated with respect to previous order stock, material availability and construction situation. It is the foundation for purchasing and gives dates for production start.

The level of detail and horizon of planning for a corporation

The detailed plan is meant for controlling the shop floor work so that delivery times are held. Its purpose is also to make sure that material, equipment, material and capacity is available for production and that costs for WIP and warehouse is kept a minimum. See figure 4.9. (Segerstedt 1999)

A method for planning the needed material is using a material requirements plan (MRP). A prognosticated demand is made for every product with an external demand. This demand is interpreted as delivery dates in the planning. Using lead times for externally required or in-house manufactured components the total requirement is determined. The total requirement is then checked against the storage and planned deliveries in order to make a start production or initialise purchase to secure future availability. Calculations begin with the highest article in the product structure, and stretches down to each component on every level. (Segerstedt 1999)

MRP is not always suitable, and there are criteria that have to be fulfilled (Segerstedt 1999);

- The existence of a continuously updated production plan
- A complete structure register illustrating what articles and components that are a part of overlying components in the product structure
• Correct inventory levels for every single component
• Correct lead times for all components, both purchased and in-house manufactured

There are other, not entirely complementary but different, planning methods such as the cyclical planning which is a combination of material and production planning method. Products are produced in a cyclical manner that is repeated after a specific interval. All products are produced at constant interval or in multiples of this interval. The cyclical planning is useful when;

• The production has a rhythm, or when rhythm can be created
• Demand is relatively even
• Demand for flexibility are moderate

The cyclical planning time is determined by

\[ T_{opt} = \sqrt{2 \times \frac{\sum A_i}{\sum h_i d_i (1 - o_i d_i)}} \]

Where;

\( T \) = cycle time, shared by all products
\( A_i \) = Set up cost for product i
\( h_i \) = storage cost for product i per unit and time
\( d_i \) = Demand per time unit of product i
\( o_i \) = operation time of product i

Cyclical planning gives shorter lead time, shorter set up time and less planning work. Segerstedt (1999)

The production planning function uses information about the state of the production environment. Planned production output must be based on the production capacity. Therefore tools for analysing capacity is very important.

### 4.9 Production capacity and bottlenecks

The definition of capacity is clear, but there are different ideas of capacity. The peak capacity is the maximum output that a process or facility can achieve under ideal conditions. The rated capacity on the other hand is the maximum annual output assuming continuous operation except for an allowance for normal maintenance and repair downtime. The effective capacity is the maximum output that a process or firm can economically sustain under normal conditions. Krajewski et al (2002) and Anupindi (1999) further state that resource pools with minimum theoretical capacity are called theoretical bottlenecks.

A capacity can vary from different operations, means need to be taken to maximise output and minimize WIP. Line balancing is a method of levelling the production capacity between operations in a production line. As the total production capacity is determined by the production line bottleneck. In order to maximise production as much as possible the capacity
should be equal at every operation. The available time at every operation determines the production pace, called cycle time. Segerstedt (1999)

The balancing loss is determined by;

\[ d = n \times c - \frac{n \times \sum t_i}{n \times c} \]

where

- \( n \) = number of operations
- \( c \) = cycle time
- \( t_i \) = operation time for operation \( i \)
- \( \sum t_i \) = total work contents

The cycle time is chosen in the interval of

\[ t_{\text{max}} \leq c \leq \sum t_i \]

Where \( t_{\text{max}} \) is the longest individual cycle time. (Segerstedt 1999)

The theory of constraints (TOC) is an approach to management that focuses on maximising the flow of total value-added funds or sales, less discounts and variable costs. The fundamental idea is to focus on bottlenecks and increase their outputs. The theory of constraints involves five steps; (Goldtratt 1990)

1. Identify the system bottlenecks
2. Exploit the bottlenecks
3. Subordinate all other decisions to step 2
4. Elevate the bottleneck in terms of capacity
5. Do not let inertia set in, continue the process from step one.

In order to elevate the bottleneck there are a few good rules. They are;

1. Decreasing the unit load on the bottleneck resource pool
2. Increasing the load batch of resources in the bottleneck
3. Increasing the number of units in the bottleneck resource pool
4. Increasing scheduled availability

Flow time, throughput and capacity depend on all elements of the process. That is the nature and mix of the flow units, the required activities, buffers and their network structure. It is also the resources allocated to perform them and the operating procedures used to manage them. Anupindi (1999)

Anupindi (1999) means that throughput and capacity utilization is set in relation by:

\[ \text{Capacity utilization} = \frac{\text{throughput}}{\text{theoretical capacity}} \]
In order to manage capacity, there are different variables to adjust. Anupindi (1999) suggests four levers;

1. Manage supply and demand to increase the throughput by having reliable suppliers and produce better forecasts of demand

2. Decrease resource idleness to increase process capacity by synchronize flows within the process to reduce starvation and set appropriate size of buffers to reduce blockage

3. Increase the net availability of resources to increase effective capacity by improve maintenance policies, perform preventive maintenance outside periods of scheduled availability, institute effective problem solving measures that reduce frequency and duration of breakdowns. Also motivational programs and incentives to reduce absenteeism, increase employee moral should be instituted. Further the frequencies of or time required for set-ups or changeovers for a given product mix or change the product mix should be reduced.

4. Increase the theoretical capacity by decreasing the unit load in the bottleneck resource pool. This could be interpreted to work faster, work smarter, do it right the first time, change the product mix, subcontract or outsource and invest in flexible resources. The load batch of resources in the bottleneck resource pool should be increased. That is an increase in scale of resource. Further the number of units in the bottleneck resource pool should be increased, an increased scale of the whole process. Last the scheduled availability should be increased.

Just as production capacity, lead times are also an important lever to be able to control and monitor.

4.10 Product flow and lead times

Jackson (1999) proposes a time approach where the ratio between value adding time and total time. It is said to be easy to measure, easy to understand, easy to compare and state that there is approximately a linear correlation between time and cost.

Anupindi (1999) presents a number of flow measures for flow time and flow rate.

- Average flow rate or throughput of a process, indicating how many units that pass per time unit (R)
- Average flow time for a unit through the process is the average time that a typical flow unit spends within process boundaries (T)
- Average inventory, the average number of units within a process (I)

Little’s formula shows the connection between the average flow rate, the average flow time and the average inventory.

\[ I = R \times T \]

Anupindi (1999) defines the slack time of an activity as the time it can be delayed without affecting the process time and the flow time efficiency as the product between the theoretical flow time and the average flow time.
Flow time efficiency = Theoretical flow time / Average flow time

Ultimately both capacity and lead times affect the output of the production process. Looking at quality is also a way of illustrating important concepts of operations management.

### 4.11 Quality and process improvement

TQM, total quality management, is a philosophy, which stresses three principles to more efficiently manufacture quality products; (Krajewski et al 2002)

1. Customer satisfaction
2. Employee involvement
3. Continuous improvement in quality

Quality itself is the ability of a firm to meet or exceed the expectations of the customer. Basically quality is described by conformance to expectations, value of the product, its fitness for use, the given support and psychological impressions. The complete program in employee involvement includes changing organizational culture, encouraging teamwork, fostering individual development through training and establishing award incentives. Employee empowerment is an approach that moves responsibility farther down the organizational chart – to the level of the employee actually doing the job. Continuous improvement is naturally the philosophy of continually seeking ways to improve operation.

Three techniques for documenting and evaluating processes. The first one is flow diagrams. It is defined as a diagram that traces the flow of information, customers, employees, equipment or materials through a process. The second one is a process chart, which is an organized way of recording all the activities performed by a person, by a machine, at a workstation, with a customer or on materials. It contains operations, transportation, inspection, delay and storage. The third technique is simulation models. Simulation reproduces the behaviour of a process using a model that describes each step of the process. (Krajewski et al 2002)

Whether trying to manage the current situation or planning for the future there are new tools helping out. Computer simulation is one that, used in a proper way, can be very useful.

### 4.12 Simulation

Simulation is the act of reproducing the behaviour of a system using a model that describes the processes of a system. A fully developed model is a tool where specific variables can be changed to observe the change of the whole system. Simulation model cannot give answers about how problems can be solved, but are useful in analysing different solutions to problems. Krajewski et al (2002)

Chan et al (1992) means that accurate simulations of existing systems serve as a good basis for comparisons with modified systems. The simulation model can be used to test if anticipated capacity can be reached.

Chaharbaghi (1990) defines the making of simulation projects as a three step process. The first is the definition phase. The second is the communication phase, followed by a third model construction phase. See fig 4.9.
Simulation project model

Define the project aim

Define configuration & collect data

Revise system definition

Modify the model

Present schematic model

Construct schematic model

Make computer model

Run the computer model

Is the schematic model an accurate representation?

Are the results valid?

Does the system configuration meet the objectives?

Conclude the project

Present the results

Yes

No

Yes

No

Yes

No

Yes

No

Yes

No

Free interpretation from Chaharbaghi (1990)

Fig. 4.10 – Simulation project model
5. Results

_In this chapter the results from the empirical study at the Xaar plant is presented_
5.1 Production process – variables affecting the flow

Using the definition of a process from chapter 4.1 the entire production process at Xaar can be said to need a number of items. The process takes bought materials for an input and delivers manufactured print heads as output. The entire production process needs information in terms of production start, a build plan that indicates what is to be built from the material. Additional information such as changes in the production plan, priorities of e.g. print head individuals is also needed. This communication is mainly carried out by the administrative management. The production process also needs resources in terms of adequately educated operators and working machinery. As shown in the chapter 4.1 definition the, strategy and aims of the corporation strongly effects the layout and function of the production process. See figure 5.1.

From the process definition, several variables have been identified that affect the product flow:

- Staff availability, competence and experience
- Machine capacity, reliability
- Output quality, yield
- Planning input (priorities, product mix)
- Performance measures, scorecards

5.2 Production strategy/ Planning input

The expressed manufacturing strategy today is to produce to customer orders. That is that Xaar wants to minimise the storage of finished goods as much as possible but at the same time deliver quickly to customers. The planning department starts production at two concurrent places, the wafer production and the final assembly. The production is started by delivering a weekly production plan to each part. By using a standard lead time through the production, preliminary daily production plans for every operation is created. See figure 5.2.
Looking further in to the production process, a few issues can be enlightened to give an idea of the articulated strategy in real production. Planning lead times, delivery time stock levels and back log can give a good picture of the situation.

5.3 Operator availability & competence

In order for staff to be present there needs to be a base of available operators. Xaar has about 90 operators for the production. Although having a great number of staff, all operators can not handle every operation. Some operations require more working experience and that the operator possesses knowledge of the production process.
Also some operations are fairly easy and can be carried out by virtually anybody. Xaar has a system for certification of machine operators. The idea of the certificate is to make sure every operator has the proper education on the machines necessary for each operation.

The reason is to maximise output quantity, output quality and to minimise the risk of injury and the need of technical support.
Today most operators are certified with the operations they use, but that does not account for everybody. The pattern of competence is presented in figure 5.3, 5.4, 5.5 and 5.6.

Not only is it important to have formal education but experience is naturally very important. The operator experience has been mapped, which is shown in figure 5.7.
5.4 Machine reliability

Xaar has no direct way of measuring machine reliability. Instead a number of other variables can be illustrated to give an idea of the situation. The work in process, WIP, is illustrated for the production lines. In figures 5.8-5.11 the production WIP of the front and back end production (Wafer, cover, nozzle) is illustrated.

The data is collected in period between January and September 2004. The WIP at each operation and at different times is shown along the x-axis, indicating the trend of changing WIP at the operation over time. Fluctuations can easily be observed.
Both the XJ126 and XJ500 have no recorded information for early spring of 2004, as the production information system Shopfloor had not been fully incorporated at the time.
A way of illustrating the same phenomena is to look at lead time variance, which is commented in the lead time section.

### 5.5 Physical product flow

Firstly the shipped product volumes are illustrated to give a view of the comparative work load different product lines has. Figure 5.12 shows all Xaar products sorted after yearly shipped volume. The scale is normalized, showing each products volume as a percentage of the entire shipping volume.
The Xaar production line manufactures different types of products. The flow is not direct, nor is the flow of the different products the same. Figure 5.13 shows the product flow through the different operations. The flow starts with respective wafer, cover and nozzle production on the left hand side. In the middle of the production process there is a buffer of finished actuators, and the flow goes in to the assembly part on the right hand side of the central buffer. Down right is the last operation, packaging. See appendix 8 for a more detailed version.

**5.6 Production lead times**

The average lead times through the production are illustrated in figures 5.14 and 5.15. The front end lead time has been restricted, handily excluding the buffer.
after operation 100 which was used during the sample period (Jan – sep 2004) to make up for industrial holidays. The lead time for front end XJ128 and XJ126 batches are virtually the same as they both have 128 channels. They have therefore been put together. The lead time variance is presented alongside the lead time.

The lead time is naturally distributed over several operations. Figures 5.16 and 5.17 illustrate randomly chosen samples of product lead times in the front end production area.
Each line represents one batch in the production flow. Its exit record from the operations indicated by the x-axis is shown against the recorded time on the y-axis. The time is related to the production start of that very batch.

As the back end production has limited number of data entries, only the back end production data for XJ126 and XJ500 is shown. Figure 5.18 shows the XJ500 lead times from operation 500 to 510.
5 – Results

Figure 5.19 shows the back end lead times for the XJ126 from operation 127 to 187.

5.7 Product yield
There are several inspection and testing steps along the production line. Print heads of undesired quality are scrapped, and registered into the system. The produced yield data is presented in figures 5.20 – 5.24.
All yield data stretches through both front and back end production areas. Although scrapping does not occur at all operations, they are all represented in the graphs.

The yield of both the 200 and 360 DPI versions of the XJ128 is presented. In general the high resolution print heads are more difficult to manufacture.
The XJ500, being a more expensive product, has more steps for inspection and scrapping than the other two products. There is also a significant difference between the 200 and 360 DPI versions.
5.8 Operations capacity

Figures 5.25 and 5.26 show the process layout. They show the production flow and the operation layout, in the sense of how each operation is capable of working parallel tasks. As individual lead times have been presented, this capacity chart shows how many parallel jobs each operation can commence.
5 – Results

Figure 5.25

Figure 5.26 shows the same thing for the back end production. In this part however, the flow is divided into XJ64/X128, XJ126 and XJ500 flows.

Back end capacity layout

Fig. 5.26
The real capacity of single operations has been measured. The Capacity regards the maximum capacity an operation has today. This is measured in number of wafers per shift for front end operations, and number of print heads per shift for back end operations. Figure 5.27 shows the capacity of the front end operations. It is assumed that the operation time for 128 channel, and 500 channel wafers is the same – although each wafer contains different number of actuators.

Figure 5.27 shows the back end rated capacity for XJ126 print heads, starting with operation 127 to 175. Note that the die bond and wire bond operations together with the packing operation are also used for the production of the XJ500 and XJ126 but presented in the Figure 5.29 along with the XJ128. The capacity of these operations is therefore shared between the operations, hence the product mix may determine the total capacity for the flow of a product. Figure 5.29 shows the maximum rated capacity of the XJ128 in the back end operations. Figure 5.30 shows the maximum rated capacity of the XJ500 in the back end operations, presented in print heads per production day.
5 – Results

The capacity of different operations per day is naturally adjusted by over time work when needed. Figure 5.31 shows the total over time of production staff at Xaar. The figure shows hours per month and the entire production personnel.

5.9 Performance measures used today (Scorecard)

Xaar uses balanced score cards in the production to visualise specific variables to the employees. The following measures are used:

Current performance measures for XJ128 (Xaar)

Quality
- Back end yield
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- RMA returns as % of output
- SMQ
- Total process yield
- PPM out of box failures
- PPM in warranty failures

Delivery
- Percentage of the build plan achieved
- On time delivery to customer

People
- Overtime percentage
- Direct labour flexibility
- Sickness percentage

Cost
- Material price variance relative to initial standard
- Labour variance per head
- Inventory turns
- Cycle time (actuator receipt to head being placed in stock)
- Scrap value per head as % of total cost

5.10 Simulation model
The simulation model has been based on the results of this chapter to imitate the flow at the Xaar plant. The model simulates the production process for print heads of the studied types, XJ64, XJ128, XJ126 and XJ500. The variables that the model possesses for each operation is operating time, operating time variance, the number of parallel operations, the used worker shift, the yield, machine breakdown frequency, machine breakdown length. Each operation can either work in a “pull” or a “push” mode. In the “pull” mode it produces to fill a set buffer at the next operation. In the “push” mode, it processes everything it can. All variables can be controlled from an Excel sheet for easy simulation. All operations of fig. 5.25 and 5.26 are used in the model. The nozzle production bi-flow is also incorporated in the simulation model. See appendix 6 for model details.

5.11 Engineering poll
To obtain information on reasons for low yield, a poll was made amongst the Xaar production engineers to gather information on reasons for yield issues. This result is based on opinions, with the first and lowest number the greatest cause.

1. Physical material handling lacks procedures
2. General lack of understanding of what material specifications that give good yields.
3. bad quality, sample variations from the supplier

The same group was asked to give the reasons for operation stand stills. The first and lowest number indicates the greatest reason.

1. Lack of material
2. Machine failure
3. operator missing

5.12 Reference study at Ericsson

For evaluating the possibilities of bottle neck visualisation, a reference study at Ericsson in Nynäshamn was made. The Ericsson manufacturing facility is a high volume plant for telecommunications equipment. The products are complex, the volumes are high and there is a high degree of automation.

Bottle necks at Ericsson were calculated in a simple way using an Excel sheet, based on database lead times. The found bottleneck was marked with a sign hanging from the ceiling, clearly showing a “bottle neck”. As a second step, all production WIP was monitored on computer screens on the production shop floor. This method of monitoring WIP gave each operator the insight to the current situation. Every operator could see what WIP located at their own operation, and all other operations. This was used as a tool for helping fellow workers to cut their WIP, or to schedule lunch hours. Although naturally taking some time to adopt, this new system was in a high degree used by the machine operators themselves.
6. Analysis

This chapter discusses the Xaar situation in relation to relevant theory
6.1 Production strategy

I order to control a production flow there needs to be certain rules of assessment. As stated in chapter 4.3, all the processes within a corporation are greatly affected by the production strategy. The strategy itself comes from a company’s core competencies listed in the same chapter. The core competencies include the choice of being good at delivering on time, having high product quality or low price amongst others. It is further concluded that a company cannot compete successfully in many different core competencies. Either a company is successful in delivering on time, having high product quality or low prices. Hence, money is made either by focusing low costs in the production process or on high income from sold products. Trying to be successful in both a high quality product with a low price can be devastating.

Looking at Xaar gives a confusing picture. Xaar is said to manufacture to order. At the same time production capacity is very much locked up in order to achieve a monthly build-plan. The monthly build plan has little connection to actual customer demand, as it is based on a prognosis for the selling department. On the other hand there is room for change of the detailed production plan to fit customer orders, when it is suitable. Also there seems to be a low interest in making investments in a flexible and effective production at the same time as yields and quality are great issues. Either Xaar can choose to manufacture to stock, developing an efficient production according to the ideas in chapter 4.4. That means a constant flow of products, large lot sizes and efficient usage of staff.

The other choice is to develop the ability to manufacture to order. That would need a flexible workforce, in other words having a flexible capacity. The production could contain several steps with actuators being made as a module and stored till the arrival of an order. Thereafter the print head could be quickly assembled. This scenario is of course more costly – but gives Xaar other premises of competition. The important thing might not be which strategy Xaar picks, but the fact that they pick one.

As shown in fig 5.2 of the production layout today, the planning department starts batches at two points in the production. Firstly the wafer production is initialized. The wafer production manufactures in it’s own pace. The second step is the assembly which has its own production plan. Today the idea is to have a buffer of actuators in between the two production areas, and make assembly lead time as short as possible. This production method coincides with the definition of chapter 4.5 of a push system. Xaar pushes products through the production lines. Looking at the lead time figures gives the impression of products being started on schedule, although coming out in an apparent more spread pace. The work in process, WIP, is also clearly uneven. It is uneven both between different operations and at one operation at different occasions.

6.2 Operators and production staff

Xaar operator availability is quite uneven. Many operations have a good base of operators, while others have quite few. Looking at the results of operator licensing, it is obvious that some operations are vulnerable to staff illness or other staff absenteeism. This can be even clearer at operations that require more experience. By looking at the discussion of section 4.9 it can be a painful realization that competence amongst other staff is simply not good enough. In this area Xaar could, in a more active way, make sure that staff rotates to learn more tasks.
The certification system is not up to date as non certified operators are working in the plant. The certification method is not only a way of increasing knowledge amongst the operators, but it also brings transparency to the staffing situation. Rotating staff might not be the most efficient way of running staff, as it means that one operator leaves his or her operation in order to become a student on another. In this fashion operator productivity will drop. On the other hand it should be seen as an investment for future competence and production reliability. According to the survey 79% of Xaar’s operators would approve of being given new working tasks. Hence action taken to increase worker flexibility might even result in a higher degree of motivation. Along with the discussion in chapter 4.3, the human capital is important, where successful companies don’t neglect this asset.

There is a broad base of experienced operators at Xaar, where almost half the work force has worked for more than four years. Also about forty percent of the operators have more than eight years of experience at other companies than Xaar. This base of experienced staff is important for the running of the plant and should be kept between the factory walls.

6.3 Lead time and process reliability

It is obvious that the lead time reliability is low. According to the figures of the results chapter, the lead time variance of both front end and back end production parts are significant. As both lead time and WIP ultimately concerns the amount of products that are in the production lines, a varying inventory shows neither tendencies of a production system that is in line with the JIT philosophy nor the theory of constraints. The production system has no particular focus on neither efficient usage of machine capacity nor minimization of lead times and inventory. The WIP analysis shows a similar pattern as well, where inventory levels are uneven. Looking at the figures 5.14-5.19 there is an image projected of fairly even lead times in the front end production area, in opposite to the average lead time and its variance. There is a tendency, however, indicating that products spend unreasonable time at operation 30. This operation is according to the process layout, the first operation in the washing facility. Four operations use the same machinery; the flow crosses this particular washing facility four times. There is visibly a delay of batches at this point. The washing operation is a bottle neck, at least in an isolated front end flow. Similar lead time patterns can be observed for the XJ500 and XJ126 back end production flows. The XJ500 spends more time at operation 502 than at any other operation, pinpointing a bottleneck for the XJ500 back end production. In the same manor, the XJ126 seems to have a capacity shortage at operation 127.

6.4 Physical product flow

The flow is naturally depending on the product mix, as the products do not have identical production flows. The process layout chart shows that all products share the same operations in the front end production part. After the actuators have been manufactured the products go different ways, with only the XJ64 and XJ128 going the same path as they practically share the same components - only the XJ64 being half the size of the XJ128. All flows meet in the die bond operation (155) and the wire bond operation (160). The shipping volume data shows that the XJ128-200 is the dominating product.

The flow is complicated, as several operations are taken place inside dust free compartments, making the exchange of materials and information difficult. It also makes it more difficult to keep an overview of the situation.
6.5 Lead times
Looking at the lead times, it is apparent that there is a mismatch between the measured average lead times and the number used for planning. The planning department uses a lead time of 10 production days through the front end production. In reality the lead time average is almost 12 days for the 128 channel wafers, and almost 15 days for the 500 channel wafers. An increase of overall yields with 10% would logically increase the total output with the same amount. As the product scrapping takes place along the entire production line, a low yield puts pressure on the first operations to keep a flow of finished products.

6.6 Product yields
The yields at Xaar are fairly low, reaching levels at about 60% on the lower resolution products, and being as low as 30% on higher resolution products. The yields put high demands on the front end production, which manufactures large amount of wafers that are later scrapped. This is a capacity issue of great magnitude, where the effective capacity of the entire plant could be increased considerably only by increasing the yields. The yield is of course also a matter of economic margins, yet another incitement for increasing the yields. To improve the quality, staff should be more involved in the process of increasing yields in analogy with the discussion in chapter 4.11.

6.7 Operations capacity
The operations lead time has been found and together with complete information of operations layout the capacity is obtained. This analysis shows the vulnerability of the production process where the washing operation (30, 60, 75 and 320) together with the die bond operation that have only one machine. These operations are particularly vulnerable to machine break downs, as the entire flow would stop. Changing the lead time of these operations would also be more apparent to the entire flow.

Although the maximum technical capacity is not yet met in the Xaar production plant investments in new machinery to increase production capacity could affect yield and reliability. There is a choice of outsourcing chosen parts of the production, such as the making of platforms for mounting actuators on or entire actuator nozzles. The dimension of these buffers is also important, which is considered under its dedicated part.

The operations capacity analysis shows what operations that have the least theoretical capacity. For the front end production, it is the washing operations. As the flow crosses this operation in a total of four times, the demand on this operation also increases fourfold to the increase of total line throughput. In the back end operations the theoretical bottle neck is the frame assembly operation. However, the real bottle neck is the operating staff, as several operations are shared between the operators. The capacity at today’s staffing plan, the actual capacity is much lower. For the XJ128 the back end theoretical bottle neck is the fill and fire operation. Again here, along the XJ128/XJ64 line, several operations share operators. This makes the actual capacity to differ from the theoretical capacity. For the XJ500 the bottle neck is the manual fill and fire. Looking at staffing, again, the same reality faces this line. Naturally the production lines are staffed to fit the flow, not to provide maximum capacity.

6.8 The planning process
This process is very much affected by the strategy. There is also a possibility to use a more pull-like flow within the production. In stead of making a plan with expected batch-start per
day a system of Kanban or cover time planning could be used for the front end part. The planners would then not need to consider the exact amount of started batches, as the flow would control itself. This way of planning would also enable buffering between certain operations. Focus would hit upon what comes out of the production line, not what goes in. The supply of materials and bi-flows could be controlled the same way.
This chapter presents the results of the thesis as to how Xaar shall go about with maximising the product flow. The suggestions are discussed as they are presented.
7.1 Production capacity and bottle necks

The production capacity at Xaar has been measured, pinpointing exact capacity weaknesses. Although capacity is not a fix concept within a company, the theoretical capacity bottlenecks can be stated as the following:

- Washing operation (30, 60, 75 and 320) is a bottleneck for the front end
- The nozzle manufacturing operation (120) is a potential bottleneck mid end manufacturing
- The die bond (155) is a bottleneck for the XJ128 back end manufacturing
- The frame assembly operation (127) is the back end XJ126 bottle neck
- The fill and fire operation (570) is the bottleneck for the XJ500 back end production

See appendix 5 for a complete list of Xaar operations.

However, different product mixes may change the pattern, as some operations process more than one product. Also, there might be no need for maximum capacity utilization, but only a fraction. In these cases the number of shifts used in production can be reduced. However, to keep an optimal flow the new produced “pseudo” bottleneck, being the operation with the least available capacity, needs to be viewed as a full bottleneck to prevent over time or an uneven flow.

As stated above, the product flow – capacity – depends on a number of different variables. These variables tend to fluctuate considerably over time. It is therefore important to have these variables under control. Xaar should develop a method to instantly overview these variables in the actual production activities. Firstly, using statistical data on theoretical operations capacity, an idea of the production characteristic can easily be presented. The theoretical capacity found in this study at each operation per shift stands as an ideal base for capacity calculations; (see appendix 2) In order to get a steady flow, these capacities must be leveled by different usage of operator shifts. At this point the possibility of a steady flow has very much increased. The operation with the lowest calculated capacity is considered the bottleneck.

As the theoretical capacity differs between operations, different shift patterns are needed to level the production. The maximum theoretical production pace of the facility is;

- 126 wafers per shift (5 batches per day) in the front end
- 1,826 print heads per production day of the back end XJ128/XJ64
- 1,372 XJ126 print heads can be manufactured per production day
- 140 XJ500 print can be processed by the front end per production day

These are maximum theoretical paces and will not be possible to hold for longer periods. Also, they do not consider the yield. A low yield value will put high demands on early operations to keep the late operations busy. This means a high workload for front end operations to keep back end operations going. However, a focus on bottle necks and implementations of pull system, buffers the production. In this way the production may come close to these figures. A pull system would make every operation concentrate on filling up missing items in the buffer of the following operation. Note that this could mean over time on operations using less than three shifts per day.
The suggestion for production capacity and bottlenecks mainly involves a first step in developing a focus on the front end washing operations. Further bottleneck analysis needs to be carried out as suggested in respect to rated capacity.

7.2 Visualizing bottlenecks in production

Xaar should visualize the production capacity in a clear manner. This is made in two simultaneous ways;

- By using a computer aid to monitor production WIP and theoretical bottlenecks (see appendix 3)
- By physical decoration of low capacity operations and machines (see figure 7.1)

The computer monitor should show two things. First the theoretical capacities based on current staffing and machine usage. This would be illustrated according to the example in appendix 2. It is important that this information is presented in a way that gives a clear overview of production capacities. This information may be very useful in planning staffing, service and as information for operations upgrade. Although good for some decisions, using an analysis such as this for determining bottlenecks is not sufficient. There are too many stochastic variables affecting the real instantaneous capacity. Therefore the second visualization is a real time information system that keeps production staff informed of the current WIP. An example of this is shown as appendix 2. This information gives production management an instant view of the production situation. As the theoretical bottlenecks per definition are theoretical, the real bottlenecks may occur at other places due to factors such as machine failure, operator illness or individual operator working capabilities. The idea of monitoring this information is to give the production manager and staff the tool to level the production WIP by reducing pace or helping out at other operations. In this way there is less risk that bottleneck operations run dry from material to work on.
The theoretical bottleneck(s) that are pointed out should be decorated as a bottleneck. The decoration in practice means having a sign that is clear enough to catch the operator’s attention. This sign is not meant to irritate, or point out operators but is a part of the bottleneck focus. See fig 7.1 for an example of how this could look. Note that the sign is for easy transportation, as the bottleneck may vary.

The two methods are needed simultaneously side by side for a complete and versatile overview of the production environment. The first step in the work to visualize the bottleneck operations should be for Xaar to arrange for the physical decorations as well as develop a simple but effective computer system for visualizing WIP. Computer monitors should preferable be placed in the production environment showing this information.

7.3 Bottleneck focus

Simulations show that the front end capacity would increase with between two and seven percent using buffers at the bottle neck operations. The identification of a bottleneck is worth little if it is not surrounded by an entire concept of bottleneck focus. That is, to enjoy increased capacity in reality a complete bottleneck focus is needed. In order to keep the wanted output, the bottleneck must not stand still. The actions that need to be taken are;

- Accumulate a buffer before the bottle neck. (this is done by deliberately working too much in the preceding operations). The buffer size is presented in the other section of this chapter. This gives the preceding operations time to make up for lost production, in order to keep the bottle neck busy

- Practically work at the bottle neck to maximize the running time. This includes minimizing set up times, minimizing stops for change of material and worker breaks
These points need to be supported by an

- Education program for engineers and operators

Whether the aim is to keep a steady flow or to maximize the throughput, control of a variable bottleneck should be tight. Uncontrolled increase in WIP should always be avoided.

The decoration of the bottle neck itself needs to be complemented by a total understanding of the need of the bottleneck to run continuously and effectively. This is why the tools for controlling the production flow are followed by an education program. The aim of this program is firstly to give an understanding of production flows, how different capacities affect the output. This part could be completed by relevant staff from Xaar, using for example the book or motion picture of Goldratts “The Goal”. A second aim of the program is to increase the motivation and interest for modern production methods.

In order to get to the bottle neck focus quickly at Xaar, there is a great responsibility from the general management to organize the education program. The responsibility of developing more efficient working methods at each operation is a task that is best carried out by the process engineers together with the operator team leaders. Organizing suggested education program and responsibility areas would make Xaar production bottle neck focus take a great leap forward.

**7.4 Suggestions for buffer sizes**

Having the right buffer size is important to keep a balance between a steady flow and long lead time as large buffers smoothes flow but increases the lead time of single products. A production line without buffers puts very high demands on a low variation in capacity. Although buffers tend to hide the real problems of capacity variations, this phenomenon is impossible to avoid completely. Having the wrong buffer size may lose the intended effect of the bottleneck focus ambition. Xaar should emphasize on having a flexible buffer to put in front of bottlenecks. This buffer should be constructed to have enough size to pull out items of the operations before it. Using basic theory of safety stock, a reasonable and simple thumb rule can be used to equip theoretical bottle necks with a capacity cushion. The size of this cushion should be (using a 99% service level):

- Safety stock (Units) = \(2.33 \times \text{Capacity variance (Units)}\)

**Note that the Capacity variance reflects the capacity variance of the part to be cushioned, in case of a bottleneck it is the production part before the bottleneck. (See appendix 7 for simulation results)**

If the lead time is easier to obtain the same cushion could be described as (using 99% service level):

- Safety stock (Time units) = \(2.33 \times \text{Lead time variance (Time units)}\)

The idea of this buffer is to make sure the bottle neck is running at maximum capacity, despite stochastic variations of capacity in its supplying operations. By definition the bottleneck is the slowest section of the production, and therefore earlier operations have the capacity to build up this buffer.
In order to buffer actuators, the lead time used for planning should be extended with a buffer lead time. Using the formula presented, this buffer is:

- 128-channel production; Seven days, making a total front end lead time by 18 production days.
- 500-channel; Nine days, making the total lead time 25 production days.

However, the first step to be taken is to build a buffer in front of the washing operations. By using the suggested formula the size of this buffer would come close to three batches. Three batches per operation that is; hence the washing operation consists of four batches which makes a total buffer of twelve batches.

### 7.5 Production strategy

Xaar should emphasize on manufacturing to stock as it would give a potentially higher output than having a strategy where production is made to order. There are several other reasons as well, and the most important one is that Xaar has a high demand over most of the year, and production is not running all year. The second reason is that Xaar has a record of machine failures that could devastate customer satisfaction in an order based production. Thirdly, with the production plans of today, the most efficient way of producing would be to just manufacture according to the prognosis, and make sure there is a stock of *every* item. The last but not the least reason is that the component cost of the Xaar products is fairly low, which means that the capital stored up of this production strategy would not be too great.

Ultimately this is a decision for Xaar management to decide for which premises Xaar shall compete and formulate a production strategy.

### 7.6 Suggestions for staffing

As several operations have only a few available operators there is a risk of a lack of personnel. According to the statistics of Xaar sickness rates, there is a 2% probability that an operator is sick. That means shortfall one day every 1 ½ month at every position. Having only one or two operators available that naturally means production disturbances. Assuming disturbances are great for operations with three or less operators, there are eight operations that will be affected every month!

- Xaar should aim to have at least three active and available operators per operation
- Also every operator should be certified at three or more operations, avoiding that a few is the back up for many

### 7.7 Suggestions for maintenance

As Xaar has some very specialized production lines the manufacturing process is very sensitive to shortfall of production machinery. The lost capacity of the laser ablation operation during the fall of 2004 lowered the production capacity and increased over time costs. These kinds of production anomalies must be avoided. Xaar has to form efficient task groups with engineers and production staff for

- Making an analysis of the risks and consequences of machine capacity losses
The same group would then focus preventive maintenance to the most exposed operations. The group should also find alternative routes, either within the production facility or by finding a suitable sub-contractor. Operations involved in this work would be vulnerable operations such as the Die Bond, Laser ablation and the Washing operation.

7.8 Scorecard suggestion to focus production variables
In order to keep better control of the production environment, a few more variables should be monitored by scorecards. The aim is to minimize the operation time variances. The smaller operation time variances the production operations have, the smaller the buffers need to be. The ultimate situation is getting maximized output and minimized lead time simultaneously, the very definition of lean production. The scorecard variables are:

- Average lead time front end
- Lead time variance front end
- Average lead time back end XJ128/XJ64, XJ126 and XJ500
- Lead time variance back end XJ128/XJ64, XJ126 and XJ500
- Front end yield
- Back end yield XJ128/XJ64, XJ126 and XJ500
- Number of operator certifications

See appendix 1 for an example of scorecard, made during the time for the thesis. Also, in order to keep track of instant values – an electronically updated scorecard should emphasise on the following information:

- Packed print heads per date
- Backlog, print heads type and date
- Production line inventory, per product type and date
- Current stock of finished goods

This last information is useful to create an overview of the current situation at the plant; it gives information of what products are located in the production line, what products that are short to the customers and what has actually been packed. In the long run this information could increase the understanding of the importance of working with the right products at the right time. A helpful view in the modern production business aiming at deliver to customer needs.

7.9 Conclusion
This chapter has presented a number of results. They are to:

- Accept the washing operations 30, 60, 75 and 320 as theoretical bottlenecks
- Continuously monitor flow and bottlenecks with computer screens connected to the manufacturing information system
- Visualise bottlenecks using special eye-catching signs
- Focus physical work at bottlenecks to maximise the running time
- Level production using bottlenecks to set the pace
- Use pull driven production with buffers
- Utilise machinery efficiently and manufacture to stock
- Use more scorecards to monitor variables that can improve the total quality
- Increase the staff competence by rotating staff
- Create task groups for maintenance, yields and bottleneck capacity improvement
• Formulate a manufacturing strategy

The main points of these results is to give Xaar better tools to control the production flow, focus bottlenecks and have a logical chain of information and base for decisions in order to produce to fill a demand efficiently.

Xaar obviously has many strengths and an interesting future. However in the sense of production quality and efficiency there are issues needed to look into. With ambition to grow and reach new customers the company needs to be able to meet and excel customer expectations. These expectations affect the production process in a very high degree as the control of and ability to improve the product quality, price and delivery and custom specifications lays here. Xaar is a fairly young company, with new technology and complex production process. It has gone through periods of both decline and success. Today Xaar seems to be mature enough to take the next step and aiming at becoming a world class supplier of printer heads. What Xaar needs to do is to assess the customer needs, consider its strengths and weaknesses and formulate a roadmap for the future. In the sense of production this would mean making a clear production strategy. Either Xaar produces to stock or to customer orders. Either Xaar works towards mass production or customisation. If Xaar tries to keep all abilities there is a great risk that the company will fail to become successful in either one of the areas. The key is focus, and a strategy could provide that. The strategy would work as a foundation for the company to work towards a common goal. This collaboration would be very important where every engineer, every machine operator and every management leader would utterly work for the company’s best interests; the customer. This focus would pervade all company areas and actually make work easier for the individual within the organization.
References

Literature


References

Articles


Appendix
Appendix 1, Example of a score card

Average lead time front end (production days)

Average lead time back end (production days)

Lead variance front end (days)

Lead time variance back end (production days)

Overtime (total number of hours)

Packed per day

Number of certifications
Appendix 2, Example of maximum capacity shift gear

**XJ126 back end rated capacity**

- Print heads per production day

**XJ128 back end rated capacity**

- Print heads per production day
Appendix 2, Example of maximum capacity shift gear

**XJ500 back end rated capacity**

- Print heads per production day

**Front end rated capacity**

- Wafers per production day

- Values per line: 1, 1, 1, 1, 1, 3, 1, 3, 3, 2, 2, 2, 1, 3, 3, 3
Appendix 3, Example of real time WIP monitoring in the Shopfloor system

Front end production WIP - 2004-12-01

Cover production:

Wafer production:

Batch
Batch som bidrar till för mycket WIP
Appendix 4, Xaar product range of XJ64, XJ128, XJ126 and XJ500

<table>
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<th>Model</th>
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Appendix 5, Xaar operations listing

10 Wafer inspection
20 Channel sawing
30 Wafer cleaning
40 Aluminiztion
50 Aluminium remove
60 Wafer cleaning
70 Passivation
75 Wafer cleaning
302 Heat treatment
310 cover milling
305 Cover dicing
415 NWC coating
450 Lamination
470 Laser ablation
490 Nozzle inspection
495 Nozzle cut
320 Cover cleaning
80 Wafer bond
90 Dicing
100 Resonance test
105 Actuator inspection
110 Flushing
120 Nozzle assembly
122 Nozzle assembly
130 Filter clean
135 Filter assembly
148 Carrier assembly
127 Frame assembly
501 Chassis inserter assembly
137 Plasma clean
502 Actuator & PCB attach
155 Die bond
160 Wire bond
161 Electric test
504 Back seal and potting
510 Elbow and temperature sensor
540 Laser ablation
520 Cover attach
570 Manual fill & fire
580 Soak test
585 Cleaning inspection
595 Pre pack
185 Potting
187 Final assembly
196 Inspection
175 Cap assembly
198 Steel ball mount
201 Fill & fire
210 Pre pack
180 Potting
190 Capping
195 Inspection
200 Fill & fire
215 packing
Appendix 6, Selected simulation model blocks

A part of the front end manufacturing, showing how the operation blocks are interconnected

The operation content, with blocks for importing Excel data and communication ports to other blocks
Appendix 6, Selected simulation model blocks

The Machine block, with batching and scrapping calculations

The Machine function within the machine block, showing machines, shifts and data processing
### Appendix 7, Simulation results

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* Capacity has been indexed where the "normal" rated pace as 100
The simulated figures are averages from 50 runs each.
Process layout – Production of XJ64/XJ128, XJ126 and XJ500