Analysis of an assembly process of electric detonators with application of lean manufacturing

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Abstract

The principles of lean manufacturing made known to the world with the success of Toyota have proven to be exceptional way to reach manufacturing brilliance. In recent years these same principles have been used in other industries where for example patients, services or information flows instead of solid products.

The purpose of this thesis is to identify improvement opportunities in the assembly process of electric detonators with application of lean manufacturing. Three different tools were used to discover the areas of interests:

1. Value-stream mapping: To analyze the process on a macro level.
2. Process mapping: To analyze the processes on a micro level.
3. Spaghetti diagram mapping: To analyze the wastes built into the layout.

In addition, simulation with VBA for Excel was used (where applicable) to explore the performance and/or the possibility of suggested changes such as Kanban systems and new production order policy.

Suggested changes include new replenishment systems for company made materials to ensure availability of these materials, elimination of non-value adding processes and justification of increased automation at vital processes. Furthermore, the possibility of changing the production order policy to assembly to order from assembly to stock was explored. Few of these changes require investments in equipment and changes to current processes, for which a rough estimation of the required costs are included.
## Table of contents

1. Introduction................................................................................................................................. 1
   1.1 Objectives ............................................................................................................................... 1
   1.2 Delimitations .......................................................................................................................... 2
   1.3 General overview of the company, product and the production process ...................... 2

2. Theory ........................................................................................................................................ 4
   2.1 The 1st principle: Specify value ............................................................................................ 6
      2.1.1 Value-adding and non-value adding ............................................................................... 6
      2.1.2 Waste reduction and Ohno’s 7 wastes .......................................................................... 7
      2.1.3 Process mapping ............................................................................................................. 8
   2.2 The 2nd principle: Value-stream map ................................................................................. 10
   2.3 The 3rd principle: Flow ....................................................................................................... 12
      2.3.1 Spaghetti diagrams ......................................................................................................... 13
   2.4 The 4th principle: Pull ......................................................................................................... 14
      2.4.1 Kanban, a way to pull .................................................................................................. 15
   2.5 The 5th principle: Perfection .............................................................................................. 17
      2.5.1 Continuous improvement ............................................................................................ 17

3. Methods ...................................................................................................................................... 19
   3.1 Value-stream mapping (VSM) ............................................................................................. 20
   3.2 Process mapping .................................................................................................................. 20
   3.3 Spaghetti diagram ............................................................................................................ 20
   3.4 Simulation ............................................................................................................................. 21
      3.4.1 Fuse-head Kanban simulation ...................................................................................... 21
      3.4.2 Caps Kanban simulation ............................................................................................. 23
      3.4.3 Assembly-To-Order simulation ................................................................................. 23

4. Results ....................................................................................................................................... 24
   4.1 The value-stream maps ....................................................................................................... 25
   4.2 Establishing pull through upstream processes ................................................................. 26
      4.2.1 Kanban system for fuse-head replenishments .......................................................... 27
      4.2.2 Replenishment of explosive caps ............................................................................. 31
   4.3 Eliminating stations that are waste generators ................................................................. 33
      4.3.1 Elimination of the cap filling process ......................................................................... 33
      4.3.2 Elimination of the tube labeling process ................................................................... 35
   4.4 Increasing throughput at the pacemaker ............................................................................ 37
4.5 Establishing continuous flow through downstream processes

4.5.1 Eliminate the need for trolleys by allowing operators to inspect and pack directly from the machines

4.5.2 Assembly to order

4.6 More efficient work-environment

5. Discussion

6. Direction of future work

7. Acknowledgements

8. References

Appendix I – Process mapping

Appendix II – Spaghetti diagrams

Appendix III – Fuse-head simulation code

Appendix IV – Caps simulation template and code

Appendix V – Elsa 4 downtime report

Appendix VI – Current facility layout
1. **Introduction**

The philosophy and techniques behind lean manufacturing has proven to be a successful method of increasing the productivity within a company. In the latest years, these same concepts have even been applied to industries outside of the field of manufacturing, such as hospitals and office sectors. Essentially, they are applicable in some form wherever there exists a flow and value-added work.

The content of this thesis is the application of lean manufacturing methodology to a production process of electric detonators. The goal is to increase productivity. Caution is kept to not to treat lean as just set of tools with one time gain in productivity as the improvement are realized, but rather to provide the company’s management a guidance on where and how the productivity can be improved via lean manufacturing.

Data was collected in three ways:

1. Through direct observations.
2. By interviewing the employees.
3. With extraction from the company SAP system.

To start with, the data collection was focused towards creating the current value stream map. As that was finished, the developing of the future state map would bring to light few areas within the process that required more investigation. In these cases a process map and/or spaghetti diagram was developed to clearly see the wasted activities that were being performed. The employees working in these specific processes were interviewed and asked how they viewed the process, if they felt there was a problem with it or if they saw any potential improvement to it.

As the future state map was developed, a list of improvement changes was created that would need to be implemented to reach this future state. In the result sections these improvement changes are described and argued how they are an improvement from the current situation. The arguments are supported with references to literature and results from simulations.

1.1 **Objectives**

The purpose of this thesis is to identify improvement opportunities in the assembly process of electric detonators with application of lean manufacturing. The predetermined objectives were:

1. To create a current value stream map (VSM).
2. To develop a future value stream map.
3. To suggest actions on how to reach the future map.
4. To develop an action plan of improvement suggestions for the management to follow up on.

It is the hope of the author that this thesis will serve to inspire and set in motion the work towards developing these improvement changes in details and their implementation.
1.2 Delimitations

Focus is put on one of the two product families of explosive detonators, or the detonators based on electrical current for ignition. The production process for these detonators is quite extensive so the thesis work is limited to the last step in this process, that is; the final assembly.

The results are presented and argued to be useful improvements to this process but a detailed development and implementation will be left with the employees of Orica who will see to their realization.

The literature under the topic lean manufacturing is extensive and countless tools exist to investigate and get a clear picture of production processes. The thesis is limited to using VSM, Process Mapping, Spaghetti Diagrams and Simulation to discover these wastes and build up the argument for their elimination.

1.3 General overview of the company, product and the production process

Orica Mining Services is a global corporation and a supplier of commercial explosives, used for mining, tunneling and construction and runs regional offices in Australia (HQ), Asia, Europe, Middle East, Africa, North America and Latin America. Orica Initiating Systems or Orica IS is a division within Orica Sweden AB and is based in Gyttorp, Sweden. At Orica in Gyttorp is the development and production of explosives and their relevant initiating systems for the European market.

Improving productivity is considered to be one of Orica’s three critical enablers to success, along with growth and company culture. In order to reach their goal for market leadership, it is considered a key element, measured as the ratio of total fixed costs to gross margin (Orica, Strength and Focus - Business Overview, 2009). In the production part of Orica this is achieved by reducing the production cost per unit to increase margins and by reducing the total fixed cost. Among the activities that Orica IS has engaged into as a part of their continuous productivity improvement are lean manufacturing and six sigma projects. This thesis is a contribution to these improvement activities.

Orica IS produces two different families of detonators. One which is usually referred to as electric detonator where electric current is used to ignite a fuse-head within an explosive capsule to ignite the detonator and the other usually referred to as non-el, where the ignition of the fuse-head is done with a shock-tube. The non-el detonators are the newer design and are considered safer as they are not sensitive to ESD or other electric disturbances that can be found in production and application sites. The total yearly production volume of detonators is about 40 million units, about 10% of that is electric detonators, the other 90% non-electric detonators.

The assembly process which will be the focus of this thesis is the assembly of electric detonators only. This is the final step in the production of these detonators. Of the about 3,4 million pieces produced in the year 2010, 70% were produced to a stock holding finished products and 30% to
specially ordered customized products. This customization is usually in terms of length and/or color of the wires. Some countries have preferences and/or rules about the colors for the wires of these kinds of products so they get special ordered. The product variety is large, or about 600 products, of which around 150 are kept on stock. The product is assembled out of 7 components which can be seen in Figure 1 and their description in Table 1.

![Figure 1: Shows a fully assembled electric detonator and its components.](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Purpose</th>
<th># of variations</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosive cap</td>
<td>Contains the explosive and a delay element</td>
<td>21</td>
<td>Produced by Orica IS</td>
</tr>
<tr>
<td>Fuse-head</td>
<td>Ignition</td>
<td>9*</td>
<td>Produced by Orica IS</td>
</tr>
<tr>
<td>Isolation</td>
<td>Isolating the cap</td>
<td>1</td>
<td>External supplier</td>
</tr>
<tr>
<td>(Black plastic)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wires</td>
<td>Conduct electricity from trigger to fuse-head</td>
<td>N/A **</td>
<td>Partly produced by Orica IS</td>
</tr>
<tr>
<td>Label roll</td>
<td>Contains date of production and information that allows track ability to machine</td>
<td>1</td>
<td>External supplier</td>
</tr>
<tr>
<td>Plastic tube</td>
<td>A part of the protection of the end of the wires</td>
<td>1</td>
<td>External supplier</td>
</tr>
<tr>
<td>Tube label</td>
<td>Put on the tube, contains information about the type of explosive cap</td>
<td>20</td>
<td>External supplier</td>
</tr>
</tbody>
</table>
Plastic block | The second part of the protection of the end of the wires | 1 | External supplier

*There are 4 main product types but one of these has 6 different weight categories

**The varieties are in colors, insulation thickness and length which make up for countless variations

Table 1: Overview of the components in the product.

Due to the fact that the product contains explosives, safety requirements are strict in the production and while the products stay on the production floor they have to be isolated in containers so that if one would blow up it would not lead to a chain reaction so to ignite others around. This is done with fixtures called 1-gram fixtures that are fitted on trays. In the process, these trays are used to transport the products from assembly machines to the next step.

There are also limits to the amount of explosive products that can be stored in different houses/rooms. In the assembly process are 4 explosive container storages that allow for storage of total 40,000 explosives caps.

2. Theory

Lean manufacturing originates from the Toyota Production System (TPS) and was made known to the world through the success of Toyota between 1940s and 1980s. TPS was created by Taichii Ohno and Shigeo Shingo which used Henry Ford’s manufacturing techniques and Edward Deming’s statistical quality control ideas as foundation (The-About-Group). TPS was created in the years following World War II and it is interesting to reflect on the environment that existed in Japan at the time. Japanese economy was struggling; low availability of capital, labor movements were rising up and the western automotive giants were dominating the world market by outperforming the smaller manufacturers like Toyota. Being starved for capital, Toyota managers realized that their most valuable asset was the employees of the company. They made a deal with labor movements about promising a lifelong job security in exchange for salaries being linked to the company profit (which was very low at that time). This created the initiative for everyone to make sure that the company survived and playing their role in increasing its profits. Taking the advantage of this, the management grouped up the workers into quality circles that would discuss improvements to their work environment and present to the management (The-About-Group). The innovative solutions for various problems evolved into best practices or to what we know now as the lean manufacturing tools and concepts such as one-piece-flow, Kanban and many more. Through the years, additional tools were developed and the culture grew to be centered on waste elimination and continuous improvement practiced by everyone in the company.

The phrase lean manufacturing was made known to the world by Womack, Jones and Roos in The Machine That Changed the World (1990) which was written about the results of a 5 year study of the automotive industry in Japan (Swift). Lean is interpreted by many to be a toolbox consisting of simple tools that lead to one time improved efficiency. This same crowd could possible also refer to lean as being mean, that is, that this would lead to reduced headcount on the shop-floor.
Lean does consist of a set of tools but that is not the whole picture. The best way to provide an explanation of what lean manufacturing is beyond the tools is by looking at the TPS house. The TPS house, created by Taiichi Ohno’s disciple Fujio Cho is widely used to provide a simple representation of what lean manufacturing is (Liker, 2004, p. 32), see Figure 2.

![Figure 2: A simple representation of lean, the house of TPS (COATS, 2008).](image)

Cho used a house to represent the concept because it’s symbolic in the way that a house is just as strong as its weakest link; it needs to have a solid foundation, strong pillars and sturdy roof. The roof holds the goals that any organization seeks out to achieve; superior quality at low price, quick and reliable delivery, safe work environment and a good morale. The pillars contain some of the concepts that started to be known (in this relatively small company) as best practices in Toyota and were developed and fine-tuned over the years to their current forms. Among these is Just-In-Time (JIT) which is probably the best known concept of TPS that is a set of tools that aims at making sure the product goes in the right quantities to the right place and exactly when it’s needed. The other pillar, Jidoka, consists of concepts such as; never let a defect pass on to the next station, free people from machines and solve problems as they emerge. In the foundation there is stability; leveled production, both in volume and variety, aimed to secure a low inventory and stable process. If there is a production spike for one specific product it will likely lead to component stock-outs unless a lot of inventory is held in the system. To ensure stable quality requires firstly standardized actions because no two workers perform the same work in the same way and secondly reliable processes to minimize downtime and interruptions. In the house, the heart of TPS is the people; its solid teamwork while working toward common goals enriched with mutual respect (there is nothing to be gained from playing the blame game when things go wrong), its continuous improvement activities with
application of Deming’s circle and its constant search for ways to reduce waste. In the light of that
the foundations represent stability it is interesting to reflect on the concepts in the left pillar who aim
to reduce inventory and in traditional manufacturing, inventory has been used to provide stability. If
there is a lot of inventory; an incident stopping one machine doesn’t seem to be a big problem
because other stations can keep on working on the inventory and the maintenance team just has to
fix the problem before that inventory runs out. But this is one of the key elements in lean
manufacturing, as the inventory is reduced; these small problems become big problems as they could
halt the entire production. When that happens, it creates urgency for the workers to solve the
problem as fast as possible to get things up and running again. If the same issue happens repeatedly
it would be implemented into the Total-Productive-Maintenance system (TPM) and dealt with
accordingly.

Now that some of the individual parts have been clarified, it’s interesting to reflect on how they are
related. The left pillar, JIT, is applied in order to reduce inventory so that lead times will be shorter
and fixed cost reduced. The resulting system has less room for errors and interruptions which will
surface one after other as inventory is pushed more aggressively down. Then the concepts of the
right pillar, Jidoka, are applied to deal with these problems one by one. After each problem that gets
resolved, stability is achieved again at a lower overall inventory level. The process is slightly improved
and has less waste. In the middle of the house, the heart of the TPS, are the people that are
continuously doing that work, reducing the inventory, dealing with the problems that surface,
reducing waste and balancing the production at a new inventory level.

The following 5 sub-sections have the title of each of the 5 lean principles introduced in Lean
Thinking (Womack & Jones, 1996). It provides a decent framework to view the theory behind lean
with.

2.1 The 1st principle: Specify value

What is value? Ask the question, are the activities and products made by the company really what
the customer is asking for. Specify what the value is to the customer; being it the end user of the
product, the next node in the supply chain or even the next process or department. Without joint
cooperation by all the nodes in a supply-chain, each one will focus on maximizing their own efficiency
which is likely to directly lower what is seen as value to the customer.

The lack of customer focus can often be seen in product development when companies try to fill a
hole in the competitions product variety or adding a new slightly changes version of their own
products to the market. Are the specifications of the product as they are because it’s convenient for
the manufacturer, allowing him to get more use of equipment or facilities? Or are they as they are
because the designers found the new added features to be neat? This first principle teaches us to
stop engaging in these kinds of wasted activities and start focusing on what is really needed, and how
to deliver that.

2.1.1 Value-adding and non-value adding

As the company has specified what it should be doing to fulfill its customer’s requirements we can
make a judgment on each and every activity performed by the company whether its value adding or
non-value adding. Value adding activities are those that directly add value to the product with pure processing. What is left, are the non-value adding activities or wastes. These are sometimes categorized in two, necessary and unnecessary activities (Bicheno & Holweg, 2009). The necessary activities are those that don’t directly affect the final output of the product but are necessary to fulfill other requirements such as safety or to overcome inefficiencies in transport. The unnecessary activities are all handling and transport of the product, operators and equipment waiting for upstream processes, and production of something that hasn’t been requested – that is, pure waste.

2.1.2 Waste reduction and Ohno’s 7 wastes

As it has been established what the value adding and non-value adding activities are – the organization can start working toward increasing its overall efficiency by:

- Elimination or reduction of non-value adding activities.
- Preventing waste as new procedures and processes are designed.
- Enhancing the value-adding activities, that is, reducing the micro-wastes within the value adding activity. Such as unnecessary movement and positioning of a machine tool in a CNC machine.

Every employee in the organization, from top to bottom, needs to learn to see these wastes and actively and systematically work towards eliminate, reduce or prevent them. Systematically is a keyword since it is an ongoing project and at the minute some waste is reduced, it will get easier to see other wastes that were hidden and harder to see before. Tacchii Ohno identified 7 wastes in the TPS, these are (Liker, 2004):

1. Overproduction: Overproduction was in Ohno’s mind the worst kind of waste as it usually hides or generates other forms of waste. Overproduction is about producing too much, too early or producing units that haven’t been ordered by a customer. Its direct effects are overstaffing, higher inventory, transportation and motion waste involved in handling of those extra units. It may also create artificial pressure when the production line is busy making product varieties that aren’t demanded and then a demand spike appears for one of the product varieties that haven’t been produced recently. In a process were overproduction or batch production is common, inventories exist between most of the processes and as one of the them get interrupted, a machine breaks down or has a part shortages; it won’t create a sense of urgency to fix it because the rest of the processes have the inventories to work on. Similarly, it’s easier to throw out defects and not worry too much about the quality problems when you can’t see the direct effects. If there is a solid problem-solving procedure in place, then this urgency is the push towards improvement as everyone will work commonly towards relieving that urgency.

2. Waiting: Workers or waiting; for tools, as a result of a bottleneck, for an automatic machine to finish its processing or just waiting because there is no work because of stock-out. And if a product in production is not moving while no value adding work is being performed on it.

3. Unnecessary transport: The movement of products between processing steps or to and from buffers and storage. Transport increases the likelihood of damage and if distances are long discourages communication which could have direct effect on quality.
4. Over-processing or incorrect processing: Going through unnecessary steps to process the product. Providing higher quality products than is demanded. Using one centered high throughput machine instead of few smaller ones distributed to where they are needed. Using the wrong or poor tool or poorly designed process.

5. Excess inventory: Some inventory will always be necessary to smooth out the inefficiencies that exist in the process. As these inefficiencies are found and resolved, inventory can be lowered. Inventory does not only tie up capital (the value of the products and facility) which for some companies is directly related to their productivity measures (see how Orica measures productivity in 1.3) but it will also lead to overstaffing as the inventory requires handling; moving around, counting. Inventory can hide problems (see section 0 and Figure 11) such as defects, instability in the production, supplier’s late deliveries, and bottle-necks.

6. Unnecessary movement: Any movement such as walking, bending, stretching or reaching performed by a worker getting a tool, getting a part, looking for something or just to be able to see better.

7. Defects: The production of non-conforming parts and products. As defects are discovered internally they lead to scrap, rework and interruptions, as they are discovered externally they lead to repairs, warranty, and damaged goodwill. Usually, the cost of a defect escalates as the defected unit is allowed to continue higher up the process, which underlines the importance of defective units not being allowed to continue to the next step in the process. A quality inspection is a non-value adding activity and thus a waste itself. Defects should be prevented to the point that minimum quality inspection is necessary.

That concludes Ohno’s 7 wastes or Muda (the Japanese word for waste). But since their time, more have been identified and added. Such as (Liker, 2004): Unused employee creativity: Not listening to the ideas of the people working with the processes every day. Not using their skill and not improving their skills through education.

Liker (Liker, 2004) emphasizes the importance of not just eliminating the Muda but also the other two “M’s” in what is called the three M’s. These are Muri and Mura or overburdening people or equipment and unevenness respectively.

2.1.3 Process mapping

Process map is a visual representation of a single process and contains sequence of steps taken to carry the process from start to end. It’s a tool that is useful to investigate process and to categorize the micro steps taken by an operator or a robot into value-added or non-value added. Each activity is represented with a symbol specific to that type of activity or event. On Figure 3 are displayed some of the recognized symbols used in process mapping.
The process map can be used by line manager, operator or just anyone that wants to familiarize himself with the process and explore possible improvements or changes. It can also be used to design or revise a process for new products or services to explore the effects on people and efficiency (Means & Adams, 2004). An example of a process map is displayed in Figure 4.

When improving a process with process mapping, each activity is categorized in the three categories introduced in previous section; value-adding, non-value adding but necessary (at the moment) and pure non-value adding. The activities that are pure non-value adding, that is, not serving any purpose are immediately eliminated. The non-value adding activities that are necessary are looked into with the goal of reducing the time and energy wasted performing them. The overall aim is similar as with the value-stream map which is discussed in the next section. To eliminate wasted activities and reduce wastes in the activities which are necessary.
2.2. The 2\textsuperscript{nd} principle: Value-stream map

The value-stream map is a graphical representation of the process where every action required to create and deliver the product to the customer are followed and drawn from supplier to customer. The traditional way of production has been to arrange in departments similar machines or similar production methods. The 2\textsuperscript{nd} principle of value-stream mapping defies that approach and instead teaches us to look at the value-stream for a product family. Focus on how the product flows through the company, from order to delivery, not on min-maxing each department’s efficiency. Break down the departmental barriers and arrangements that halt the flow of value.

As the value-stream map is created, following a product family through the company, every action performed is listed up and categorized into the three categories; value-adding activities that directly add value to the product, non-value adding activities but necessary at the moment to ensure safety or for the system to function properly and non-value adding activities that are pure waste.

A new map is created that has been cleaned of the discovered wasted activities and can be seen as the target goal for the transformation of the process, this kind of map is usually called the future state and the initial map - the current state. Some of the more standard symbols that are used to draw a value-stream map are shown in Figure 5. These symbols (among others) are then used to represent the following activities:

- The process steps.
- How the products are moved between the process steps (push, pull etc.).
- The information flow, from production control down to the processes, from one process to another, between production control and customer etc.
- The queues and the time the products spend in them.
- The process; -cycle times, OEE, -scrap rate, -number of operators working in the process.
- Additional information such as; available time each day, total yearly capacity, number of operators
Figure 5: Some of the standard VSM symbols.

Figure 6 shows an example of a current state for a production process. As this map has been created, work can start towards systematically improve it by eliminating the non-value adding activities. Figure 7 shows an example of potential future state for this production process. This map is then the target goal for the employees of this company to achieve.

This future state is far from something that can be called an ideal state. There is always room for additional improvement. When the company reaches this future state with its production process, the process is repeated; the future state will become the new current state and a new future state is mapped that eliminates the wastes that can now be seen.

Figure 6: An example of a current value-stream map.
2.3 The 3rd principle: Flow

The real value to the customer has been identified with the first principle, now it’s important to make sure it flows. This is done by focusing on the path the products take through the process. Every indication of an interruption to the flow, such as when the product stops, waits, gets batched up and un-batched need to be investigated and eliminated. Having the target goal to deliver the product without any motion or transport wastes or any unnecessary wait will assist in identifying these interruptions.

The concept of takt time is important when establishing flow. It sets the rhythm the production needs to have in order to have even flow of value. The takt time is defined as:

\[
Takt \text{ time} = \frac{\text{demand in period } i}{\text{available time in period } i}
\]

Processes in series where continuous flow is desirable need to have a cycle time that is lower than the takt time and preferably by just a little. These processes also need to have the same cycle time so none of them will act as a bottle neck and interrupt the flow, see Figure 8 and Figure 9.
By balancing the cycle times to be close to the takt time will result in continuous flow and reduced WIP. Ideally, the flow should be one piece, then the employees focus will be on one unit at a time and in case there is a quality problem discovered, there is a minimum WIP buffer which might have the same problem.

A series of balanced processes (like in Figure 9) that have continuous flow or even one-piece-flow will require a lot less space than a series of processes with imbalanced flow (like in Figure 8). The reason is simply that the imbalanced processes will have a lot of WIP units that need to be stored somewhere between the processes.

**2.3.1 Spaghetti diagrams**

The spaghetti diagrams are useful to identify interruptions to flow where transportation and movement waste play a big part. To visually see the transportation waste, a route is drawn on the layout plan for the facility for the flow of products from one workstation to the other. Or to visually see the movement waste of the operators, a route is drawn on the facility floor plans they take as
they perform their work. It is a simple and highly effective tool. An abstract example can be seen on Figure 10.

![Figure 10: An example of a spaghetti diagram showing an operator working in a CNC workshop.](image)

### 2.4 The 4th principle: Pull

To clarify the differences between push and pull systems, the definition of both systems are as follows:

**In a push system:** production or material replenishment orders are initiated with application of predetermined schedule that has been derived from forecast or another form of projected customer demand (Liker, 2004). Commonly, push systems are the result of maximizing usage of resources, being it machines or labor without regards that those products or activities are actually needed at that particular moment they’re generated. Overproduction, and thus, large inventories are usually seen in a push system processes. Different partners within a supply chain or departments within a company are operating according to an internal schedule, it might be beneficial to produce product A after product E if that saves a changeover and the management can boast of impressive equipment uptime numbers. This extra inventory is then pushed downstream to next department or partner that has to stockpile it.

**In a pull system:** production or material replenishment orders are initiated by a downstream process when it is ready to receive the sub-assembled products or material. By only producing to requests, overproduction is impossible and the resulting inventories will be limited to what is needed to balance the overall system against delays in the process. With a pull system the number of changeovers will likely increase as replenishment of inventories are done more frequently and the overall inventory is kept at a lower level, but there are means to reduce the time spent on changeovers.

The benefits of a pull production are those that it is likely to reduce overall inventory as the initiation of a process or creation of a new unit is only done with an order from a downstream process saying that they’ll need more units soon. Large inventories is the convenient way for companies to deal with
(or rather ignore) the inefficiencies that hide in the production process. By gradually reducing the inventory, the inefficiencies become evident as they start causing problems. In lean manufacturing literature it is popular to represent this concept as a lake, see Figure 11.

![Figure 11: As the water level goes lower the rocks at the bottom will surface one by one and cause problems for ships that sail the water. For a production environment; the water represents the inventory and the rocks the endless different problems that hide in the process. As the inventory level is moved lower, these problems surface and the interruptions they cause are more visible.](image)

In the figure the inventory is represented by water, and as the water level is lowered; rocks start to appear. These rocks are symbolizing the problems that can be found in the production environment, as one of these problems is discovered and dealt with, the inventory can be lowered more. This provides a pathway for continuous improvement of the process. Care must be taken to not prematurely blame “the new system” as these problems appear. Of course, the system needs to be correctly designed to work efficiently but the purpose of it is partly to surface the problems so that they can be dealt with, what is then left is an improved process.

But push systems are not always inferior to pull. In situations where replenishment is for wide variety of different products which each has high variation in demand and there exists good demand information then Kanban has been shown to be inferior to push (Krishnamurthy, Suri, & Vernon, 2004). The opposing situation, where the product variety is low and has a steady demand, favors the Kanban system.

The comparisons in the reference mentioned above are made in terms of WIP and stock-outs. But there is also more to it than that, or control and the sustainability of the system. One of the strengths of the Kanban system is that it involves using physical entities, cards, to communicate the orders opposed to MRP which is reliant on accurate stock quantities and demand information. Spearman & Zazanis (1992) conclude that pull systems are easier to control as controlling WIP (cards) is more robust than controlling throughput.

### 2.4.1 Kanban, a way to pull

Kanban is not the only means on acquiring the properties mentioned earlier about inventory limit and control. Others known and tested systems exist, such as CONWIP (Spearman & Zazanis, 1992) which stands for Constant Work In Progress and can be classified as a hybrid between push and pull (see Figure 13). However, focus will be put on the Kanban system, developed by Dr. Taichi Ohno at Toyota Motors.
Figure 12: Shows the difference between pure push, pure pull and the hybrid system, CONWIP (Spearman & Zazanis, 1992).

Figure 13: Shows the functionality of a basic Kanban system. (1) When the production process requires additional material, it is picked out of the supermarket. The box has a Kanban attached to it that includes the information about type of product and quantity in the box. (2) The Kanban is separated from the box and put in a Kanban post and the box sent to the production process. (3) At defined time the Kanban post is emptied and all the Kanbans in it sent to the supplying process. (4) The supplying process will then supply the material along with the Kanban cards it holds to the supermarket and the process repeats itself.

The Japanese word Kanban stands for “card” or “sign” and is meant to provide a physical signal to initiate some event. There exists many forms of Kanban, Figure 13 shows one of the basic ones. To calculate the necessary number of Kanban cards for a given material replenishment, the following formula can be used (Bicheno & Holweg, 2009, pp. 152 - 154):

$$Kanbans = \frac{D_{LT} \cdot (LT + ST)}{CS}$$

Where:

- $D_{LT}$ is the demand during the materials lead time
- $LT$ is the lead time for the material replenishment
ST is the safety lead time

CS is the container size

This equation assumed very steady demand which in reality is rarely the case. Increased variation in the material demand will result in higher required cards and the safest way to find out how many are needed is to start the system with enough and gradually reduce as stability is achieved.

The robustness of the Kanban system is highly dependent on its structure where every detail has to be well thought out and tailored to the application. For example, these could include:

- The supermarket: Its placement on the shop-floor and how it is managed, visual management goes a long way – a place for everything and everything in its place (5s reference).
- The Kanbans: Need to include necessary information in compact form such as the quantity it represents and the product type (it can be a good idea to distinguish between types with different colors). They need to have a place on each container where they can be seen.
- The Kanban post: Should be in a visible place right next to (or on) the supermarket.
- Standardization and responsibilities: Who moves the Kanbans from its post to the upstream process and when. How and where does the supplier of the material fit the Kanbans into its production schedule so it’s clear what to produce next? Care must be taken that the order of Kanbans will not be disrupted while in Kanban post and through to the supplier (there are exceptions of course, such as leveling in the production at the supplier).

2.5 The 5th principle: Perfection

Imagine an organization that has started with the four previously discussed principles. It has defined the value-adding activities from the non-value adding activities, mapped the value stream and has started to eliminate the waste identified while doing so. Flow has been established where interruptions have been eliminated and things are really started to run smoothly and fast. Pull has also been established where inventory levels are limited and the customer pulls the value through the organization. Now what is left is perfection; there is always waste to be identified and eliminated, there are always interruptions to the flow and the inventory can always be lowered more. It’s a continuous work that never ends and the only way to achieve that is by changing the organizations culture and work environment to embrace continuous improvement.

2.5.1 Continuous improvement

Kaizen is the Japanese term for continuous improvement. Continuous improvement is the heart of lean manufacturing and it is also what industries taking up lean manufacturing have had the most problems with adapting. It requires a certain cultural change within the company where people are encouraged to challenge themselves and embrace changes. The workers undergo continuous learning and adopt skills to work efficiently in small group using tools to solve problems, measure, analyze data and reach a group-accepted decision for the issue at hand. This pushes the
improvement work down on the workers who are the people working around in the process and around the machines every day, thus they have the best knowledge of the details of each process. It was the work of Edward Deming in Japan in the 1950s that contributed great deal to the birth of the cultural continuous improvement ways of Toyota. His 14 principles on changing business effectiveness guided the management towards this change (Deming, 1982, pp. 23-24):

1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive and stay in business, and to provide jobs.
2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.
3. Cease dependence on inspection to achieve quality. Eliminate the need for massive inspection by building quality into the product in the first place.
4. End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move towards a single supplier for any one item, on a long-term relationship of loyalty and trust.
5. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.
6. Institute training on the job.
7. Institute leadership (see Point 12 and Ch. 8 of "Out of the Crisis"). The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.
8. Drive out fear, so that everyone may work effectively for the company. (See Ch. 3 of "Out of the Crisis")
9. Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.
10. Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.
11. a. Eliminate work standards (quotas) on the factory floor. Substitute leadership.
   b. Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.
12. a. Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.
   b. Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means, inter alia, "abolishment of the annual or merit rating and of management by objective (See Ch. 3 of "Out of the Crisis").
13. Institute a vigorous program of education and self-improvement.
14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

The top management in an organization that wants to transform the organizations culture into lean manufacturing culture must be dedicated to the cause. The drive and support must come from the top to the bottom. A capitalist view on lean manufacturing would be saying that it is about doing things more efficiently, save money and increase the growth of the organization through improved productivity. That is all true, but it’s also about enriching the morale in the organization where mutual respect between coworkers is valued and practiced by everyone. The employees should have fun with their coworkers working towards a common goal by improving their work environment and feel pride in the results.
But how can an organization establish a sustainable continuous improvement culture? First of all, every employee needs to receive training in the principles behind lean manufacturing and the best practices that have evolved to be known under its name. Everyone has to learn how to see the waste and deal with it appropriately. Secondly, management has to take into account the time needed for continuous improvement activities when creating the production plan. Thirdly, the employees have to feel the need for an improvement. That might mean that a certain situation is forced in the process so that everyone sees the weaknesses, such as reducing a stock level or reducing storage space for a stock. Improvements have low sustainability or won’t yield the desired benefits unless the people working in the process feel their needed (Yamamoto & Bellgran, 2009, p. 5).

Deming also encouraged the Japanese to use his Plan-Do-Check-Act cycle (also known as PDAC or Deming’s cycle, see Figure 14) as a systematic approach to continuous improvement activities (Liker, 2004). Using the PDCA cycle as structure, a team of employees come together and discuss issues in their workplace. These can be very minor issue to severe quality problems. The group works together to find a solution and implements a solution or proposes it to the management.

![Deming cycle](image)

**Figure 14:** The Deming cycle by W. Edward Deming used by Toyota to provide systematic approach to continuous improvement.

### 3. Methods

Three methods were used to analyze the process and identify improvement opportunities; these are VSM or value-stream mapping, process mapping and spaghetti diagram. Together, these tools provide a solid overview of the process. The VSM works on a macro level and shows how the processes are connected, how the products flow between them and how the required information is
delivered to where it is needed. Creating a current value-stream map should always be the first step in any major lean improvement activities where the whole process is subjected to be transformed.

Opposed to VSM, the process map works on a micro level and is a powerful tool when it comes to analyze what really happens within a process. It can be as detailed as the one creating the map wishes it to be; such as just listing the activities performed in the process for an easier understanding of the process or in order to reduce cycle times of a robot arm where it’s every move is mapped.

The spaghetti diagram can be used to validate the facility layout. It is a good tool to expose the transportation and movement wastes that hide in the process and steal operators’ time that could be used doing value-adding activities.

A fourth tool was used to verify results, that is; simulation. Simulations were carried out using visual basic application for Excel where a program is used to simulate a Kanban pull system or an Assembly-To-Order system using historical data.

3.1 Value-stream mapping (VSM)

Value-stream mapping is a useful tool to help understand the flow of material and information on a larger scale. The current value-stream map was created based on interviews with the employees and direct observations and measurements. The future value-stream map was created with the goal of eliminating as much of the waste that could be identified on the current VSM as possible and seemed reasonable as a next step. These maps are shown in the result section, see 4.1.

3.2 Process mapping

The process maps were created alongside with the value-stream map early on in analysis of the process. They served mainly as a way to understand each individual process. That is, to see the steps of action required to fully assemble a detonator and to see where information was required and used. Process maps for the detonator assembly process can be seen in Appendix I – Process mapping.

3.3 Spaghetti diagram

Spaghetti diagrams were used to identify the travel and transportation wastes that are in the final assembly. The facility is large and the machines require a lot of space making it hard to strategically place material close. The material and product flow is quite smooth, going from one end of the facility to the other so all the spaghetti diagrams are focused on the routes the operators need to take to do their work. There are few factors contributing to the movement waste. Such as; the machines need to be accessible from all sides which require them to be spread out on the middle of the floor and due to the fact that the products contain explosives, which need to be stored in specialized containers in a certain room. Spaghetti diagrams for the detonator assembly process can be seen in Appendix II – Spaghetti diagrams.
3.4 Simulation

Simulation is “the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system.” (C. D. Pegden, 1990).

Three simulation were created; two to explore the possibility of using a Kanban system for fuseheads and caps replenishment and to see what level of inventory would be required for the system to function properly, and one to explore the possibility of assembly to order. All the simulations were made in Excel. Excel was chosen as a simulation tool for this application as no dynamic activity is required in the simulation (such as activities initiated by events which are then initiated using a probability distribution). Excel is ideal for data handling and its’ programming environment, VBA for Excel (Visual-Basic-Application for Excel), offers a convenient way to create simple simulations with the data. In the case of the Kanban simulations, a program was written in VBA for Excel to simulate the material orders with Kanban cards.

3.4.1. Fuse-head Kanban simulation

The simulation was made using historical data from 2009-12-15 to 2010-12-17. Figure 15 shows the controllable variables for this simulation. The number of Kanbans was calculated using the formula shown in section 2.4.1. By filling in the “Extra Kanbans” cells the total number of Kanbans could be altered for sake of evaluation. It offers the possibility to add a safety lead time (instead of a safety stock) as a buffer to accommodate for interruptions.

![Figure 15: Changeable parameters in the fuse-head simulation.](image)

Figure 16 shows the first part out of two for the template for this simulation. The first 4 columns to the left contain the historical production order data for the 4 fuse-head types, VA, XS, U and S. The next two columns show the date and weekday for all working days from 2009-12-15 to 2010-12-17. Thereafter is the status of inventory for each fuse-head type for each day, when a production order or new batch of material is received this status gets lowered or increased respectively.
The second part of this template is shown on Figure 17. This part tracks the Kanban system. Each type of fuse-head has a maximum number of Kanban cards derived from control table (see Figure 15). A program was written in VBA for Excel that tracks the inventory status level for each fuse-head type. The Kanban simulation is done by monitoring the inventory level, if a drop in inventory in a single day is equal to one container size (6000 pcs); one Kanban card is issued. If the drop in a single day is equal to two container sizes (total 12,000 pcs); two Kanban cards are issued and so on. The control variable “Material lead time” then controls when the Kanbans are sent back along with the material replenishment. The code behind the fuse-head Kanban system is shown in full in Appendix III – Fuse-head simulation code.
3.4.2. Caps Kanban simulation

The caps Kanban simulation is almost identical to the fuse-head simulation, apart from one small change; it simulates a 2 bin Kanban system instead of the traditional Kanban card per container size. The template and code are shown in Appendix IV – Caps simulation template and code.

3.4.3. Assembly-To-Order simulation

The simulation was done on historical demand data from 2010-02-02 to 2011-03-04. The purpose of the simulation is to validate what the lead time would be if Orica would assemble to orders, that is, don’t keep an end stock of finished items to attain the desired service level. The simulation template is shown on Figure 18.

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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 18: Simulation template for the ATO simulation.**

Columns F holds the actual demand data while in columns A to E the top 5, 10, 15, 20 and 25 most sold products are kept as stock keeping units. In column I (Morning status) is the order status in the start of the day (before any production) and in column K (Leftovers) is the status in the end of the day, it shows if there are any outstanding orders to be serviced the next day. Column M (Lead-time in hours) has the estimate throughput time for each day. The simulation was run with various throughputs for all the six sets of demand data. An example of the derived results can be seen on Figure 19. More detailed results are presented in the result section, sub-section 4.5.2.
4. Results

The four automatic machines and the three manual assembly machines work in parallel and are the pacemaker for this assembly. There are seven different material and sub-assembly types that are assembled into one product at these assembly machines/cells. Ideal would be to establish continuous flow from this point downstream through packing and shipping, and a pull from the upstream processes. The capacity of the pacemaker and its downstream processes will determine the throughput and lead-time through the assembly.

Figure 20 holds a structure of this section where the recommended actions are categorized under their relevant position in the process. The numbering in the top icons represents the relevant sub-section that addresses the underlying actions.

![Figure 20: Overview of the results.](image-url)
4.1 The value-stream maps

The current value-stream map (see Figure 21) is not of the entire process of production of electrical detonators from the beginning to the end but only the last step, or the final assembly (see delimitations, section 1.2). The green “suppliers” are other departments in the company and housed with few hundred meters of where the final assembly is housed. Deliveries between houses are performed by internal logistic service. The operational items are plastic tubes, the black plastic that is melted down to form the isolation, label rolls etc. These items are bought in bulks and do not cause problems because of availability or inventory as the other items, especially the fuse-heads and caps.

The caps and the plastic tubes are prepared in separate work-stations before they get assembled. The caps are inserted into fixtures that isolate each cap from each other in order to prevent chain reaction if one explodes. The tubes are labeled with a label that indicates the type of cap that will be on the detonator.

The products that have 3 to 6m long wires get assembled in the automatic machines and longer wire products get assembled manually (up to 36m long wires). About 97% of the capacity goes through the automatic machines. Almost all value-adding work in the assembly process is performed in this step (the only other value adding activity is the direct labeling of the tubes).

The assembled products get moved on trolleys to the X-ray where they’re inspected and packed into boxes. The boxes are then moved out into a shipping area where the company’s internal logistics will pick them up. These pick-ups are twice a day and as they’re picked up - the finished units get registered into the SAP system as an increment to the finished stock or in the case it was for a customer order; to indicate that it is being served.

Figure 21: The current value-stream map.
The encircled areas on the current VSM are the points of interest. That is, the areas that generate the greatest waste and might provide significant higher productivity if improved. The future state map shows the improvements that will be discussed in following sections. It is far from an ideal map, in fact; an ideal map doesn’t exist as further improvements can always be made. If the system works flawlessly then there is always opportunity in further reducing the inventory and/or processing times.

Figure 22: The future state map.

4.2 Establishing pull through upstream processes

Having pull replenishment system where a downstream process pulls material from the upstream processes as needed is desirable in this situation for three reasons:

**Control**: There are frequent stock-outs with current system, especially for fuse-heads and explosive caps. One material can have 26 days on stock when another is close to 0 days. Standardized process where material is replenished as it is used and signaled with physical identities (Kanbans) can offer the necessary control.

**Limit to inventory**: Pull with Kanban will put a limit to how much inventory can be at the downstream process. That is:

\[ \text{Inventory} = \text{Kanbans} \cdot \text{ContainerSize} \]

This is especially desirable for Orica because of two reasons; high inventory of explosive creates a safety risk for employees and the government issues a limit to the allowable amount that can be stored in each house.

**Relatively cheap inventory**: Inventory is one of the eight waste forms and should be minimized as possible. As was discussed in section 2.4 a Kanban system can get outperformed by a well planned
push system in cases where product variety and demand variation is high. This can be argued to be the case for fuse-heads and explosive caps which forces a higher inventory to ensure smooth production flow. The theory tells us that inventory will hide the inefficiencies in the process so we don’t see and resolve them. It tells us that it requires handling time of operators that could be used in other value-adding activities, it takes up floor space and it is a tied-up capital.

4.2.1 Kanban system for fuse-head replenishments

**Current situation**

Currently, replenishment of fuse head stock is not in a controlled state, being it the quantities in the replenishments or their timing. The supervisor at the electric assembly orders replenishments via phone call to the fuse head production department (see relevant part of current VSM on Figure 23). This is however not done in standardized manner so naturally, it’s not uncommon that the production stops because there is a stock-out of the right type of fuse heads. In these cases an emergency call is made to the fuse head department requesting replenishment as soon as possible causing sense of rush and discomfort for employees at the fuse-head department.

Answering to that emergency call can prove to be very difficult since the fuse-head production process is difficult to control. The VA type fuse-heads are the most used ones, and it has a few layers of explosive coating on it and the end weight of can vary depending on the coating solution and length of time the fuse-heads spend dipped into it. This means that if production is started for VA type fuse-head in the weight category 24-26 mg, it is not guaranteed that the end-product of the process will have the right weight; it might end up being 22-24 mg or 26-28 mg. For the 4 major types of fuse-heads (VA, S, U and XS) the VA is the only one with varying weights. There are 6 weight categories for the VA so that makes up 9 total variations of fuse-heads.

**Major concerns**

The major concern here is establishing more control and standardization of this material replenishment to ensure availability and smooth flow. A situation where the whole process is stop for hours because of material stock-out when the production is already behind schedule cannot happen.

A Kanban system can offer this control and standardization but since there are a total of 9 product varieties it might not be the optimal system. As was discussed in section 2.4 for systems where product variety is not low a well planned push system can outperform a Kanban system in terms of
inventory level. In this case however, this demand information doesn’t exist. Of the production order, 70% is MTS and 30% MTO. For the MTS orders, the demand information could be given with few days’ advance but not for the MTO orders.

**Fuse-head Kanbans for automatic assembly machines**

Using the basic calculations we saw in section 2.4.1 the below table (The containers sizes are magazines that are fitted directly into the machines holding about 6000 pieces each. The Calc. number of Kanbans is created using the Kanban calculation formula presented in section 2.4.1 and the Extra Kanbans cells gives the option to manually add Kanbans to the system for sake of evaluation.

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs):</td>
<td>9146</td>
<td>360</td>
<td>2248</td>
<td>3810</td>
</tr>
<tr>
<td>Material lead time (Days):</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Safety lead time (Days):</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Container size (Pcs):</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Extra kanbans:</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calc. number of kanbans:</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2: Calculated number of Kanbans needed for fuse-heads for automatic machines.

The formula (see section 2.4.1) assumes very steady demand for each item type, which is not the case. In Table 3 are the mean and standard deviation of demand per day for each item type.

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs):</td>
<td>9146</td>
<td>360</td>
<td>2248</td>
<td>3810</td>
</tr>
<tr>
<td>Standard deviation:</td>
<td>7062</td>
<td>1560</td>
<td>3793</td>
<td>3827</td>
</tr>
</tbody>
</table>

Table 3: Shows the demand variation for fuse-heads for automatic machines.
Since the demand is highly varying, it can be expected that the inventory will have to be increased to accommodate for that fact. A simulation was made to see how a Kanban system would perform given the 2010-2011 demand data (see under Methods, section 3.4.1). The results are shown below in Table 4 where the criteria used to find necessary number of Kanbans was decided so that there would never be a stock-out.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs)</td>
<td>9146</td>
<td>360</td>
<td>2248</td>
<td>3810</td>
</tr>
<tr>
<td>Material lead time (Days)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Container size (Pcs)</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Number of kanbans</td>
<td>12</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Maximum inventory (Pcs)</td>
<td>78000</td>
<td>24000</td>
<td>30000</td>
<td>42000</td>
</tr>
<tr>
<td>Average inventory (Pcs)</td>
<td>52985</td>
<td>20025</td>
<td>21559</td>
<td>29519</td>
</tr>
</tbody>
</table>

**Simulation results**

<table>
<thead>
<tr>
<th>Nr of stockouts</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr of times between 0-25% of stock</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 4: Shows result from a simulation where necessary number of Kanbans was calculated to reach the criteria of no stock-outs for fuse-heads for automatic machines.

By comparing the two tables (The containers sizes are magazines that are fitted directly into the machines holding about 6000 pieces each. The Calc. number of Kanbans is created using the Kanban calculation formula presented in section 2.4.1 and the Extra Kanbans cells gives the option to manually add Kanbans to the system for sake of evaluation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs)</td>
<td>9146</td>
<td>360</td>
<td>2248</td>
<td>3810</td>
</tr>
<tr>
<td>Material lead time (Days)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Safety lead time (Days)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Container size (Pcs)</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Extra kanbans</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calc. number of kanbans</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2: Calculated number of Kanbans needed for fuse-heads for automatic machines.

and Table 4), we see that the variation in the demand is causing the inventory level to increase by 56% to provide the desired availability of the material. This large variation is the effect of large production and customer orders. The reason why the orders are large is not entirely to limit the number of setups each day but also due to how things have normally been done. By working towards reducing the setup time and systematically reduce the size of the production orders, the inventory can be reduced, not just for the fuse-heads but for all material and the finished stock.

**Fuse-head Kanbans for manual assembly cells**

The amount of products that get assembled in the manual assembly cells are only about 3% of the total throughput per year. Going through the same calculations as in the previous section for fuse-heads for automatic machines the following table (Table 5) was generated. Demand per day is the average daily demand for each fuse-head type. The material lead time is assumed to be 3 days
normally as for the fuse-heads in magazines (for the automatic machines), and the same reasoning as for the fuse-heads for automatic machines is used when adding 1 day as a safety lead time. The container sizes (500 pieces) are according to current arrangements, the fuse-heads sold to external customers (not in assembled detonators) are packed in boxes holding 500 pieces.

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs):</td>
<td>143</td>
<td>0</td>
<td>160</td>
<td>46</td>
</tr>
<tr>
<td>Material lead time (Days):</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Safety lead time (Days):</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Container size (Pcs):</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Calc. number of kanbans:</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Calculated number of Kanbans needed for fuse-heads for manual assembly cells. The fuse-head type XS was never assembled into a detonator in the manual assembly over the data period (2010-2011).

Table 5 indicates that 1 container holding 500 fuse-heads is enough for each of the fuse-head types, that is, given steady demand. In Table 6 the standard deviation is displayed for each of the fuse-head types. It is quite large compared to the mean value.

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs):</td>
<td>143</td>
<td>0</td>
<td>160</td>
<td>46</td>
</tr>
<tr>
<td>Standard deviation:</td>
<td>293</td>
<td>0</td>
<td>448</td>
<td>257</td>
</tr>
</tbody>
</table>

Table 6: Shows the demand variation for fuse-heads for manual assembly cells.

The results from a simulation are shown below in Table 7 where again the same criteria was used to find necessary number of Kanbans - that there should never be a stock-out.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VA</th>
<th>XS</th>
<th>U</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand per day (Pcs):</td>
<td>143</td>
<td>0</td>
<td>160</td>
<td>46</td>
</tr>
<tr>
<td>Material lead time (Days):</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Safety lead time (Days):</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Container size (Pcs):</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Number of kanbans:</td>
<td>8</td>
<td>0</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Maximum inventory:</td>
<td>4000</td>
<td>0</td>
<td>4500</td>
<td>2500</td>
</tr>
<tr>
<td>Average inventory:</td>
<td>3809</td>
<td>0</td>
<td>4258</td>
<td>2400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation results</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr of stockouts</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nr of times between 0-25% of stock</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7: Shows result from a simulation where necessary number of Kanbans was calculated to reach the criteria of no stock-outs for fuse-heads for manual assembly cells.
Further possibilities to improve this system:

- Reduce the lead time through fuse-heads.
- Increase the reliability of the fuse-head production process so it can be known with certainty what weight category the fuse-heads will fall in when the production order is started.
- Reduce the size of production orders (smaller batches) for electrical detonators to level out the demand for the materials to it.

4.2.2 Replenishment of explosive caps

Current situation

The caps are replenished to the assembly area from a warehouse which is in the area close by. The replenishments are done once a day and according to the daily production plan, so the caps that are needed for the day are delivered in the morning. While they’re in the assembly area (the house hosting the final assembly) they have to be stored in a specialized explosive containers and the total amount cannot exceed 40,000 units, which is little more than twice the daily throughput (~18,000 units). As the replenishment is ordered by management in head office that don’t have a real picture of how many caps are currently stored in the explosive containers - it can create issues with the level of inventory. If in day 1 there are some problems in the assembly, machine breakdowns or some other form of interruptions so that the daily order plan cannot be finished, the day 2 caps will still arrive the morning after causing problems in storage as the previous days caps haven’t been assembled into products and shipped out. Another issue is the slow build-up of excess caps in the explosive containers as there is always a little extra ordered to account for potential scrap.

Major concerns

The major concern is to secure availability of the products awhile making sure the amount will not exceed the limit of 40,000 units. A traditional Kanban system is not suitable in this situation as there are 21 variations of caps that would need to be stored in a supermarket arrangement. With maximum allowed inventory of 40,000 units the replenishments would have to be performed many times a day to provide the availability, which is not practical. A simulation was performed using data from the year 2010 to see how much inventory would be required for a 2 bin Kanban system to offer the required availability (no stock-outs) for the top 4 most assembled type of caps. The inventory requirements for just those 4 types exceed the allowed maximum limit by close to 50%. With above concerns in mind, the factors that need to be present are:

- The employee ordering the caps to the assembly area will need to have detailed information of the level of inventory so the allowable limit of 40,000 units will not be exceeded.
- Standardized actions to deal with excess caps to prevent build-up of unwanted inventory.

Centralized planning board
In conjunction with the elimination of the caps filling process (see later section 4.3.1) and the decoupling of operators from the assembly machines (see later section 4.4) a centralized planning board might prove useful to monitor this material. An example is shown on Figure 24.

Caps replenishment

As mentioned earlier when the current situation was described for the cap replenishment there are two problems:

- Cap replenishments are not ordered from the downstream process to which they’re delivered to. And as an effect, the 40,000 unit limit is often exceeded.
- Leftover caps are not sent back and will slowly build up inventory.

Using the board (Figure 24) in conjunction with standardized work this can be prevented. The caps will need to be ordered by someone with knowledge of how well the production is going at the moment of order. By having the supervisor of each shift order the caps required for next shift – this will be achieved. For example, on Figure 24, we can see there is no production currently on Elsa 3 because of some kind of interruption. The supervisor on the morning shift will thus not order the caps required for night shift orders as the night shift should produce the morning shifts orders instead (if the interruption has been resolved). The inventory of caps should therefore be little more than is needed for one shift at a time.

The supervisor will usually order little more than what is required in the production as the scrap rate can go as high as 10% so there will always be a slow build-up of inventory of caps that are perhaps
not needed for the next days. This can be resolved with standardized work if one of the explosive containers would be dedicated to “Return” caps, see Figure 25.

![Figure 25: The 4 explosive containers - a place for "Return" caps that will be emptied by internal logistics as they deliver caps to the assembly.](image)

The leftover caps are moved to this dedicated container and it should be emptied by internal logistics regularly.

**Set-ups**

Having a centralized board with live counter for automatic machines (it moves up rather fast) and written down counter for the manual cells (added to when a trolley is finished) will improve the visual information available about the time of set-ups. A set-up worker and free-roaming operator of the Elsa machines can prepare accordingly in advance of set-up.

**Motivation**

Having a live visual representation of the current status of the production can serve to motivate people to do better if there are interruptions and some catching up is required. And if good progress is achieved, it will be before the eyes of everyone and should be celebrated.

### 4.3 Eliminating stations that are waste generators

As was discussed in the section about value-adding and non-value adding activities, there are three categories that an activity can be sorted too. One of these categories is a non-value adding activity that is required at present moment because of some process or safety concerns. For that reason, these activities fly under the radar and get left alone even though they perhaps generate a lot of waste. After the obvious pure waste activities have been eliminated, these should be next in line to be in the center of attention.

#### 4.3.1 Elimination of the cap magazine filling process

**Current situation**

The purpose of the caps magazine filling process is to move the caps from being stored in numbers of 60 in containers to being stored in numbers of 20 in a fixture that isolates one cap from the other, preventing a chain reaction if one explodes. This is done for safety reason so the caps can be stored on the shop-floor at the machines in these fixtures without causing an explosive risk for the operators around. This process occupies one operator per one shift. A relevant part of the current VSM is shown on Figure 26.
Major concerns

As mentioned, the main purpose is to safely store the explosive caps around the machines where they’re at hand for the operator to replenish the machine. If there is another acceptable measure to do that - such as containers at each machine able to hold a small inventory of explosive cap, it would eliminate wasted activities occupying an operator for one shift. It would also require changes to the automatic machines feeding system for the caps, as it currently requires the caps to be in fixtures.

Cost estimation

The table below (Table 8) displays the investment costs and the respective savings included in the elimination of the caps magazine filling process. These are rough estimations and should only serve the purpose of making a rough picture of the expected return from the project.

<table>
<thead>
<tr>
<th>Expected investments</th>
<th>Units</th>
<th>Cost per unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes to feeding mechanism in automatic machines&lt;sup&gt;1&lt;/sup&gt;</td>
<td>4</td>
<td>250 000 kr</td>
<td>1 000 000 kr</td>
</tr>
<tr>
<td>ML481 Type 2 explosive detonator container&lt;sup&gt;2&lt;/sup&gt;</td>
<td>4</td>
<td>10 000 kr</td>
<td>40 000 kr</td>
</tr>
</tbody>
</table>

Total investment cost: 1 040 000 kr

<table>
<thead>
<tr>
<th>Expected savings</th>
<th>Qty</th>
<th>Salary /month</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1</td>
<td>26 000 kr</td>
<td>26 000 kr</td>
</tr>
</tbody>
</table>

Savings Present Worth(2,25%) over 4 years<sup>4</sup>: 1 192 420 kr

Table 8: Cost and savings estimations for elimination of caps magazine filling.

There are additional cost factors such as safety analysis to see if it’s acceptable risk to store the caps near the automatic machines. As the current process occupies one operator full time, the project can be expected to come out on zero after about 42 months.

<sup>1</sup> According to estimations made by Orica (Orica, Orica Sweden AB, 2011).
<sup>3</sup> Average salary of a worker.
<sup>4</sup> Using interest rates provided by Nordea for companies – www.nordea.se.
4.3.2 Elimination of the tube labeling process

Current situation

The function of the plastic tube and block (see Figure 1) is to isolate the end of the wires to protect the detonator from igniting accidentally through ESD. The plastic tube has a label that contains information about the explosive cap on that detonator. Current process for this activity can be seen on Figure 27 which is a relevant part of the current VSM.

1. The purchased tubes/blocks are received on pallets in container boxes holding 10,000 pcs. These pallets are stored on the production floor.
2. A box of tubes is moved closer to the process as needed.
3. The operator pours tubes into 3 feeders that each has attached a labeling machine.
4. He then fits the right label roll in the labeling machine and starts labeling the tubes.
5. The labeled tubes are put into plastic bags and put up on a shelf in twofold inventory system. On one side of the shelf the tubes are categorized to machine (what is to be used on what machine during the same day) and on the other side there are leftovers categorized according to the labels.
6. When an operator on the assembly machine needs more labeled tubes, he walks over to this supermarket and collects a bag with the tubes he needs.
7. He then pours from this bag into a feeder at the machine.

Major concerns

These activities from the relevant process map (see Appendix I – Process mapping) occupy one operator during one shift each day. The actual value-adding work is the direct labeling of the tubes which takes less than 1 second for each of the three machines, so 3 tubes are labeled each second if they’re all running. The rest of the time is wasted in waiting, bagging products, stacking in shelves, transporting material. A list of generated wastes in this process:

- Overproduction.
  - The tubes are not labeled exactly when they are needed which leads to inventory.
  - The production volume is always higher than the requested amount to account for scrap in the assembling machines.
• Inventory.
  o Takes up floor space.
  o Tied up capital (neglect able in this case since the material is very cheap).

• Transportation waste.
  o Operators on assembling machines need to walk up to 40 meters depending on which machine they’re operating to retrieve a bag of labeled tubes.

• Incorrect processing.
  o When a new job is to be set-up on the machines / manual stations, the feeder with labeled tubes has to be emptied.

• Wait
  o If for some reason the tubes aren’t ready when they’re needed, the assembly machines will not be able to operate until the tubes have been labeled.

**Labeling machines to feeders at assembly machines/cells**

In steps 3 and 7 the same tubes are being poured in identical feeders. The difference is that the feeders in step 7 are at each assembly machines and the tubes going into those feeders are already labeled. By attaching a labeling machine directly to the feeders at each machine it could be possible to eliminate steps 4, 5 and 6. And instead of pouring labeled tubes in the feeder at assembly machines, unlabelled tubes are used and they labeled directly before entering the assembly machine. This would not only free up one operator on one shift each day but also eliminate the wastes listed above.

**Cost estimation**

The table below (Table 8) displays the investment costs and the respective savings included in the elimination of the tube labeling process. These are rough estimations and should only serve the purpose of making a rough picture of the expected return from the project. The project can be expected to come out on zero after 57 months.

<table>
<thead>
<tr>
<th>Expected investments</th>
<th>Units</th>
<th>Cost per unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>New labeling machines and installation⁵</td>
<td>4</td>
<td>350 000 kr</td>
<td>1 400 000 kr</td>
</tr>
</tbody>
</table>

Total investment cost: 1 400 000 kr

<table>
<thead>
<tr>
<th>Expected savings</th>
<th>Qty</th>
<th>Salary /month</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>1</td>
<td>26 000 kr</td>
<td>26 000 kr</td>
</tr>
</tbody>
</table>

Savings Present Worth(2,25%) over 4 years: 1 192 420 kr

*Table 9: Cost and savings estimations for elimination of the tube labeling process.*

⁵ According to estimations made by Orica (Orica, Orica Sweden AB, 2011).
4.4 Increasing throughput at the pacemaker

Current situation

The pacemaker or the automatic assembly machines and manual assembly stations are each run by one operator. For the automatic machines, the operator picks up the assembled detonators (every 4 second) and places them onto trays as well as deal with minor problems that come up and getting additional material as needed. In the manual stations, the operator assembles the product in 45 seconds by moving it between machines and then places it onto a tray.

Major concerns

As the automatic machines do not have an automated ejection of finished products in the sense that it cannot run without the attention of an operator the machines are stop whenever that operator will need to go away from the machines (or if there aren’t enough operators to man each machine). That includes; replenishing material, going to the toilet or on a break or dealing with administrative issues. As a result, the actual production time of the machines is very low, see Figure 28.

Figure 28: A pie chart from a cause-of-stop analysis made for April month of one of the automatic machines. The part “Personal” is probably a bit larger than it should be; there have been some mistakes in documenting some of that stop time under right codes. See full report in Appendix V – Elsa 4 downtime report.

A spaghetti diagram for an operator of one of the automatic machines is shown Figure 29. It shows well the distances that the operator needs to go to get replenishments, delivering finished products or attend to administrative issues. While this travel and work is performed, the machine is idle (a machine that assembles a detonator every 4 seconds).

Figure 29: A spaghetti diagram showing the travels of operator for one of the automatic machines.
Removing dependency of an operator at the machines with automation

There are two things the operator does in this step:

• Moves the detonator from a conveyor band leading out from the machine to a tray.
• Performs visual inspection of the detonator, that is; checks if the plastic block and tube are fastened and checks if the shrinkage on the cap is in the right place.

The first point can easily be performed by a pick-and-place robot but the visual inspection might prove harder. The best solution would of course be to analyze why these quality problems occur and eliminate the source so a visual inspection is unnecessary. Figure 28 indicates that there is much to be gained with removing the dependency of an operator at the machine, the top reason for a machine stop is “Personal” – even though it might be a little overestimated. Other reasons supporting automation are (Groover, 2008):

• To increase labor productivity. Currently the assembly is operated on 3 shifts starting at 06:00 in the morning and finishing up at 23:15 in the night. Automating this step would result in higher output per labor work hour which could offer a reduction to work hours.
• To reduce labor cost. The assembly line could be operated with fewer operators.
• To improve working conditions by eliminating routine and boring tasks.
• To improve the safety of the operators by reducing the time they’re exposed to and handling the product.

Cost estimation with installing pick-and-place robots to the automatic machines

The table below (Table 8) displays the investment costs and the respective savings included in the installation of pick-and-place robots to the automatic machines. These are rough estimations and should only serve the purpose of making a rough picture of the expected return from the project. The project can be expected to come out on zero after about 20 months.

<table>
<thead>
<tr>
<th>Expected investments</th>
<th>Units</th>
<th>Cost per unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>KR 5 SCARA R350 4-axis Pick-and-Place robot⁶</td>
<td>4</td>
<td>215 000 kr</td>
<td>860 000 kr</td>
</tr>
<tr>
<td>Installation of robots</td>
<td>4</td>
<td>25 000 kr</td>
<td>100 000 kr</td>
</tr>
<tr>
<td>One gram fixture trays compatible with robot feeding</td>
<td>80</td>
<td>500 kr</td>
<td>40 000 kr</td>
</tr>
<tr>
<td>Changes to workcell</td>
<td>4</td>
<td>5 000 kr</td>
<td>20 000 kr</td>
</tr>
</tbody>
</table>

Total investment cost: 1 020 000 kr

<table>
<thead>
<tr>
<th>Expected savings</th>
<th>Qty</th>
<th>Salary /month</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>2</td>
<td>26 000 kr</td>
<td>52 000 kr</td>
</tr>
</tbody>
</table>

Present Worth(2,25%) over 4 years: 2 384 839 kr

Table 10: Cost and savings estimations with installation of pick-and-place robots to the automatic machines.

4.5 Establishing continuous flow through downstream processes

Current situation

As the detonators are assembled at the pacemaker (assembling machine and assembling work-cell on Figure 30) they are placed on a tray by an operator. When the tray is full (with 30-40 detonators) it gets placed on a trolley. When the trolley is full with enough trays to fill up exactly one shipping box (180 or 250 detonators so 6-7 trays) the trolley is pushed towards a conveyor band that leads to the X-ray station. So the detonators are batched up, up to 250 pieces for the move down to X-ray, there they are un-batched again as the trays are taken one by one and placed on the conveyor (as room exists) by the operator at X-ray. After the trays go through the X-ray they’re physically pushed on a FIFO band towards Packing where the detonators get packed 10 by 10 in bags and into shipment boxes. The boxes are then sealed with glue and tape and put into an outside storage where they get picked up. This process is shown on Figure 30 below. The arrangements of the X-ray and packing stations are good as the operator on the X-ray has the possibility to help out in Packing. The cycle time in Packing is very close to the Takt time so there isn’t much room for interruptions or delays. However, the cycle time for X-ray is well under the Takt time so the operator on X-ray has time available to help out in packing if that is needed, such as bag detonators and put them in boxes or assemble cardboard boxes to have them ready.

4.5.1 Eliminate the need for trolleys by allowing operators to inspect and pack directly from the machines

It takes the products about an hour to go from the assembly machines / cells through X-ray, packing and box sealing. The flow through X-ray down to box sealing happens mostly on FIFO conveyor bands which is very positive. However, the move of products from the assembly machines / cells down to X-ray takes place on trolleys; the products get hand-picked onto trays, the trays put on the trolleys, and the trolley is moved few meters where it stays in a queue before X-ray. As needed, the trays are picked off the trolleys and put on a conveyor band.

This involves a lot of wasted activities with all the hand-picking of detonators on and off the trays and the movement of trolleys around. However, the size of the machines are so big that it is likely to prove impractical to install some form of conveyor system to remove the need for the trolleys, and
the fact is that the trays isolate each detonator from each other preventing a chain reaction and increasing the safety.

A possible solution could be to establish a way that the operators can inspect and pack directly from the machines - see Figure 31 for an explanation.

Figure 31: Shows a set-up for a system that allows the machine operators to inspect and pack directly from the machine.

As 10 detonators are packed into the bags; it provides the necessary batching that allows time for inspection and packing. The figures are taken together in Table 11.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available time (10 det. · C/T)</td>
<td>40</td>
</tr>
<tr>
<td>X-ray inspection</td>
<td>-6.2</td>
</tr>
<tr>
<td>Visual inspection</td>
<td>-10</td>
</tr>
<tr>
<td>Packing the products into bags</td>
<td>-13</td>
</tr>
<tr>
<td>Available time for transport</td>
<td>40 - 29.2 = 10.8</td>
</tr>
</tbody>
</table>

Table 11: Time calculations to see if it is possible for an operator to pack directly from the automatic machines.
The pros with this system are:

- The wasted activities involving the trolley system will be eliminated.
- The operators at the machine will provide higher productivity as they can inspect the X-rays and pack the detonators directly.

But there are few cons as well:

- It is not a solution for the manual assembly cells which would still need a working X-ray and packing station.
- The operators are still tied with the machines – and they’ll need to be stopped if the operator needs to go away.
- Requires support personnel to remove packed boxes as the available time does not allow the operators to do that.
- Requires investments in installment of X-rays and conveyor system at each automatic machine.

**Cost estimation**

The table below (Table 8) displays the investment costs and the respective savings included in the installation of pick-and-place robots to the automatic machines. These are rough estimations and should only serve the purpose of making a rough picture of the expected return from the project.

<table>
<thead>
<tr>
<th>Expected investments</th>
<th>Units</th>
<th>Cost per unit</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>InspireX R20 X-ray&lt;sup&gt;7&lt;/sup&gt;</td>
<td>4</td>
<td>500 000 kr</td>
<td>2 000 000 kr</td>
</tr>
<tr>
<td>Conveyor band&lt;sup&gt;8&lt;/sup&gt;</td>
<td>12 m</td>
<td>12 000 kr</td>
<td>144 000 kr</td>
</tr>
<tr>
<td>Conveyor installation&lt;sup&gt;9&lt;/sup&gt;</td>
<td>1</td>
<td>50 000 kr</td>
<td>50 000 kr</td>
</tr>
<tr>
<td>Changes to work-cells (adding packing station)</td>
<td>4</td>
<td>2 000 kr</td>
<td>8 000 kr</td>
</tr>
<tr>
<td><strong>Total investment cost:</strong></td>
<td></td>
<td></td>
<td><strong>2 202 000 kr</strong></td>
</tr>
</tbody>
</table>

Table 12: Cost estimation with installing X-rays and conveyor system to each automatic machine.

### 4.5.2 Assembly to order

Orica aims to be able to deliver to orders in 24 hours within Sweden and in 48 hours within Europe. An exception to this are customized products and very large orders which Orica will have 4 weeks time to deliver to. In order to achieve this delivery level, a stock of finished products is kept and as the orders are received the products get sent immediately.

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<sup>7</sup> X-rays by Mettler-Toledo – se.mt.com

<sup>8</sup> Estimates for a traditional conveyor band (Onori, 2010).

<sup>9</sup> Estimates for a traditional conveyor band (Onori, 2010).
There are 600 different product types of electrical detonators Orica produces and of these 600; 100 are kept on stock. The size of this stock is in the range of 300,000 units.

Overproduction and inventory are two of the seven wastes described in section 2.1.2. Overproduction happens when units are produced that are not requested or bought by a customer. Overproduction was considered by Taichii Ohno’s to be the worst waste as it hides other forms of wastes (defects, long setup times or wait times) and creates an artificial demand through the production and supply chain. Its direct effects are inventory which is tied up capital, requires facilities to store it and manpower to keep track of it. Lean is often said to be a systematic approach to reducing inventory, no matter where it is or for what reason it is kept.

Thus a good improvement would be to eliminate the need for a finished stock of electrical detonators, or at least keep it at minimum without affecting the service level. It’s desirable to push the point where the product is customized as far upstream as possible, see Figure 32. Then, less material will be used for products that haven’t been requested resulting in less inventory and focus can be kept on delivering products that have been requested.

The reasons for attempting to do this are many:

- The 300,000 units are tied up capital.
- Increased productivity for the overall line (see section 1.3 about Orica productivity measurements).
- Frees up facilities that were kept to store the inventory.
- Material is not used for products that are not requested (Figure 32).
- Frees up manpower that keeps track of the inventory, handles and counts it.
- The detonators contain explosive which is not desirable for storage.
- The explosive in the cap on the detonator has a lifetime of 2 years, and it is already a few months old before assemble.

What forces Orica to keep inventory of finished stock is its business strategy of offering low lead time and the high variety in actual demand. In Figure 33 demand is shown for the period 2010-01-01 to 2011-03-31.
The current daily throughput capability is about 20,000 units. Looking at the graph above (Figure 33), it’s obvious that it won’t be sufficient to be able to assembly to order without it coming down on the service level. But the question is, at what level can it be done, and what if the throughput increases or some of the items are kept on stock?

Below (Figure 34) are the results of a simulation made to answer these questions. The simulation was run with three different throughputs per day capacity; 20,000, 25,000 and 30,000 and number of SKUs of 5, 10, 15, 20 and 25.

![Demand for detonators](image)

**Figure 33: Actual demand for electrical detonators.**

**Figure 34: Results from simulation that was made to assess if it’s possible to assembly to order without reducing service level. The table shows the number of days in the simulation period where the lead time exceeds 12 hours, 24 hours or 48 hours for different throughput levels.**
The simulation was made for working days from beginning of year 2010 to end of March 2011. It’s worth mentioning that the data is not perfect; it is likely that some of the peaks in the demand chart (Figure 33) are orders that Orica has 4 weeks to deliver to, which could explain some of the longer lead times.

From the results however, it is apparent that the throughput will have to be increased substantially in order to be able to reduce the SKUs down to 25 product types if the same delivery level is to be maintained. There have two ways been suggested already that would directly increase the throughput. That is: establishing more control of the material replenishments, see 4.2 and removing dependency of operator at the automatic machines, see 374.4.

Another concern is the number of set-ups each day and if there is available time for that. Theoretical maximum number of changeovers is as follows:

<table>
<thead>
<tr>
<th>Available time (operation time -maintenance -breaks)</th>
<th>780</th>
<th>minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical cap. for 4 automatic machines in available time</td>
<td>46800</td>
<td>pcs.</td>
</tr>
<tr>
<td>Theoretical cap. for 3 manual cells in available time</td>
<td>2340</td>
<td>pcs.</td>
</tr>
<tr>
<td>Overall theoretical capacity</td>
<td>49140</td>
<td>pcs.</td>
</tr>
<tr>
<td>Current throughput with assumed 10% scrap rate</td>
<td>22000</td>
<td>pcs.</td>
</tr>
<tr>
<td>Time available for changeovers</td>
<td>431</td>
<td>minutes</td>
</tr>
<tr>
<td>Time each changeovers takes</td>
<td>15</td>
<td>minutes</td>
</tr>
<tr>
<td>Maximum number of changeovers</td>
<td>29</td>
<td>times</td>
</tr>
</tbody>
</table>

Table 13: Theoretical maximum number of changeovers calculations. If the throughput gets increased to 30,000 units per day, the maximum number of changeovers gets reduced to 18 per day.

Figure 35: Required setups per day for Assembly-To-Order.
The ability to Assembly-To-Order given the current service level is limited by both the throughput and the number of required setups per day. As mentioned, Orica aims to serve to orders within 24 hours on the Scandinavia region and within 48 hours in Europe outside Scandinavia. That means that the products to each customer order have to be assembled at the day of order arrival. It’s not uncommon that the incoming orders are for many different product varieties with small volumes of each product increasing the number of required setups per day necessary if the aim is to directly assemble to that order with the same service level. There are however various ways to increase the throughput, some of which have been discussed in previous sections, and how to reduce the setup time (one has been discussed in section 4.2.2).

4.6 More efficient work-environment

Previous sections have addressed changes to workstations or material replenishment procedures. These are the big waste generators and naturally should get a lot of focus. But there is a lot in the work environment that can affect how smooth things run. A suggestion for a new layout that suits the future state can be seen in Figure 36. It is designed to minimize the transportation and movement wastes for operators retrieving material or dropping of finished products to the X-ray. The material is located on the right side of the production area (red circle on Figure 36), close to the automatic machines which are between the material and the X-ray and packing. The centralized planning board (green circle on Figure 36) is visual to everyone in the area and serves to signal changeovers to the setup personnel and displays the current status of production. Instead of having the automatic machines in straight line as in current arrangements (see Appendix VI – Current facility layout), they’re grouped up. This reduces movement waste for operators that are making sure they’re up and running and allows them to help out with loading the X-ray conveyor band if they have time.

Figure 36: A future state facility layout.
Visual management can be used to several tasks in the process, one of these is to visually control the replenishments of operational materials such as labels and label rolls. The inventory is stacked next to a color bar which has the color indicating when it is required to order replenishment, see Figure 37.

Figure 37: An example of visual management for material replenishment. Shows label roll replenishment being controlled by color codes. Green color means that the status is good for now, yellow means that replenishments will be needed soon and red means that replenishments are needed right now.

These are the changes that are best tackled by the people working in the process themselves. They are the experts on the details involved in the process and are best suited to find out the best ways to find and implement the improvements to it. But in order for the employees to be able to do so, they’ll require training; such as, in the lean principles, the tools to analyze the process and the problem solving techniques to find solution to the problems and inefficiencies they discover. Providing them this training, organize them in teams and encouraging them to start improving their work-environment will improve communication and morale (one of the goals of lean manufacturing organization).
5. Discussion

The material replenishment lack stability and control overall. Frequent shortages of materials directly affect the throughput and are probably the biggest contributor to the waiting waste in this assembly process. A Kanban system is proven to be suitable for the fuse-heads and there exist measures to reduce the fuse-head inventory, such as; reducing the lead-time through the fuse-head production and reduce the size of the production orders while manufacturing to stock. The cap replenishment is not done with a pure pull as the orders for replenishment come from an employee outside of the assembly process who can’t know if there are occurring problems that interrupt the work. The implementation of a planning board along with standardized work for ordering this material, it would be best if the orders came from the assembly process itself. That way, it is far less likely that there will be too many caps in the assembly process facility causing problems as they don’t fit in the explosive containers. A Kanban system had already been implemented for the wire replenishment so there was not a reason to interfere in that work. But overall, a pull for material replenishments is probably the best way given the nature of the products. It makes it easy to have a strict cap on the inventory so it will never exceed the allowed limit, which could pose a safety risk.

The two workstation; cap filling and tube labeling are close to pure waste. It is however not possible to eliminate them right away but research should be done to see if that is possible in the near future.

The manual assembly cells seem to be decently designed in terms of minimizing pickups of items, how far they have to reach and the movement the operators need to make while working there. So focus was put on those processes where a lot of waste is present and offers the opportunity to increase the overall efficiency greatly if eliminated.

For the automatic machines; the greatest importance is to remove the dependency for operators to be present at the machine so it will run. This greatly reduces the throughput as the operator has to stop the machine every time one of the 7 materials for it is going empty, when the operator has to deliver the finished products to the X-ray or when he needs to go to the bathroom or on a break (a machine that produces a new unit every 4 seconds). Exploration is required to see if it is possible to eliminate the need for visual inspection, such as by finding out the causes for the faults and eliminate them (see section 4.4).

The flow through X-ray and packing is far from ideal but it’s not bad either. The major waste generator is the trolley system where products are batched onto trays and trays batched onto trolleys. The trolleys are driven few meters where the trays are un-batched to the conveyor band and in packing the products are un-batched from the trays. It might however be difficult to find a good alternative solution; an automated conveyor band will not be practical given the distances it will need to move the products.

Overall, there is a great importance for a layout that minimizes the transportation and movement wastes which can be tricky; the machines take a lot of space and need to be accessible from all sides, the boxes with the finished products need to be stacked up in room at the far end of the facility where they’re picked up. Some research and innovative solution are required to reduce these factors, such as exploring ways to store the caps safely near the machines that allows for the elimination of caps filling (see section 4.3.1).
The inventory holding the finished products that contains 100 to 150 different product varieties and about 300,000 total units is a huge waste generator. The required service level for Orica’s business strategy and the current status of the final assembly does not allow for a full Assembly-To-Order. The variation in the demand in both quantities and product varieties are too high so that in order to eliminate the final stock, Orica would have to; reduce the service level and / or work hard towards increasing the throughput and reducing the setup times.
6. **Direction of future work**

Implementing new material replenishment systems; Kanban for fuse-heads and a pull via centralized planning board for caps is best to do soon as possible as these systems don’t require a lot of planning or investments. The other solutions need a little bit of research before decision can be taken if they’re implementable. What follows is the list of actions that need to be performed:

**Project: Kanban system for fuse-heads**

**Design:**
- Supermarket arrangements.
- Kanban post.
- Kanban cards.
- Document or signs to explain how to use the system and to display the Kanban rules.

Assign responsibilities; decide on who should move the cards from final assembly to fuse-head department and when.

Monitor the system until its stable.

**Future tasks:** Work towards improving the system and reducing this inventory (fewer Kanban cards).

**Project: Planning board for caps**

**Design:**
- The planning board.
- Document or signs to explain how to use it.
- Explosive container arrangements, assign one container for returns.

Assign responsibilities; decide on who should order more caps.

Standardize; the order point, delivery point, the movement of extra caps to a return container, time when return container is emptied.

**Project: Eliminate tube labeling work-station**

**Tasks:**
- Build and install four new labeling machines.
- Integrate a stop function into the control of computer on the automatic assembly machines to that it will automatically stop as labels run out.

**Project: Eliminate the caps magazine filling work-station**

**Tasks:**
- Explore methods to safely store the caps closer to the machines.
• If a storage method is found, a simplification of the feeding system is required so that the caps won’t have to be in magazines when they get loaded to the machine.

**Project: Removing dependency for operators at automatic machines**

Tasks:

• If it’s possible to eliminate the visual inspection. Buy 4 pick-and-place robots to move detonators from the machines to trays.
• If it’s not possible to eliminate visual inspection. Buy 4 X-ray machines and design the work-station so that the operators can pack directly from the machine.

**Project: Train the employees**

Tasks:

• Teach the employees the principles of lean manufacturing.
• Teach the employees how to use lean tools to analyze the process to discover wastes.
• Teach the employees how to use problem solving tools to find develop improvement for the wastes they discover.
• Motivate and encourage them to improve their work environment.
7. Acknowledgements

I’d like to give my thanks to the employees of Orica for the warm welcome and their patience while answering all my questions. I’d especially like to thank Ann-Britt Jansson, my advisor at Orica for the part she played in the creation of this thesis. I’d also like to thank my professor and advisor at the Royal School of Technology, Jerzy Mikler.
8. References


Orica. (2011). Orica Sweden AB.


Appendix I – Process mapping

Figure 38: A process map for the work an operator performs while working on one of the automatic assembly machines.
Figure 39: A process map for the tube labeling work-station.

Figure 40: A process map for the caps magazine filling work-station.
Figure 41: A process map of the X-ray work-station.
Appendix II – Spaghetti diagrams

On Figure 42 is a spaghetti diagram of the routes an operator takes while working on an assembly machines. In some routes the operator is delivering finished products, on some he’s retrieving additional material and on some he’s checking the production plan to see what’s next on the schedule.

![Figure 42: The routes an operator for Elsa 4 (one of the automatic assembly machines) takes in his work.](image)

Figure 43 shows the routes for an operator on one of the manual assembly machines. The operators on the manual machines/cells retrieve the caps they need by themselves. The caps are not filled into fixtures for the manual machines/cells.

![Figure 43: Travel performed by an operator working on one of the manual machines.](image)

Figure 44 shows the routes for an operator working on the caps filling workstation. The four orange boxes are the explosive containers where the caps are stored. As the operator has filled a trolley with
fixtures containing caps, he’ll drive it to the designated machine. He then goes around to see which machine will be out next and fills fixtures for that machine.

Figure 44: The travel performed by an operator in caps filling. When starting a new order he needs to go to every machine to see which one will be finished with its caps first.
Appendix III – Fuse-head simulation code

Dim VA_Init, XS_Init, U_Init, S_Init, i, Container_Size, VB_Kanban, XS_Kanban, U_Kanban, S_Kanban As Integer
Dim Kanban_Out, Kanban_In, Send_Out, SendOut As Integer

'The initial stock values:
VA_Init = Cells(9, "M").Value
VA_Kanban = Cells(15, "S").Value
XS_Init = Cells(9, "N").Value
XS_Kanban = Cells(15, "U").Value
U_Init = Cells(9, "O").Value
U_Kanban = Cells(15, "W").Value
S_Init = Cells(9, "P").Value
S_Kanban = Cells(15, "Y").Value
Container_Size = Cells(7, "M").Value

'Array made for each fusehead type. Each slot in the array represents material amount equal to one kanban card.
Dim VA_B() As Long
ReDim VA_B(1 To VA_Kanban)
For g = 1 To (UBound(VA_B) - LBound(VA_B) + 1)
    VA_B(g) = g * Container_Size
Next g
Dim XS_B() As Long
ReDim XS_B(1 To XS_Kanban)
For g = 1 To (UBound(XS_B) - LBound(XS_B) + 1)
    XS_B(g) = g * Container_Size
Next g
Dim U_B() As Long
ReDim U_B(1 To U_Kanban)
For g = 1 To (UBound(U_B) - LBound(U_B) + 1)
    U_B(g) = g * Container_Size
Next g
Dim S_B() As Long
ReDim S_B(1 To S_Kanban)
For g = 1 To (UBound(S_B) - LBound(S_B) + 1)
    S_B(g) = g * Container_Size
Next g

i = 16
Do
    Cells(i, "N").Value = Cells(i, "N").Value + Cells(i - 1, "N").Value - Cells(i, "G").Value
    Cells(i, "O").Value = Cells(i, "O").Value + Cells(i - 1, "O").Value - Cells(i, "H").Value
    Cells(i, "P").Value = Cells(i, "P").Value + Cells(i - 1, "P").Value - Cells(i, "I").Value
    Cells(i, "Q").Value = Cells(i, "Q").Value + Cells(i - 1, "Q").Value - Cells(i, "J").Value
    Cells(i, "R").Value = Cells(i, "R").Value + Cells(i - 1, "R").Value - Cells(i, "K").Value
    Cells(i, "S").Value = Cells(i, "S").Value + Cells(i - 1, "S").Value - Cells(i, "L").Value
    Cells(i, "T").Value = Cells(i, "T").Value + Cells(i - 1, "T").Value - Cells(i, "U").Value
    Cells(i, "V").Value = Cells(i, "V").Value + Cells(i - 1, "V").Value - Cells(i, "W").Value
    Cells(i, "X").Value = Cells(i, "X").Value + Cells(i - 1, "X").Value - Cells(i, "Y").Value
    Cells(i, "Z").Value = Cells(i, "Z").Value + Cells(i - 1, "Z").Value - Cells(i, "A").Value
    Cells(i - 1, "N").Value = Cells(i - 1, "N").Value - Cells(i - 1, "G").Value
    Cells(i - 1, "O").Value = Cells(i - 1, "O").Value - Cells(i - 1, "H").Value
    Cells(i - 1, "P").Value = Cells(i - 1, "P").Value - Cells(i - 1, "I").Value
    Cells(i - 1, "Q").Value = Cells(i - 1, "Q").Value - Cells(i - 1, "J").Value
    Cells(i - 1, "R").Value = Cells(i - 1, "R").Value - Cells(i - 1, "K").Value
    Cells(i - 1, "S").Value = Cells(i - 1, "S").Value - Cells(i - 1, "L").Value
    Cells(i - 1, "T").Value = Cells(i - 1, "T").Value - Cells(i - 1, "U").Value
    Cells(i - 1, "V").Value = Cells(i - 1, "V").Value - Cells(i - 1, "W").Value
    Cells(i - 1, "X").Value = Cells(i - 1, "X").Value - Cells(i - 1, "Y").Value
    Cells(i - 1, "Z").Value = Cells(i - 1, "Z").Value - Cells(i - 1, "A").Value
    i = i + 1
Loop
'VA boundaries
For a = (UBound(VA_B) - LBound(VA_B) + 1) To 1 Step -1
    If Cells(i, "N").Value < Container_Size Then
        Send_Out = (UBound(VA_B) - LBound(VA_B) + 1) 'Alla miðana út
    ElseIf Cells(i, "N").Value < (VA_B(a) + Container_Size) Then 'Ætti ekki að þurfa +Container_Size?
        Send_Out = (VA_Kanban - a)
    End If
Next a

'Replenishment issued for VA
If (VA_Kanban - Send_Out) < (Cells(i - 1, "S").Value + Cells(i, "S").Value) Then
    SendOut = (Cells(i - 1, "S").Value + Cells(i, "S").Value) - (VA_Kanban - Send_Out)
    Cells(i + 3, "S").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + 3, "N").Value = SendOut * Container_Size 'Material receieved in 3 days
    Cells(i + 3, "M").Value = SendOut * Container_Size
End If

'XS boundaries
For b = (UBound(XS_B) - LBound(XS_B) + 1) To 1 Step -1
    If Cells(i, "O").Value < Container_Size Then
        Send_Out = (UBound(XS_B) - LBound(XS_B) + 1) 'Alla miðana út
    ElseIf Cells(i, "O").Value < (XS_B(b) + Container_Size) Then 'Ætti ekki að þurfa +Container_Size?
        Send_Out = (XS_Kanban - b)
    End If
Next b

'Replenishment issued for XS
If (XS_Kanban - Send_Out) < (Cells(i - 1, "U").Value + Cells(i, "U").Value) Then
    SendOut = (Cells(i - 1, "U").Value + Cells(i, "U").Value) - (XS_Kanban - Send_Out)
    Cells(i, "V").Value = SendOut 'Kanban sent out
    Cells(i + 3, "U").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + 3, "O").Value = SendOut * Container_Size 'Material receieved in 3 days
End If

'U boundaries
For c = (UBound(U_B) - LBound(U_B) + 1) To 1 Step -1
    If Cells(i, "P").Value < Container_Size Then
        Send_Out = (UBound(U_B) - LBound(U_B) + 1) 'Alla miðana út
    ElseIf Cells(i, "P").Value < (U_B(c) + Container_Size) Then 'Ætti ekki að þurfa +Container_Size?
        Send_Out = (U_Kanban - c)
    End If
Next c

'Replenishment issued for U
If (U_Kanban - Send_Out) < (Cells(i - 1, "W").Value + Cells(i, "W").Value) Then
    SendOut = (Cells(i - 1, "W").Value + Cells(i, "W").Value) - (U_Kanban - Send_Out)
    Cells(i, "X").Value = SendOut 'Kanban sent out
Cells(i + 3, "W").Value = SendOut 'Kanbans reincluded into Kanban bin
Cells(i + 3, "P").Value = SendOut * Container_Size 'Material receieved in 3 days
End If

'S boundaries
For d = (UBound(S_B) - LBound(S_B) + 1) To 1 Step -1
    If Cells(i, "Q").Value < Container_Size Then
        Send_Out = (UBound(S_B) - LBound(S_B) + 1) 'Alla miðana út
    ElseIf Cells(i, "Q").Value < (S_B(d) + Container_Size) Then 'Ætti ekki að þurfa +Container_Size?
        Send_Out = (S_Kanban - d)
    End If
Next d

'Replenishment issued for S]
If (S_Kanban - Send_Out) < (Cells(i - 1, "Y").Value + Cells(i, "Y").Value) Then
    SendOut = (Cells(i - 1, "Y").Value + Cells(i, "Y").Value) - (S_Kanban - Send_Out)
    Cells(i, "Z").Value = SendOut 'Kanban sent out
    Cells(i + 3, "Y").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + 3, "Q").Value = SendOut * Container_Size 'Material receieved in 3 days
End If

'Filled into Kanban_In cell:
 Cells(i, "S").Value = Cells(i, "S").Value + Cells(i - 1, "S").Value - Cells(i, "T").Value
 Cells(i, "U").Value = Cells(i, "U").Value + Cells(i - 1, "U").Value - Cells(i, "V").Value
 Cells(i, "W").Value = Cells(i, "W").Value + Cells(i - 1, "W").Value - Cells(i, "X").Value
 Cells(i, "Y").Value = Cells(i, "Y").Value + Cells(i - 1, "Y").Value - Cells(i, "Z").Value

'Statistics measurer:
If Cells(i, "N").Value < 0 Then
    Cells(4, "U").Value = Cells(4, "U").Value + 1
ElseIf Cells(i, "N").Value < 0.1 * (VA_Kanban * Container_Size) Then
    Cells(5, "U").Value = Cells(5, "U").Value + 1
ElseIf Cells(i, "N").Value < 0.25 * (VA_Kanban * Container_Size) Then
    Cells(6, "U").Value = Cells(6, "U").Value + 1
End If

If Cells(i, "O").Value < 0 Then
    Cells(4, "V").Value = Cells(4, "V").Value + 1
ElseIf Cells(i, "O").Value < 0.1 * (XS_Kanban * Container_Size) Then
    Cells(5, "V").Value = Cells(5, "V").Value + 1
ElseIf Cells(i, "O").Value < 0.25 * (XS_Kanban * Container_Size) Then
    Cells(6, "V").Value = Cells(6, "V").Value + 1
End If

If Cells(i, "P").Value < 0 Then
    Cells(4, "W").Value = Cells(4, "W").Value + 1
ElseIf Cells(i, "P").Value < 0.1 * (U_Kanban * Container_Size) Then
    Cells(5, "W").Value = Cells(5, "W").Value + 1
ElseIf Cells(i, "P").Value < 0.25 * (U_Kanban * Container_Size) Then
    Cells(6, "W").Value = Cells(6, "W").Value + 1
End If
Appendix IV – Caps simulation template and code

The template for this simulation is shown on Figure 45. It has similar structure as the fuse-head Kanban template described in the methods section. The red arrow on the figure points on a table which has the Kanban calculations for every product variety. The green arrow is pointed towards the demand data for all the caps varieties. The purple arrow points towards the work days. The blue arrow points towards the automatic statistic calculation from the simulation. And the orange arrow points towards the simulated inventory level.

The code for the simulation of Kanban system for 4 product varieities is as follows:

```
Dim i, Container_Size, NR0_Kanban, NR1_Kanban, NR2_Kanban, NR3_Kanban As Integer
Dim NR0_bin, NR1_bin, NR2_bin, NR3_bin As Integer
Dim Kanban_Out, Kanban_In, Send_Out, SendOut, Twobin As Integer
```

```vbnet
Cells(6, "W").Value = Cells(5, "W").Value + 1
End If

If Cells(i, "Q").Value < 0 Then
    Cells(4, "X").Value = Cells(4, "X").Value + 1
End If

ElseIf Cells(i, "Q").Value < 0.25 * (S_Kanban * Container_Size) Then
    Cells(6, "X").Value = Cells(5, "X").Value + 1
End If

i = i + 1
Loop Until IsEmpty(Cells(i, "K"))
```
'The initial stock values:
NR0_Kanban = Cells(9, "I").Value
NR1_Kanban = Cells(9, "J").Value
NR2_Kanban = Cells(9, "K").Value
NR3_Kanban = Cells(9, "L").Value
TwoBin = 2
Leadtime = Cells(5, "I").Value
Container_Size = Cells(7, "I").Value

'Array made for each fusehead type. Each slot in the array represents material amount equal to one kanban card.
NR0_bin = (NR0_Kanban / 2) * Container_Size
NR1_bin = (NR1_Kanban / 2) * Container_Size
NR2_bin = (NR2_Kanban / 2) * Container_Size
NR3_bin = (NR3_Kanban / 2) * Container_Size

i = 16
Do
    Cells(i, "AG").Value = Cells(i, "AG").Value + Cells(i - 1, "AG").Value - Cells(i, "I").Value
    Cells(i, "AH").Value = Cells(i, "AH").Value + Cells(i - 1, "AH").Value - Cells(i, "J").Value
    Cells(i, "AI").Value = Cells(i, "AI").Value + Cells(i - 1, "AI").Value - Cells(i, "K").Value
    Cells(i, "AJ").Value = Cells(i, "AJ").Value + Cells(i - 1, "AJ").Value - Cells(i, "L").Value

'NR0 boundaries
If Cells(i, "AG").Value <= 0 Then
    Send_Out = 2
ElseIf Cells(i, "AG").Value < NR0_bin Then
    Send_Out = 1
Else
    Send_Out = 0
End If

'[Replenishment issued for NR0]
If (TwoBin - Send_Out) < (Cells(i - 1, "BC").Value + Cells(i, "BC").Value) Then
    SendOut = (Cells(i - 1, "BC").Value + Cells(i, "BC").Value) - (TwoBin - Send_Out)
    Cells(i, "BD").Value = SendOut 'Kanban sent out
    Cells(i + Leadtime, "BC").Value = SendOut 'Kanbons reincluded into Kanban bin
    Cells(i + Leadtime, "AG").Value = SendOut * NR0_bin 'Material recieived in 3 days
End If

'NR1 boundaries
If Cells(i, "AH").Value <= 0 Then
    Send_Out = 2
ElseIf Cells(i, "AH").Value < NR1_bin Then
    Send_Out = 1
Else
    Send_Out = 0
End If

'[Replenishment issued for NR0]...
End If

'Replenishment issued for NR1
If (Twobin - Send_Out) < (Cells(i - 1, "BE").Value + Cells(i, "BE").Value) Then
    SendOut = (Cells(i - 1, "BE").Value + Cells(i, "BE").Value) - (Twobin - Send_Out)
    Cells(i, "BF").Value = SendOut 'Kanban sent out
    Cells(i + Leadtime, "BE").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + Leadtime, "AH").Value = SendOut * NR1_bin 'Material receieved in 3 days
End If

'NR2 boundaries
If Cells(i, "AI").Value <= 0 Then
    Send_Out = 2
ElseIf Cells(i, "AI").Value < NR2_bin Then
    Send_Out = 1
Else
    Send_Out = 0
End If

'Replenishment issued for NR2
If (Twobin - Send_Out) < (Cells(i - 1, "BG").Value + Cells(i, "BG").Value) Then
    SendOut = (Cells(i - 1, "BG").Value + Cells(i, "BG").Value) - (Twobin - Send_Out)
    Cells(i, "BH").Value = SendOut 'Kanban sent out
    Cells(i + Leadtime, "BG").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + Leadtime, "AI").Value = SendOut * NR2_bin 'Material received in 3 days
End If

'NR3 boundaries
If Cells(i, "AJ").Value <= 0 Then
    Send_Out = 2
ElseIf Cells(i, "AJ").Value < NR3_bin Then
    Send_Out = 1
Else
    Send_Out = 0
End If

'Replenishment issued for NR3
If (Twobin - Send_Out) < (Cells(i - 1, "BI").Value + Cells(i, "BI").Value) Then
    SendOut = (Cells(i - 1, "BI").Value + Cells(i, "BI").Value) - (Twobin - Send_Out)
    Cells(i, "BJ").Value = SendOut 'Kanban sent out
    Cells(i + Leadtime, "BI").Value = SendOut 'Kanbans reincluded into Kanban bin
    Cells(i + Leadtime, "AJ").Value = SendOut * NR3_bin 'Material received in 3 days
End If

'Filled into Kanban_In cell:
Cells(i, "BC").Value = Cells(i, "BC").Value + Cells(i - 1, "BC").Value - Cells(i, "BD").Value
Cells(i, "BE").Value = Cells(i, "BE").Value + Cells(i - 1, "BE").Value - Cells(i, "BF").Value
Cells(i, "BG").Value = Cells(i, "BG").Value + Cells(i - 1, "BG").Value - Cells(i, "BH").Value
Cells(i, "BI").Value = Cells(i, "BI").Value + Cells(i - 1, "BI").Value - Cells(i, "BJ").Value
'Statistics measurer:

'NR0
If Cells(i, "AG").Value < 0 Then
    Cells(4, "AG").Value = Cells(4, "AG").Value + 1
ElseIf Cells(i, "AG").Value < 0.1 * 2 * NR0_bin Then
    Cells(5, "AG").Value = Cells(5, "AG").Value + 1
ElseIf Cells(i, "AG").Value < 0.25 * 2 * NR0_bin Then
    Cells(6, "AG").Value = Cells(6, "AG").Value + 1
End If

'NR1
If Cells(i, "AH").Value < 0 Then
    Cells(4, "AH").Value = Cells(4, "AH").Value + 1
ElseIf Cells(i, "AH").Value < 0.1 * 2 * NR1_bin Then
    Cells(5, "AH").Value = Cells(5, "AH").Value + 1
ElseIf Cells(i, "AH").Value < 0.25 * 2 * NR1_bin Then
    Cells(6, "AH").Value = Cells(6, "AH").Value + 1
End If

'NR2
If Cells(i, "AI").Value < 0 Then
    Cells(4, "AI").Value = Cells(4, "AI").Value + 1
ElseIf Cells(i, "AI").Value < 0.1 * 2 * NR2_bin Then
    Cells(5, "AI").Value = Cells(5, "AI").Value + 1
ElseIf Cells(i, "AI").Value < 0.25 * 2 * NR2_bin Then
    Cells(6, "AI").Value = Cells(6, "AI").Value + 1
End If

'NR3
If Cells(i, "AJ").Value < 0 Then
    Cells(4, "AJ").Value = Cells(4, "AJ").Value + 1
ElseIf Cells(i, "AJ").Value < 0.1 * 2 * NR3_bin Then
    Cells(5, "AJ").Value = Cells(5, "AJ").Value + 1
ElseIf Cells(i, "AJ").Value < 0.25 * 2 * NR3_bin Then
    Cells(6, "AJ").Value = Cells(6, "AJ").Value + 1
End If

i = i + 1
Loop Until IsEmpty(Cells(i, "AD"))
Appendix V – Elsa 4 downtime report

2e. Produktionsplats rapport, stopporsak

Utskriftsdatum: 2011-05-06
Tidintervall: 2011-04-31 00:00:00 - 2011-05-03 23:59:59
Vara: Produktionsplats: ELSA4
Produktionsplats: ELSA4

Hanerad produktionsstid (tm): 318,43
Verklig produktionsstid (tm): 68,16
Produktionsstid utanför plan tid (Tim): 2,25
Total stopptid ST (tm): 250,28
Stopp tid (tm): 2,76
Total tid TT (tm): 247,51
Ej belagt tid (tm): 0,00

Total tid TT (tm): 720,00

Totalt producerad mängd: 64043
Godkänd producerad mängd: 58192
Antal korningar: 1
Antal korrosioner: 58,51

Genomsnittlig cykeltid (sek): 3.8
Mjölkcykel tid (sek): 4.0
Genomsnittlig ställtid (min): 21

Genomsnittlig partiorlek: 64043
Genomsnittlig partiorlek: 64043
Antal korningar: 1

Tillgänglighet: 21,4
Anläggningstid: 100,0
Kvalitetstid: 90,0
TAK-värde: 19,4
Mål TAK: 50,0

Anteckningar:

Sida: 1
### 2e. Produktionsplats rapport, stoppsorsak

_Bevisstfyllt datum:_ 2011-05-06  
_Tidintervall:_ 2011-04-01 00:00:00 - 2011-04-30 23:59:59  
_Vals:_ Produktionsplats: ELSA4  
_Tillgänglighet:_

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<th>Tidkvarn</th>
<th>Andel av TT (%)</th>
<th>Andel av TP (%)</th>
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<td>STR_13 Uppspråk kans Mtm:1 ej OK</td>
<td>2,02</td>
<td>2</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>STR_15 Öknomt kappal - övik krynp</td>
<td>1,95</td>
<td>1</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>STR_7 Tävlings 3PRES innspurning (Summatsam)</td>
<td>1,65</td>
<td>1</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>STR_12 Uppspråk kans Kappal fants</td>
<td>0,60</td>
<td>2</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>STR_12 3PRES-innsparing (Summatsam)</td>
<td>0,72</td>
<td>1</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>STR_11 Falls med tomassvarter</td>
<td>0,27</td>
<td>1</td>
<td>0,0</td>
<td>0,0</td>
</tr>
</tbody>
</table>

| Summa: 15 010,55 | 1 045 |

### Anteckningar

_Sida:_ 2
Appendix VI – Current facility layout