Optimizing the efficiency of a production flow line at 3M.

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Synopsis

A Production flow line at 3M was investigated to find the cause for the inefficient flow line. The demand of the products is not met on time, making this area a consistent problem for many grounds. 3M's unit cost is furthermore a problem area, which is too high for 3M to stay competitive in the market. In this paper, methods were investigated to see clearly what the appropriate method would be to select for this type of circumstances. It was concluded that Theory of Constraints (TOC) would be the most appropriate to apply for several beneficial reasons. Performance measurement's is done in conjunction with the five focusing steps in TOC. The whole system was tested in Simulation to observe the improvement of TOC in the system. The results obtained were a smoother flow line which result in an improved throughput of the system, decreased back orders present and product demand met on time; and extra time left for an opportunity to increase the production without expenses.

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1. Introduction and Background

3M is fundamentally a science-based company. They produce thousands of inventive products and are the leader in score markets. Products include from health care and highway safety to office products, abrasives and adhesives. 3M has operations in more than 60 countries, while their products are selling in over 200 countries. 3M South-Africa is the largest 3M subsidiary in Africa. Electrical, telecommunications, abrasives and pharmaceutical products are manufactured locally.

The electrical flow line, in which the project will focus upon consist of four flow lines in parallel. Each of the four lines makes a selection of the specific generic products. When an order is received, planning in correlation of forecasting is done to decide what product will be manufactured on the next day.

Consistent problems in the electrical flow line are that the unit costs are too high and the products do not meet the customer demand on time. This in turn results in customer dissatisfaction and lost sales; and the unit cost that's too high makes is difficult to compete in the market.

2. Aim

The Aim of the project is to inspect the current flow rate of 3M's flow line and make and improvement on it. Improvement can be a decrease in the unit cost in 3M's electrical department, making them competitive in the market or increasing the efficiency of the current flow line of the electrical factory, making the flow line faster will increase customer satisfaction, decrease waste and increase overall profit.

3. Scope

3M is the local manufacturer of electrical, telecommunications, abrasives and pharmaceutical products. The manufacturing of these products are done on multiple flow lines. For the purpose of this project the focus is on the electrical flow line, which consists of polymer products and kit assemblers.

The polymer products are generic products that are packaged in various size divisions being, 100g, 169g, 412g and 769g. These packages become a part of a set which provides a generic size to the customer. There are 60 different products made in the electrical flow line. As part of the project unit cost will be inspected as well as the throughput rate of the current flow.

A broad literature review will be completed in order to identify the most applicable methodologies to operate the flow line. The focus will be on methods for increasing the efficiency and decreasing the unit cost. Furthermore a data analysis will be done, after which the development of the solution will precede.

4. Literature review

4.1 Improving throughput rate

The following methods were reviewed to apply at 3M for a more efficient flow line and an improved throughput rate.

4.1.1 Benchmarking

Benchmarking is a quality tool with breakthrough improvements. It originated from the Xerox in 1980, a well known international company. Benchmarking looks at the best-in-class achievement, not measurements against "a" reference point. The best-in-class achievement is a standard which a process similar to it can be measured against. The process consists of continuous comparing and measurement with businesses to ultimately gain information for improving its performance. A Benchmarking study is completed by several forms. Questionnaires, site visiting and literature searches are a few methods to do Benchmarking. Improved customer satisfaction, reduced cycle time and increased quality levels are results obtained from Benchmarking. Xerox applied Benchmarking which resulted in significant savings from using the approach

There are four types of partners for benchmarking studies:

1. **Internal study**: operations within different units in an organization. This simplifies implementation and data access. For example production planning approaches.
2. **Competitive studies**: target specific methods, products or processes used by an organization's competitors. It is usually completed by a third party. This type of information is extremely difficult to get due to concern of antitrust or disclosure issues. Examples would be the comparison of product distribution methods used, comparing companies using the same distribution channel.
3. **Functional or industry studies**: compare the functions that are similar within the same extensive industry or organizational performance with the leaders in

that industry. This type of method has potential to provide considerable improvement in performance. This type of study is done by a “blind” third party. Example of functional study is the evaluation of supplier management systems from different countries in the same industry.

4. **Generic benchmarking:** compares work practices and/or processes that are independent of industry. This is the most innovative method and the results can be a changed paradigm for reengineering specific operations. Example of generic benchmarking is the bar-coding application in different industries as a PC based inventory control and reordering system (Bodek & Longmire 1993).

Case study: Operational search accuracy of a national identification system

This report did benchmarking on automated fingerprint identification system. The best-in-class achievement that they compared it to is the system in England, Scotland and Whales. The knowledge gained from benchmarking allowed PITO to learn tremendously on the theoretical and practical area concerning the design and implementation of the system for themselves. The benefits they gained from using benchmarking were the saving of an enormous amount of time and money (Jain & Ratha 2005).

Case study: Operating efficiency of Asia container ports

The efficiency of container ports in Asia was studied in this report. The bootstrap method and data envelopment analysis (DEA) was used to create more reliable results. This study looked at the Return to Scale (RTS) for container ports. Based on the RTS estimation method, Benchmarking approach was used to compare similar best-in-practise container ports to improve the operating efficiency. They concluded in their study that the technical inefficiencies are due to pure technical inefficiencies rather than scale inefficiencies (Hung, Lu & Wing 2009).

Case study: Benchmarking in municipal solid waste recycling

The disposing of household waste in Israel was analyzed in this article. Recycling regulations was issued due to the serious crisis that there will be no space in the landfills for all the waste in the next few years. Benchmarking was used to see what method will be economically efficient for the given municipality. The study revealed which method to apply, with 90% accuracy whether it will in fact be economically efficient (Lavee & Khatib 2010).

4.1.2 Theory of Constraints

Theory of Constraints (TOC) was developed by E. M. Goldratt. Constraints are defined by Gautschi as “Any element or factor that prevents a system from achieving a higher level of performance with respect to its goal” (Gautschi 1995)

TOC principle works on a weakest link principle, meaning that the weakest link in a system is its constraint. The weakest link also depend the performance of a system. The strategy of TOC is to identify the weakest link, and focus on improving it. Drum-Buffer-Rope method in TOC will ensure that the system will always operate at its highest point. The Drum is capacity constraints and will set the pace for the system. The Buffer is a protecting system, ensuring that upstream processes know if the Drum is faster or slower preventing deviation from making the system out of synchronization. The Rope is a communication system that notifies the system what the pace is according to the Drum. Results from TOC include reduction of lead time as well as improvement in quality of service delivery (Van Zyl 2005)

There are three different buffers:

- Constraint buffer
- Shipping buffer
- Assembly buffer.

The Constraint buffer is to protect the system’s schedule of the constraint and is placed before the constraint resource. The Shipping buffer is to protect the delivery date of an order and is placed at the end of a process. The Assembly buffer is to prevent a part to wait for the other part in an assembly operation (a point where to parts are combined in the flow line). This might happen if one part comes from a constraint resource (Louw & Page 2010).

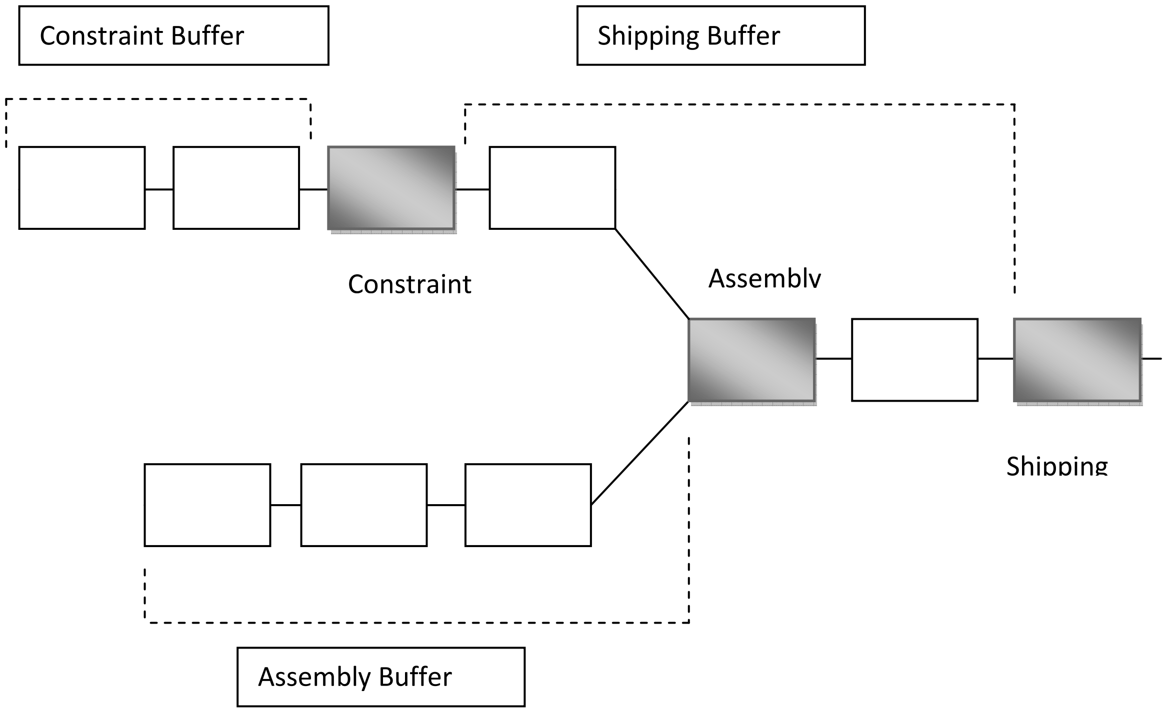


Figure 1 Illustration of time buffers in a simple flow line

adapted from (Queuing network analysis approach for estimating the sizes of the time buffers in Theory of Constraints controlled production system,(2010)).

4.1.2.1 WIP and lead times:

There is a close relationship between Work in Progress and Lead time. According to Little's law:

"WIP = Throughput × Lead time "

If the Lead time is decreased, it indirectly affects the WIP which will also decrease. Improved estimates of the time buffer will have considerable benefits for the plant's performance.

According to TOC literature, to determine the length of the time buffer is a trail-and-error approach. By applying Empirical rules the initial size of the time buffers can be determined (Srikanth & Umble 1997). Goldratt advises to determine the initial buffer length by estimating the present lead time of the tasks to the specific buffer origin and then dividing it by five (Goldrat & Cox 1984).

4.1.2.2 Using evaporating cloud diagram to identify the constraint

The first and sometimes most difficult part in applying TOC, is the first step: Identifying the constraint. The evaporating cloud method is a problem solving tool developed by Goldratt. The thinking process is a series of steps to find the constraint, establish the solution and the final step aids in how to implement it. The true core problem must be identified in the first step. The true core problem is usually symptoms of the bigger problem. The systems present itself as Undesirable effects (UDE). The cloud analyses what the common goal is, what the conflict is and what the possible solution could be. Figure 2 is an example of an evaporating cloud diagram. The thinking process is used to identify and resolve the conflicts relevant to the constraints. Undesirable effects (UDE) were identified and evaporating clouds method was developed to aid in the solution.

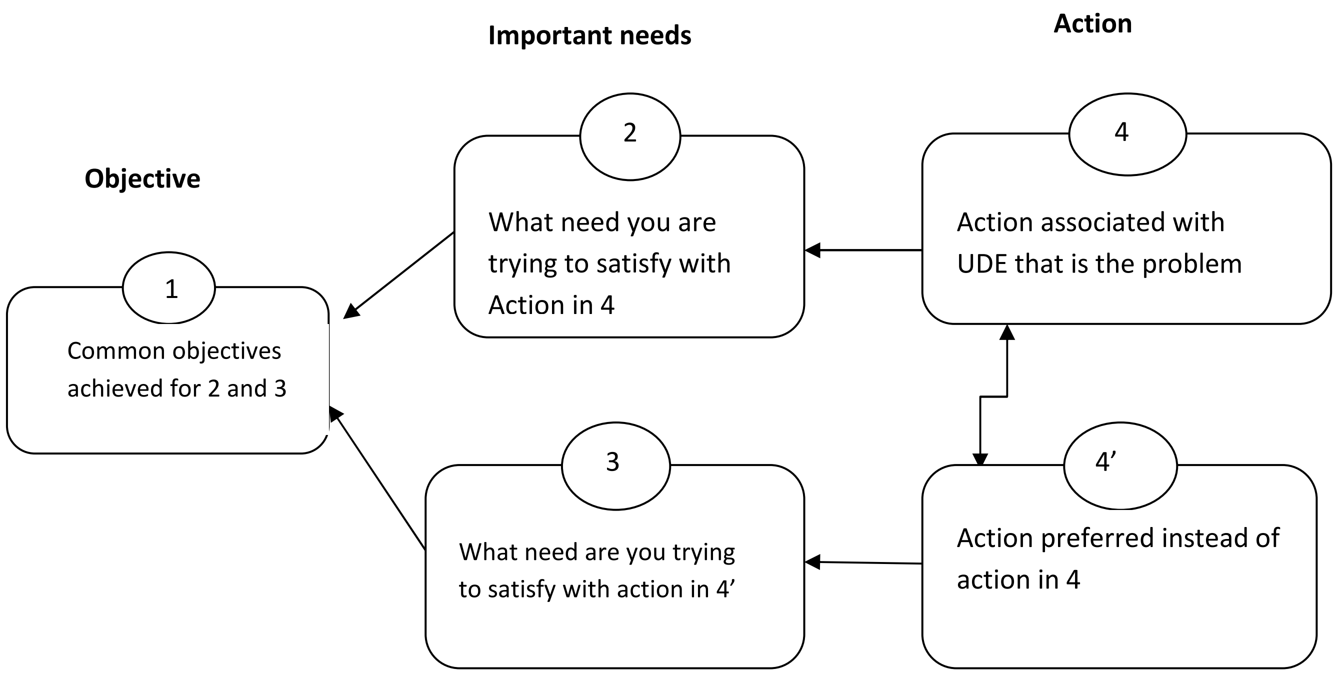


Figure 2. Schematic example of UDE. MacMillian 2004

4.1.2.3 Estimating the size of a buffers

To determine the size of a time buffer is not an easy task. Literature sources show different ways to approach it. Some authors say that the total size of the time buffers should be approximately half the size of the manufacturing lead time. Another way to estimate the time buffer is to make it one fourth of the total time of the system. When choosing a preliminary buffer size, it may take even months to decrease it to the appropriate level. When using analysis and calculations in determining the size of the time buffers one can decrease the time it takes to get it to the appropriate level. A More accurate initial size will be determined. One approach will be Queuing theory.

Queuing theory

Queuing theory revolves around mathematical techniques for analyzing the flow of objects through a network. At the network a restriction of time takes place before the object can pass through. If an object cannot pass immediately, it waits in a queue until it can. The queue can be seen as items being stored in a real or fictitious reservoir until it can be serviced. Objects can be anything that has to move from place to place. It can be a valve that regulates water, people waiting at a bank, cars on the highway in a bottleneck, or units waiting to be processed in a production flow line. Figure 4 is a schematic presentation of objects that move through the same restrictions (Newel 1982).

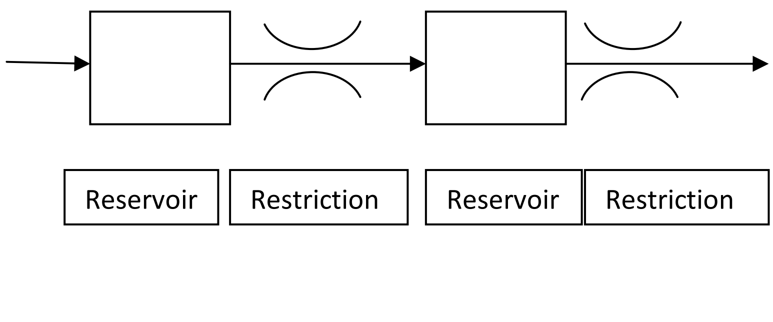


Figure 3. Schematic picture of the flow of objects along a channel

(Adapted from Applications of Queuing theory, 1982)

Capacity constraint resources (CCP), is a server that process the incoming products. A Server's capacity is the same or almost the same as the production demand and fluctuations in the incoming products can make this a bottleneck resource. A Time Buffer is put in front of the CCR, which can be seen as a waiting line of arriving products. If the waiting line is short or none existing, the CCP will be idle and the process will be delayed. But if the waiting line is too long, more operating expenses will be tied up in the production. The solution would be to determine an optimal waiting line capacity, which is the optimal size of the time buffer. The optimal time buffer must maintain the highest profits in the operation and at the same time keep the CCR from becoming idle. This description indicates that we can use Queuing theory. Customer arrival time is the incoming units arriving; service rate is the time it takes to process one unit. The size of the time buffer is the number of units in the line. Optimal size of the time buffer is then the maximum number of units that should be queuing in front of the CCR. The model can be described as an M/M/1/K model. One server and queue capacity of k, first come first serve (FIFO) (Radovilsky 1998).

Queuing theory in TOC application: Estimation of sizes of the time buffers in TOC controlled production

The article describes the use of queuing network analysis approach to get the size of their time buffers. The production system is Theory of constraints implemented. The work stations are GI/G/m queuing models. Queuing analysis is used to estimate the flow time buffer origin. Also determining the standard deviation of the flow time and assuming normal distribution of the flow times, a final time buffer length can be determined. After testing this concept by simulating it, it showed that the procedure is sufficiently accurate to provide the initial buffer length time at the design stage of the line (Louw & Page 2010).

Case study: Applications of Theory of constraints in an integrated poultry industry

In this case study, the limiting factor was identified as the internal policies. By appliance of TOC principles, the results obtained include increased throughput rate and profit (Chaudhardi & Mukhopadhyay 2003).

Case study: Simulation and optimization on inventory of distribution system using theory of constraints

In a distribution system, inventory plays a very important role. In this study, the inventory level and ordering policy was investigated. A Simulation model was conducted to test the Theory of constraints concept in the distribution system. The results were an optimized simulation, reduced quantity of the inventory and improved the efficiency. Simulated showed results that prove the method will be effective to enhance the interactive effect of simulation (Wang, Zhen & Gao 2009)

Case study: The application of TOC to improve the performance of the Inspection and Enforcement services Business Unit, South African Department of Labour.

The case study investigates the introduction of TOC principles within the Inspection and Enforcement Service Business Unit (IES). IES oversees compliance with labour laws. The constraint of the system was identified as the system inspector which was evident due to the large volume of cases waiting to be investigated. A New Performance measurement system was entrenched to ensure improvement on the system and a Drum-Buffer-Rope schedule was implemented. Significant improvement in the quality of their service delivery and reduced lead time will be the result if the method is implemented (Van Zyl 2005).

4.1.3 Integer Programming

Branch and Bound method

This method is used to shorten the processing time by operating the set up processes and the other processes in parallel. To calculate this, apply the branch-and-bound method then recalculate the total processing time’s lower bound.

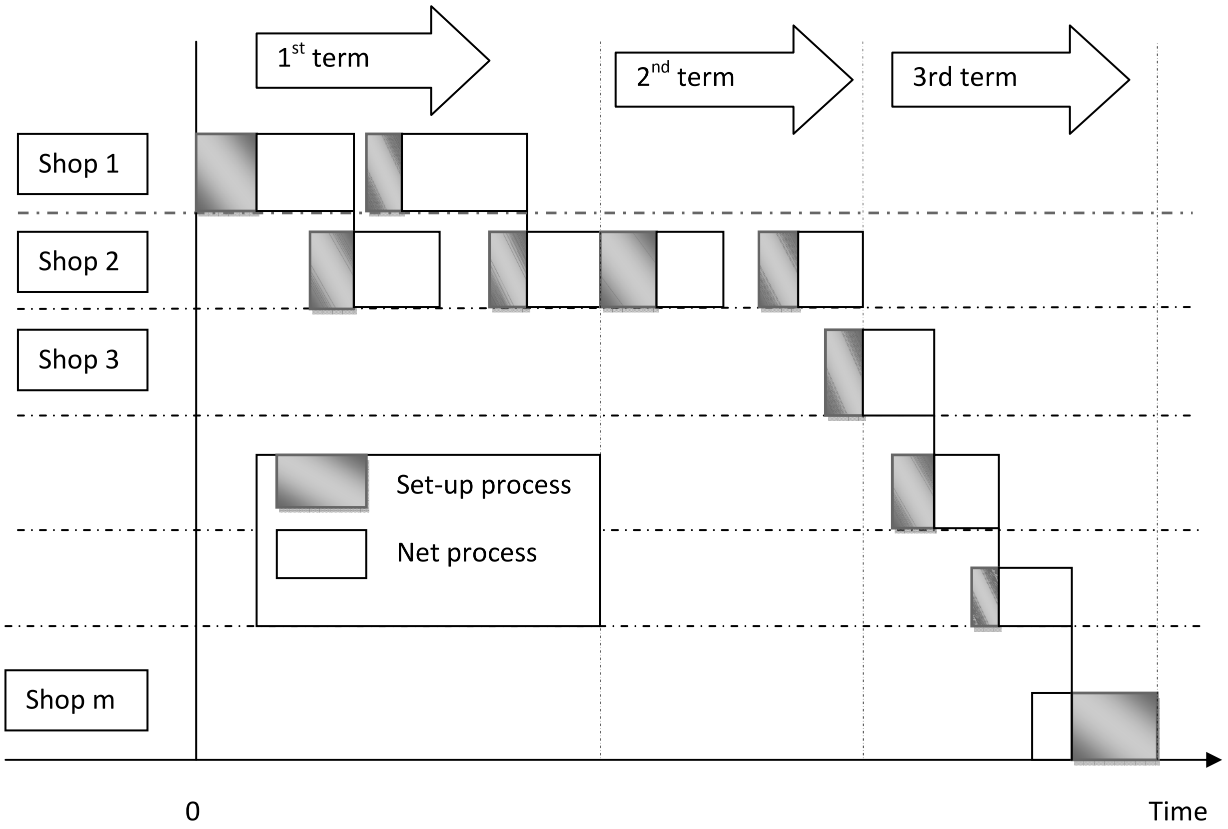


Figure 4. The schematic presentation of the shortening process time concept

(From Flow shop scheduling for separation model of set-up and process based on Branch-And-Bound method, 2008).

In Figure 4 can be perceived how to shorten the processing time, making every second machine start set-up time when the previous machine is still running the net process.

Each branching node can be calculated by using Equation 1:

$$LB(J_r) = Max_{1 \le k \le m} \left(T_k(J_r) + \sum_{j \in jr} (\tau_{j,k} + t_{j,k}) \right) + Min_{j \in jr} \left(\sum_{q=k+1}^{m} (\tau_{j,q} + t_{j,q}) \right) \quad (1)$$

$T_k(J_r)$ is the completion time of the process, of product order set J_r in shop k.

$\sum_{j \in jr} (\tau_{j,k} + t_{j,k})$ is the total processing time. It's the sum of the set-up and net process time, for the product set J_r that has un-assigned processes at the shop k.

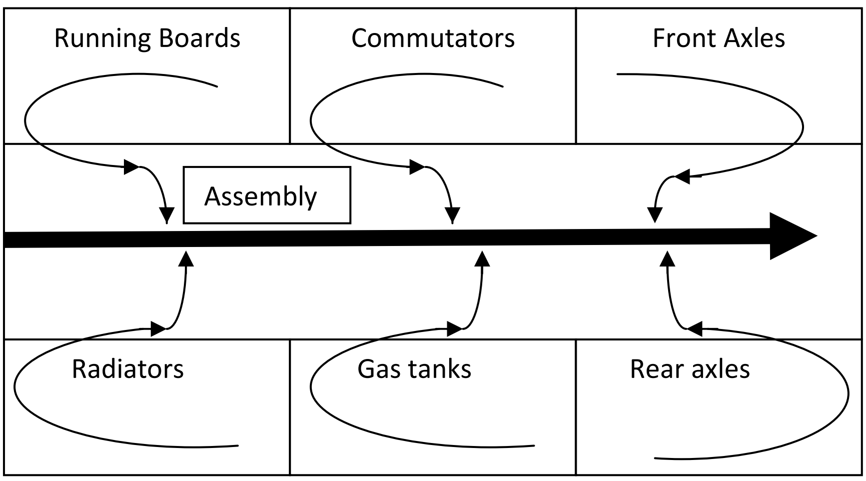
$Min_{j\in jr}(\Sigma_{\downarrow}(q=k+1)^{\uparrow}m \, [\![(\tau_{\downarrow}(j,q)]\!] \; +t_{j,q}))$ is total processing time of the lower bound of that is necessary to be processed from the next k+1 shop to the last shop m, for un-assigned product set J_r..

Case study: Flow shop scheduling for separation model of set-up and process based on Branch-And-Bound method

The method was tested on a production line with two sub lines, one head-end process and one tail-end process. The results from the method were that a total of 4 hours each week of the production time was cut (Nishiuchi et al. 2008).

4.1.4 Lean Manufacturing

In the 1980's, Japanese producers like Taiichi Ohno (Production Manager of Toyota) where out-performing most of the manufacturer's in other parts of the world. Their secret was the appliance of Lean Approaches. The logic of what we call a single-piece flow reached a peak in Henry Ford's first large assembly plant, the layout shown in figure1. This is the famous model T, where every machine making a component was lined up in a process sequence and the whole system was completely synchronized.



250,000 Vehicles per year, one model.

Figure5. Ford Highland Park plant

(Adapted from Manufacturing Operations and Supply chain management, 2001)

Lean methods include flexible teams with improvement responsibility, general purpose tools and machines, and ever decreasing model life cycles of products (Womack, Jones & Roos 1990). The result of the Lean Manufacturing approach in the production world can clearly be seen in Table1. Virtually every aspect measured, the Japanese was far ahead of the European Manufacturers.

Application of Lean Manufacturing decreases the factory space occupied, the human effort, the investment tools and the inventory needed on site. Decreasing the inventory needed will result in a decreased number of defects, production of a greater variety of products, decreased unit cost, increased performance and overall efficiency. (Taylor & Brunt 2001)

Table1. Assembly plant characteristic summary. Averages for each region.

	Japanese in Japan	***Japanese in North America***	***America in North America***	***All Europe***
Performance:				
Productivity	16.8	21.2	25.1	36.2
Quality (assembly defects/ 100 vehicles)	60	65	82.3	97
Layout:				
Space (sq ft/vehicle/year)	5.7	9.1	7.8	7.8
Size of repair area (% of assembly space)	4.1	4.9	12.9	14.4
Inventories (days for 8 sample parts)	0.2	1.6	2.9	2
Work force:				
% of Work force teams	69.3	71.3	17.3	0.6
Job Rotation (0= none, 4= frequent)	3	2.7	0.9	1.9
Suggestions/employee	61.6	1.4	0.4	0.4
No of Job classes	11.9	8.7	67.1	14.8
Training of new Production workers (hours)	380.3	370	46.4	173.3
Absenteeism	5	4.8	11.7	12.1
Automation:				
Welding (% of direct steps)	86.2	85	76.2	76.6

Painting (% of direct steps)	54.6	40.7	33.6	38.2
Assembly (% of direct steps)	1.7	1.1	1.2	3.1

(Adapted from Manufacturing Operations and supply chain management (2001))

4.1.4.1 The seven value stream mapping tools

The following are considered as waste inside Toyota's production system:

1. *Overproduction*
2. *Waiting*
3. *Transport*
4. *unsuitable processing*
5. *redundant inventory*
6. *redundant motion*
7. *Defects*

The most severe waste is *overproduction*. Overproduction dampens a smooth flow of goods and services and it could probably restrain quality and productivity. Over production also lead to unnecessary lead and storage times and excessive work-in-progress stocks which result in the physical dislocation of operations, resulting in poorer communication. The Kanban or Pull system was implemented by Toyota to solve the problem.

Waiting waste is if the time is being used unsuccessfully. This waste occurs in a factory when goods aren't being moved or worked on. Both worker and goods are affected by this waste as both spend time waiting.

Transport waste entails goods being moved about. Movement in a factory could be viewed as waste and transport minimization is sought. Double handling and too much movement can cause damage to the products.

Unsuitable processing is when for a simple problem an over complex solution is used. For example if a large inflexible machine is used instead of small flexible ones. The result of this is a poor layout of the factory; it promotes workers to over produce which then leads to excessive transport and poor communication.

Redundant inventory will increase the lead time, it takes a lot of space and prevent quick identification of problems. Inventory also leads to storage costs, which add up to an increased unit cost in the end.

Redundant movement is where the operators bend, stretch or pick up. These movements tire the operators, resulting in poor productivity and often quality problems.

Defects are a direct cost (Hines & Rich 1997).

Case study: Transformation of a production assembly washing machine lines into a Lean Manufacturing system

Whirlpool Europe Naples factory had a problem with their efficiency in their production flow. The re-organization of the company's production flow needs to be completed with Lean Manufacturing philosophy as a tool to aid them. Kanban inventory links was adopted and the re-organization of the material flow has been implemented. The company adopted the Pull system methodology in order to achieve independent connected processes in the Just-in-Time (JIT) environment. The Customer order or master production schedule triggers a Kanban signal, the signal then flows backwards. The implementation of JIT concept will achieve advantages such as decreased inventory, increased quality and shorter lead times. The first stage consists of sizing the amount Kanban reintegration codes. The second step was to simulate it in ARENA and prove the progress of the production flow and a hypothesized system. The results were an improvement in business performance and immense flexibility. JIT also achieved shorter lead times, fewer inventories and better quality of products (Romano, Santillo & Zoppoli 2009).

Case study: Status of Lean Manufacturing implementation on secondary wood industries including residential, cabinet, millwork, and panel markets

One of the major outcomes Lean Manufacturing help companies achieve is increased productivity, enhanced quality, while reducing the wastes and costs. The wood industries in the U.S had to take action to regain their competitiveness. They decided to implement Lean Manufacturing. Findings conclude that a well implemented Lean Manufacturing program will lead Wood Component Manufacturing Association to recover their competitiveness and achieve significant cost reductions (Pirraglia, Saloni & van Dyk 2009).

Case study: A continuing lean journey: an electronic manufacturer's adopting of Kanban

The purpose of this paper was to examine kanban production control, at an Electronic manufacturing system based in the United Kingdom. They inspected implementation issues and reasons behind the use of a kanban system. After kanban adoption was phased, clear differences in the system was seen. The pull system has reduced their lead time and inventory, it reduced overproduction that ensures resources are used more efficiently and board obsolescence is reduced. Reduction of cost and quality failures are kept to a minimum as a result of cut inventory. The Kanban has equipped the factory with a more stable production system that will allow it to approach down and upstream supply chains to eliminate additional waste through further use of an external kanban system (Lee-Mortimer 2008).

4.1.5 Six- Sigma

Six-Sigma is a well developed methodology that aims for the improvement of processes and products. With the use of a product-driven approach it reaches a company's strategic goal (Buyukozkan & Ozturkcan 2010). The process of creating and evaluating a company's projects is one of the initial activities in implementing Six-Sigma. Six-Sigma helps a company to implement Total Quality management (TQM) concepts. Total Quality management includes concepts such as quality management, customer satisfaction, cost of poor quality and the likes. Six-Sigma enables companies to gain competitive advantage and reach business excellence by eliminating waste. Success of Six-Sigma has been reported in both manufacturing and in service environments (Saghaei & Didehkhani 2010).

4.1.5.1 Five Phases of Six-Sigma:

1. Define:

In this phase identification of the best project is done. After the project is identified, a Decision team is constructed and the organization attempts to implement the project.

2. Measure:

Measurement of the process's capabilities and identification of the most important parameters of goods and services is completed in the second phase.

3. Analyze:

The Organization collects and analyzes past and current data to identify the relations and reasons of defects and variations in process and product characteristics.

4. Improve:

Solutions and remedies are proposed to eliminate waste. Prove of the solution's effectiveness and efficiency is done and the solution is implemented.

5. Control:

The final step is to set standards and offer feedback to sustain the improvements. This is done by the decision team (Gryna, Chua & Defeo 2005).

Case study: Applying Six Sigma techniques to improving the Quality of eLearning Courseware components

The purpose of introducing Six Sigma to eLearning Courseware components is to establish benchmarks to measure the quality of the learning objects and their components. All variables involved in Six Sigma were evaluated for eLearning software. The result was an improved quality, more efficient software, decreased time spend to work on the software and an increased customer satisfaction (Nagi & Charmonman 2010).

Case study: Six-Sigma: an Evolutionary analysis through case studies

An investigation was done at Argentinean Institute of quality to analyze how Six-Sigma practises evolved within a set of organizations. The weight of critical success factors and what variables were influenced by this evolution, was analyzed. Findings in this study was that the complex landscape makes it difficult to speak about “one size fits all” definition of Six-Sigma. After implementing Six-Sigma in six case studies the positive results include a slowdown of top level push (due to different reasons) and a change in strategic priorities. Six-Sigma creates an ordered pathway when coping with a complex problems, that foster the development of analytical skills (Firka 2010).

5. **Selection of appropriate method and tools**

5.1 Benchmarking

Bench marking can contribute to achieving competitive advantage. Generic benchmarking will be an approach to consider and many companies whom used this method achieved significant improvement and savings.

5.2 Theory of constraints

This method identifies the constraint and ensures that the flow line operates at its highest point. It is the most applicable for 3M's production flow line and the best approach to consider. 3M currently does not meet the demand on time and TOC reduces the lead time and service delivery.

5.3 Queuing theory

The queuing theory can help determine TOC's buffer time. To determine the initial length of the time buffer is a trail-and-error approach. It will be applicable and an assisting tool when applying TOC. But it won't be applicable in solving the problem statement if TOC is not the method chosen.

5.4 Integer Programming

Branch and bound method is a convenient way of reducing throughput time only if the set-up time of the flow line is currently one of the biggest wastes in the company. At 3M the machines set up time is not the biggest time waster and this method won't achieve significant results in improving the efficiency of the flow line.

5.5 Lean manufacturing

Lean Manufacturing is applicable to any manufacturing company. Any mass-production can be converted to lean. Lean thinking can be summarized by five principles: the value by specific product should be exactly specified, the value stream for each product should be identified, make value flow without interruption, let customer pull value from the producer, and pursue perfection. Target improvements can be made in a company in the following areas:

1. Lead time
2. Quality
3. Customer performance
4. Time-to-market
5. Company or supply chain culture

The minimization of inventory will affect the total unit cost. Thus, solving the problem statement will be reached when applying Lean Manufacturing as a tool.

5.6 Six Sigma

Six-Sigma is focused on projects of a company. It will be difficult to apply on the goal of 3M's flow line.

By selecting the appropriate method and tool it is concluded that the deliverables of the problem statement can be achieved. TOC is the selected methods and tools.

6. Data analysis

The selected method will be implemented on flow line 2 at the electrical department. Table 2 indicates the demand, backorders and available stock for flow line 2.

Back orders can lead to more expensive transportation charges as this is usually a smaller shipment (less that truckload) or because it must be shipped faster and by a more expensive transfer. Unavailable products could also lead to a direct loss, when a customer cancels the order (Coyle, Bardi & Langley Jr. 2003). It can also contribute to losing the customer entirely.

Table 2 Demand of flow line 2 at 3M's electrical department

Item	Demand over 5 month average	March Forecast	April Forecast	Available Quantity	Months stock	Allocated	Back orders
A	2600	5660	5000	0	0	480	390
B	550	1049	1225	129	0.12	1	3
C	747	1165	1250	740	0.64	60	0
D	1500	1648	1875	1310	0.8	110	0
E	300	616	500	136	0.22	40	0
F	300	350	375	184	0.53	50	0
G	130	160	170	0	0	13	12
H	60	98	71	80	0.82	0	0
I	30	37	40	10	0.27	3	0
J	65	70	75	65	0.93	10	0

7. Description of the Flow line

In Appendix A, a schematic illustration is shown to observe the step by step flow line of 3M. A description of the operators and the process's that takes place at the indicated circles on the figure follow:

Operator 1: Is the set-up process operator. The Set-up is done by two operators:

1.1 Hars producer: Makes sure the tanks are filled for the filling of the packets.

1.2 Team leader: Does the tank's weight adjustment.

Operator 2: The filler fills the bags with the resin and puts it on the conveyor. Only one resin bag can be filled at a time.

Operator 3: The sealer, seals the bags with a special machine sealer. After it's sealed, the warning, expiry dates and identification stickers are stick on the bag. The bags are then put it in a crate.

Operator 4: The packer collects the resin bags from the sealer and start packing the customer kit bags. A Typical bag consists of a mould set, electric strips, resin filled bags and a spout. She then puts the box in a bigger box for transportation, protection and order purposes. This box is then put on a pallet.

Operator 5: The store Operator.

1. Wraps the shipping purpose boxes together as per customer order. He then moves it to the transport area using a pallet jack. When the delivery truck comes, he puts the wrapped boxes in the truck with the use of a forklift.

Minimum target time of products waiting to get picked up is 4hours.

2. Gets the picking list from the factory, originally from the production planner. He then picks all the items in the storage area and delivers it just before the

previous schedule is over. After this he gets the net line's order and repeats the whole process.

Operator 6: Quality auditor does wandering inspection with intervals and signs the product off at the end of the full order.

8. Theory of constraints as a system

8.1 System's measurements (TIOE)

To measure the system's improvement made by TOC, there needs to be areas for improvement identified.

Throughput, Inventory and Operating is all measurements of expenses in a system (TIOE).

(T) Throughput

This is a products selling price minus variable costs

(I) Inventory

Are items the company intends to sell. This includes raw materials, equipment, properties, work-in-progress and finished goods. In short, inventory is all the money caught inside the system.

(OE) Operating Expenses

OE is "all the money the system spends in turning throughput into inventory". This includes depreciation, sales, utilities, rent, supplies, wages, inventory carry costs, administrative expense and other overheads.

If you connect these three measures to measuring net profit and return on investment in the traditional way, it demonstrates that if you decrease your operating expense and inventory while you increase your throughput, it will result in an increased profit and return on investment (Goldratt & Fox 1986).

Throughput is the most important measure. (Mahesh et al. 2010)

(T) Throughput = Sales – Material and services purchased

(I) Inventory = Stock + Machines and buildings

(OE) Operating expense = Non-material conversion costs especially labour costs

Net profit = (T) Throughput – (OE) Operating expense

$$\textbf{ROI} = \frac{(T) - (OE)}{(I)}$$

(Seal, Garrison & Noreen 2009)

By using the above equations the Throughput per product, Operating cost and Net profit per week was calculated and is shown in Table 4. This is what can be achieved based on the current market demand.

The weekly demand for the products in flow line 2 is shown in table 3. As shown in table 4 it can be acknowledged that the throughput per week will be R27731.77 and the net profit will be R14892.97, if all the units can be produced in the week.

Table 3 Demand of products per week

Weekly demand			
A	650	F	75
B	138	G	33
C	187	H	15
D	375	I	8
E	75	J	17

Table 4 Profit analysis per week

	A	B	C	D	E	F	G	H	I	J	Total
Market	650	138	187	375	75	75	33	15	8.0	16	
Selling price per unit	R 20.18	R 27.16	R 17.84	R 21.43	R 22.90	R 39.46	R 129.77	R 62.36	R 240.74	R 83.71	
Variable costs:											
Direct material	R 0.5600	R 5.2997	R 2.8800	R 0.3804	R 2.0640	R 2.0640	R 5.8800	R 2.0160	R 15.3120	R 3.5640	
Direct material	R 3.0600	R 0.5600	R 0.3264	R 2.3000	R 0.2880	R 0.2880	R 3.0480	R 0.2880	R 3.9240	R 31.9894	
Direct material	R 0.3528	R 0.7624	R 2.3500	R 4.1800	R 2.4200	R 7.8400	R 0.6720	R 9.4200	R 4.7880	R 0.6417	
Direct material	R 0.6364	R 1.1508	R 0.8556	R 1.2728	R 1.6468	R 2.0148	R 0.2880	R 2.0148	R 0.2880	R 8.7612	
Direct material	R 0.7260	R 2.0640	R 0.7260	R 0.9420	R 1.1508	R 2.3016	R 19.2200	R 4.6032	R 32.4000	R 1.1508	
Direct material	R 0.0130	R 0.4080	R 0.0156	R 0.0156	R 0.1560	R 0.1560	R 0.4080	R 0.1560	R 0.4080	R 0.8724	
Direct material		R 0.1560					R 2.1596		R 2.6208	R 0.7200	
Direct material							R 17.4000		R 34.8000		
Direct material							R 0.1560		R 0.1560		
Throughput per unit	R 14.83	R 16.76	R 10.69	R 12.34	R 15.17	R 24.79	R 80.54	R 43.86	R 146.04	R 36.01	
Total throughput	R 9 642.29	R 2 312.79	R 1 998.78	R 4 626.94	R 1 137.98	R 1 859.61	R 2 657.71	R 657.89	R 1 168.31	R 576.16	R 26 638.47
Operating costs	R 8.11	R 7.71	R 4.74	R 5.20	R 7.54	R 11.64	R 37.28	R 23.07	R 65.79	R 8.11	R 12 838.79
Net profit before											R 13 799.67

8.2 The five Focusing steps of TOC

Goldratt offers a five focusing step process to aid in keeping on track with improving the system.

1. Identify the constraint

2. Decision how to Exploit the system constraint

3. Subordinate everything else to the above decision.

4. Elevate the system's constraint

5. Back to step 1, don't let inertia cause a system constraint (Reid 2007).

8.2.1 Identifying the constraint

Types of constraints

A constraint can be defined as "Any element or factor that prevents a system from achieving a higher level of performance with respect to its goal." (Cox & Spencer 1998)

According to literature, there are three types of constraints: Policy constraints, Resource constraints and material constraints.

Policy constraints are exactly what it states. It is a constraint that occurs due to a policy.

For example a company that only make large batches of a certain product at a time in order to achieve lower cost per unit. This policy can easily become a constraint. The downside of this policy can be large WIP and finished goods inventories, constant change of priorities, large lead time and overtime, and the list goes on.

Resource constraints are machines, market, skills or people. You can identify a resource constraint by considering that if you had more of the item, object or skill, it would produce more throughputs.

Material constraint is if any the materials needed to produce the product in making is scarce, not available or difficult to obtain due to Supply chain problems.

3M's constraint

It is identified that the constraint for 3M's plant is resource constraint.

In table 5 and 6 the service rate per minute and total time that's needed per week for each activity is shown.

Table 5 The service rate for Filling and sealing, activity 1.

Filling and sealing		
Product	Average per product per minute	total time on activity for products per week
A	0.71	461.5
B	1.15	158.7
C	0.67	125.29
D	0.76	285
E	1	75
F	0.79	59.25
G	1.82	60.06
H	1.46	21.9
I	3	24
J	1.03	16.48
Total		1287.18

Table 6 The service rate for Packing, activity 2

Packing		
Product	Per product per minute	total time on activity for products per week
A	0.95	617.5
B	1.875	258.75
C	1	187
D	1.07	401.25
E	1.71	128.25
F	1.76	132
G	5	165
H	3.75	56.25
I	8.57	68.56
J	2.07	33.12
Total		2047.68

Under the assumption of the weekly demand, the capacity analysis was performed and is shown in table 7. The time available per day is 6.7 hours and the total time available is 2010 minutes per week. The Utilisation percentage signify that the packing activity 2 is the constraint. The packing takes longer in total and the required time available is not enough per day to finish this activity. The data of activity 2 also explains why there is continuous back orders present.

This also means the maximum net profit cannot be reached.

Table 7 Capacity analysis weekly

Products A-E →	650A	138B	187C	375D	75E
1. Filling and sealing	461.5	158.125	125.1225	285	75
2. Packing of kits	617.5	257.8125	186.75	401.25	128.25
Products F-J →	75F	33G	15H	8I	17J
1. Filling and sealing	59.25	59.15	21.9	24	17.51
2. Packing of kits	132	162.5	56.25	68.56	35.19
	Required total time	Available time	Utilisation		
Filling and sealing	1286.5575	2010	64.01%		
Packing of kits	2046.0625	2010	101.79%		

8.2.2 Exploit the system constraint

Methods to achieve maximum productivity needs to be identified in this step. One method is the area of constraint needs to work at full steam at all times. Another method is quality control check of the material used. This will mean that the constraint time is not wasted on a defective product. Eliminating idle time is a method to ensure that the constraint generates as much throughput as it possibly can. The goal in this step is to increase the throughput without increasing the operating expenditure or inventory of the system. According to Cox and Spencer, there are two principles in this step that assists in this endeavour.

1) Marginal value of time at a constraint resource = throughput rate of the system.

2) Manager should focus on synchronizing the flow in various work centres.

3M's exploit solution

Any loss of time in the constraint will be a loss in the throughput rate of the system. Therefore the best way for 3M to achieve maximum productivity is to alter the product mix so that every minute incurred in the constraint is utilised. The reason for this method is because the activity 2, packing doesn't have the total required time it needs to make all the units per day. Therefore the products that makes the most profit needs to be made first and the ones that make the least will be the ones that doesn't meet the demand per day and thus, the loss of sales profit will be the least profitable product.

Priority will be given to the product whose throughput per constraint minute is highest based on per unit. Table 8 shows the throughput rate per minute. Product J has the highest throughput per minute (R17.40) and should therefore be the first priority of producing. The rest of the products must be produced according to their throughput per minute where the highest is ranked as first produce and the lowest throughput is last. In table 8 the Product mix row indicates how the products must be sequenced as J, A, I, G, F, H, D, C, B, E. Product E is ranked as the lowest throughput per minute and must be produced last. Which means product E will have to use the left over capacity of 88.5 minutes. Only 51 of product E will be able to be produced.

Table 8. Analysis of the optimal product mix

	A	B	C	D	E
Throughput/unit	14.83	16.76	10.69	12.34	15.17
Time on constraint	0.95	1.875	1	1.07	1.71
Throughput per unit of resource	R15.61	R8.94	R10.69	R11.53	R8.87
Product mix (1 is made first, 10 last)	4	9	8	7	10
Optimal product	650	138	187	375	51
	F	G	H	I	J
Throughput/unit	24.79	80.54	43.86	146.04	36.01
Time on constraint	1.76	5	3.75	8.57	2.07
Throughput per unit of resource	R14.09	R16.11	R11.70	R17.04	R17.40
Product mix (1 is made first, 10, last)	5	3	6	2	1
Optimal product	75	33	15	8	17

After the new product mix sequencing schedule, the new profit was calculated. The new maximum feasible profit is R13616.49, shown in table 9.

Table 9.maximum feasible profit for optimal mix

	A	B	C	D	E	F	G	H	I	J	Total
Market	650	138	187	375	51	75	33	15	8.0	16	
Selling price per unit	R 20.18	R 27.16	R 17.84	R 21.43	R 22.90	R 39.46	R 129.77	R 62.36	R 240.74	R 83.71	
Variable costs:											
Direct material	R 0.5600	R 5.2997	R 2.8800	R 0.3804	R 2.0640	R 2.0640	R 5.8800	R 2.0160	R 15.3120	R 3.5640	
Direct material	R 3.0600	R 0.5600	R 0.3264	R 2.3000	R 0.2880	R 0.2880	R 3.0480	R 0.2880	R 3.9240	R 31.9894	
Direct material	R 0.3528	R 0.7624	R 2.3500	R 4.1800	R 2.4200	R 7.8400	R 0.6720	R 9.4200	R 4.7880	R 0.6417	
Direct material	R 0.6364	R 1.1508	R 0.8556	R 1.2728	R 1.6468	R 2.0148	R 0.2880	R 2.0148	R 0.2880	R 8.7612	
Direct material	R 0.7260	R 2.0640	R 0.7260	R 0.9420	R 1.1508	R 2.3016	R 19.2200	R 4.6032	R 32.4000	R 1.1508	
Direct material	R 0.0130	R 0.4080	R 0.0156	R 0.0156	R 0.1560	R 0.1560	R 0.4080	R 0.1560	R 0.4080	R 0.8724	
Direct material		R 0.1560					R 2.1596		R 2.6208	R 0.7200	
Direct material							R 17.4000		R 34.8000		
Direct material							R 0.1560		R 0.1560		
Throughput per unit	R 14.83	R 16.76	R 10.69	R 12.34	R 15.17	R 24.79	R 80.54	R 43.86	R 146.04	R 36.01	
Total throughput	R 9 642.29	R 2 312.79	R 1 998.78	R 4 626.94	R 1 137.98	R 1 859.61	R 2 657.71	R 657.89	R 1 168.31	R 576.16	R 26274.31
Operating costs	R 8.11	R 7.71	R 4.74	R 5.20	R 7.54	R 11.64	R 37.28	R 23.07	R 65.79	R 8.11	R 12657.83
Maximum feasible profit											**R 13 616.49**

8.2.3 Subordinate everything else to the above decision

After completing step one identify and step two exploit of the constraint, the third step is to determine its impact on the non-constraint resources. The non-constraint resources should subordinate to the constraint resource in order for improvement of performance for this resource. If a non-constraint resource is activated, then it is creating inventory. The Drum-Buffer-Rope schedule will ensure that the right quantities of raw material are released to non-constraint resources to arrive at the constraint resource. Thus, a company should idle the non-constraint resources instead of using them to keep them active. This is a common mistake many companies make which builds up unnecessary inventory. Decision in this step must assist in increased throughput, reduced inventory and operating expenses without adding more additional expenses. Reduced inventory can be achieved by estimating an optimal size of the time buffer.

Two important actions to consider to:

- Have the constraint work continuously
- Never have products processed on the constraint only for inventory purposes.

Subordinate decision of 3M

The plant manager must ensure that activity 1, filling and sealing must work at full capacity with assistance of the non-constraint work centres. A Theory of Constraint schedule will be implemented to synchronize the flow of various work centres with the constraint resource.

Non-constraint activity 1, filling and sealing will release material A-J and carry out the activity according to the optimal product mix (the drum) as calculated previously. The buffer will be inventory that is maintained in front of the constraint to keep it from being idle. The rope is the processes taking place before arriving at the constraint resource. The process/activity taking place before arriving at the constrain will be the non-constraint Filling and sealing activity 1.

There is 723.442 minutes not used (2010-1286.558) on the non-constraint activity every week. (144.668min per day). When the non-constraint activity is finished, the Operators have to go to the constraint resource and double the speed. This will indicate **three** times faster than it was as there are two operators at the filling and packing activity 1. Just after 40 of product D is through the constraint, the two Operators will move to the Packing station and start working there with the packing operator.

Table 10 shows the rest of the products according to the schedule that will go through the Packing constraint when the two operators assist in the activity. If the two operators move to the packing station, a time on the constraint decreases by a **third** less. If the three operators start working on the constraint, the result is a time of 348 minutes left per week of the available time on the constraint. The entire products' demand will be met, increasing the net profit to the maximum profit and 1.16 hours a day is left. This means an opportunity to make more products exists for the available time left if the correct marketing is done (to increase the demand) and the profit can increase even more.

Table 10 new time on constraint per week after activity 1, Filling and Packing is finished.

	B	C	D	E
Throughput/unit	16.76	10.69	12.34	15.17
Time on constraint	0.625	0.333333	0.3566	0.57
Throughput per unit of resource	26.81	32.07	34.60	26.62
Product mix	9	8	7	10
Optimal product	138	187	175	75

Table 11 shows the effect the method will have on the utilisation of the activities 1 and 2. Activity 2 will be 76% utilised if this method is used.

Table 11 Utilization of work centers after Exploit step

Activity:	650A	138B	187C	375D	75E
Filling	461.5	158.125	125.1225	285	75
Packing of kits	617.5	86.25	62.3333	274.9782	42.75
Activity:	75F	33G	15H	8I	17J
Filling	59.25	59.15	21.9	24	17.51
Packing of kits	132	162.5	56.25	68.56	35.19

Activity:	Required total time	Available time	Utilisation
Filling	1286.558	2010	64.01%
Packing of kits	1538.312	2010	76.53%

8.2.3.2 Determining the size of the Buffer:

In contrary to the Just-in-time system, the buffer in TOC is initiated to protect the capacity constrained resource (CCR). TOC principle works on a weakest link principle, meaning that the weakest link in a system is its constraint. The weakest link also depend the performance of a system. External factors that can affect the constraint resource to not work at some instances could be inventory that is not there when it is needed. The smaller the time buffer, the likelier it will not protect CCR from disruptions. A Time Buffer that is too big will in effect cause waste of resources by building up unnecessary inventory stock in front of the CCR and operating expenses gets tied up in the process. The following mathematical equations is based on Queuing theory and used to estimate the initial size of the buffer.

The arrival time of the inventory to the time buffer = ʎ

The service rate is the time the inventory are processed in the CCR = µ

The size of the time buffer represents the units in the queue.

The optimal size of the queue is the maximum number of units that must be in the queue.

The model will be described as a M/M/1/c queuing model. There is a single server with a finite queue of units that is not more than k units in size.

Poison arrivals and exponential service correspond with the results and studies of many researchers

Probability formulas:

Probability that the CCR is idle:

$$\pi_0 = \frac{1-\rho}{1-\rho^{c+1}} \quad ; (\rho \neq 1) \qquad (1)$$

Where $\rho = \frac{\lambda}{\mu}$

This indicates how many products are in the waiting line. To prevent CCR from being idle, there need to be a number c, which will not allow the π_0 to go beyond an appropriate limit x.

$$\pi_0(c) \leq x \qquad (2)$$

Solving c:

$$c \geq \frac{\ln\left(\frac{\rho + x - 1}{x}\right)}{\ln \rho} - 1 \quad ; (\rho \geq 1)$$

(3)

As mentioned earlier, throughput is one of the most important measures in TOC. The throughput is constant per unit and will therefore be used in the model:

$$TH = \mu(1 - \pi_0)K_{TH} \qquad (4)$$

K_{TH} is the throughput per unit of sale, it is sales minus the material cost. The Operating expense in this scenario is the cost of carrying inventory. K_{OE} is the material cost of the stock/inventory. Operating expenses will be presented in the model as follow:

$$OE = L_S K_{OE}$$

(5)

L_S is the expected number of units in service.

$$L_s = \frac{\rho}{1-\rho} - \frac{(C+1)\rho^{C+1}}{1-\rho^{C+1}} \quad ; (\rho \neq 1)$$

(6)

Simplifying the equation to: Net Profit (NP) equals the throughput (TH) rate minus the Operating expense (OE).

$$NP = TH - OE \tag{7}$$

$$NP = \mu\,(1 - \pi_0)\,K_{TH} - L_S\,K_{OE} \tag{8}$$

To see how the sizes of the time buffer will affect expenses in a system, the NP, TH and OE was brought into the equations. A Change in the time buffer (C) will affect the NP, TH and OE. K_{OE} is the carrying costs. By varying C, an optimal value of the buffer size can be estimated.

$$NP(C) = \mu \frac{C}{1+C} K_{TH} - \frac{K}{2} K_{OE},$$

$$\frac{\partial NP(C)}{\partial C} = \frac{\mu}{([(1+c)])^2} K_{TH} - \frac{1}{2} K_{OE} = 0$$

(9)

To get an economic order quantity, the EOQ-like formula will be derived and with the EOQ the optimum size of the buffer can be attained (Radovilsky 1998).

$$C^* = \sqrt{\frac{2\mu K_{TH}}{K_{OE}}} - 1 \quad (\rho = 1) \tag{10}$$

The Optimal Net Profit can be shown as:

$$[NP]^* = 1/2(\sqrt{(2\mu K_{TH})} - \sqrt{(K_{(OE)})})^2$$

(12)

NP^* will be higher if the throughput rate (K_{TH}) and service rate (μ) are increased; and decreasing the carrying cost (K_{OE}). (Winston 2004)

A Numeric analysis needs to be done, because ρ is not equal to one. Evidently the same relationship is identified for C* if ρ > 1. Table 12 shows the initial buffer size, according to K*, the optimal buffer size.

Table 12 Initial buffer size for products A to J

	Initial buffer size
A	12
B	5
C	9
D	9
E	5
F	7
G	4
H	4
I	3
J	11

8.2.3.3 Cross functional teams

To effectively implement TOC, a cross-functional team is required. The mindset of TOC implies that team performance is crucial which is based on key performances. Members from different functional areas such as Engineering, Finance, Operating and marketing must be part of the cross-functional team. The team needs to challenge conventional ways of making localised decisions and innovative ways of improving throughput and decreasing inventory and operating expense.

8.2.4 Elevate the system constraint

In this step, the plant manager needs to make a decision of whether it is better to increase the capacity of the constraint resource and spend money to do so. This type of investment can be tactical or strategic.

Tactical elevation

When using Tactical elevation a decision must be made to increase the constraint's capacity inexpensively and relatively easy. Tactical implies that an alternative to satisfy market demand is used, like scheduling overtime on the constraint resource. This will increase the operating expenses, but will meet the demand of a product per week (if it was not met) which will increase the throughput and the overall net profit.

Strategic elevation

Strategic elevation implies the elevation of physical constraints, which include buying more capital equipment to increase the capacity of the constraint resource. A Decision to make versus buy must be inspected to see if a decrease in the operating expense is larger than to produce the material needed self and vice versa. This will not be covered in this project.

8.2.5 Go to step one, do not allow inertia

TOC is an ongoing improvement process. The whole process starts over again; otherwise inertia or a resistance to change may set in or stop the process of continuous improvement. The new constraint needs to be identified and the previous steps need to be re-evaluated.

9. Implementing the method

The method was simulated in Arena to show results and how it will affect the flow line in real life.

The simulation was done on the as-is state, how the flow is currently operated; and the to-be state, how the flow will operate with the implemented method.

Table 13 shows the results obtained. The difference in the time the resource (activity 1 and 2) use processing products is clearly visible and can be seen on figure 6 and 7.

Figure 6 Graph of the tot time of activity per day, As-is state

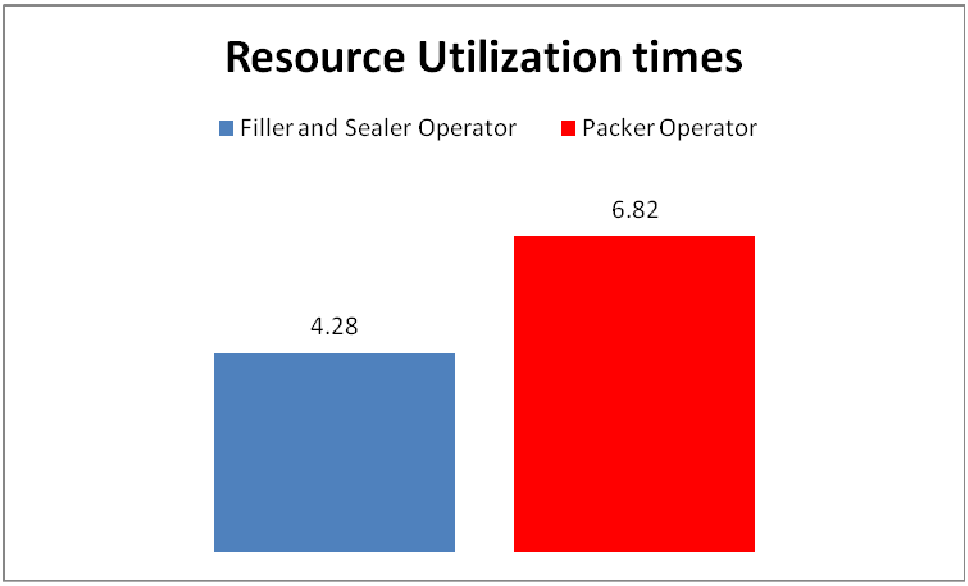


Table 13 Flow line's Resource usage in As-is and To-be states

Flow line: As is state				Flow line: To be state			
Resource				**Resource**			
Units: Minutes				Units: Minutes			
Usage				**Usage**			
Instantaneous Utilization				Instantaneous Utilization			
	Average (minutes)	Min	Max		Average (minutes)	Min	Max
Filler and Sealer Operator	0.5355	0	1	Filler and Sealer Operator	0.5355	0	1
Packer	0.6934	0	1	Packer	0.6109	0	1
				Packer help	0.0274	0	1
Number Busy				Number Busy			
	Average (minutes)	Min	Max		Average (minutes)	Min	Max
Filler and Sealer Operator	0.5355	0	1	Filler and Sealer Operator	0.5355	0	1
Packer	0.6934	0	1	Packer	0.6109	0	1
				Packer help	0.0274	0	1
Number Scheduled				Number Scheduled			
	Average (minutes)	Min	Max		Average (minutes)	Min	Max
Filler and Sealer Operator	0.8375	0	1	Filler and Sealer Operator	0.8375	0	1
Packer	0.8375	0	1	Packer	0.8375	0	1

Packer help	1	1	1

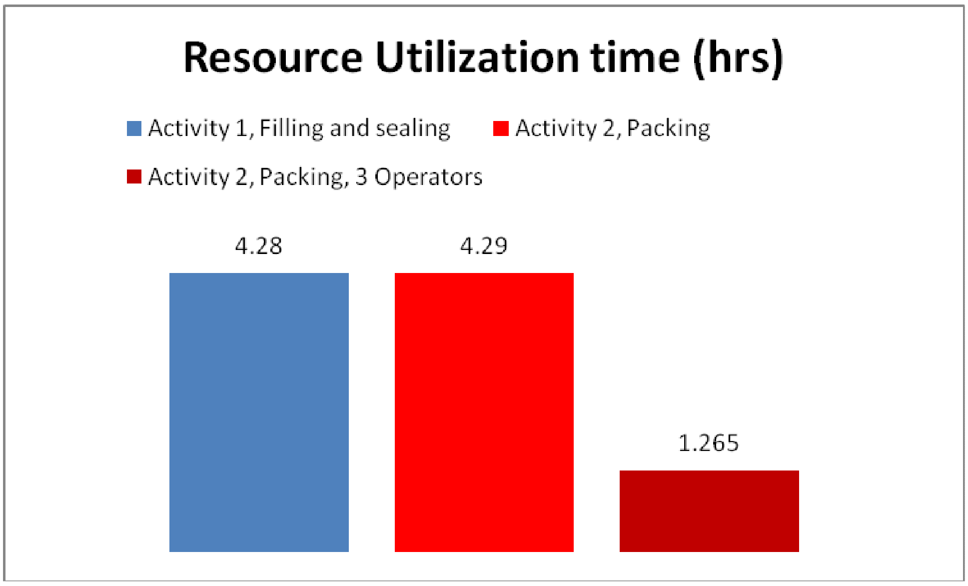
Scheduled Utilization

	Total time in hours
Filler and Sealer Operator	4.28
Packer	6.82

Scheduled Utilization

	Total time in hours
Filler and Sealer Operator	4.28
Packer	4.29
Packer help	1.265

Figure 7 Graph of tot time of activity per day, To-be state



10. Conclusion

By Implementing Theory of constraints on the flow line a simple solution to increase the efficiency of the flow line was identified and the results were immense. The five focusing steps breaks the process up in simplified steps to follow, the bigger picture will be seen clearly and the steps to change the system will be recognized with ease.

Identify the constraint

The identification of the constraint can be one of the most difficult tasks in TOC. When realising the categories (policy, resource and material constraints) and then investigate each of the categories in the system the identification of the constraint will be easier to find. Methods to assist in identifying constraints include the evaporating cloud diagram. The constraint category was resource and the activity was packing and sealing.

Decide how to Exploit the constraint

A Decision must be made in how the constraint will be exploited. Scheduling of products according to their throughput rate was done in the flow line in order to obtain maximum profit out of the products with the highest throughput rate per minute in the time available to make them. In this way the product that wasn't made on the available time per day will be the product that makes the least profit for the company

Subordinate everything else to above decision

When subordinating everything else to the above decision, the non-constraint resources must assists the constraint resource. The non-constraint resource consists of two operators and when they are finished with the production they must go to the constraint resource which is activity 2 packing, and start working there. In this way an extra 1.56 hours is saved a day and a total of 7.8 hours a week, which was used up in the previous method they work on the activities/processes.

Elevate the systems constraint

By implementing a drum-buffer-rope schedule, will ensure that the constraint is elevated. Queuing theory was the selected method to determine the initial buffer. As initial buffer size is a trial and error effort in any situation, an indication of what it can start with was used with the aid of Queuing theory.

Go back to step one, don't allow inertia

This step must be done by the company to ensure that the company keeps improving. Re-evaluation of the new implemented method also needs to be done.

Implementing the solution

The solution was simulated in Arena to show how it will affect the flow line. Results obtained was that the resource constraint needed less hours a day to finish the production demand scheduled on a day.

An average total of 1.16 hours a day is saved from the total time the flow line runs. This will decrease the operating costs per hour and the operating cost will affect the total unit cost per unit made which is what the aim of this project was.

The other aim was to increase the efficiency of the flow line, and the efficiency was increased by a total of 1.16hours less per day and a total of 5.8 hours a week. (This equals to almost one whole day) The production which always took a total of 5 days to make was cut short to 4 days a week.

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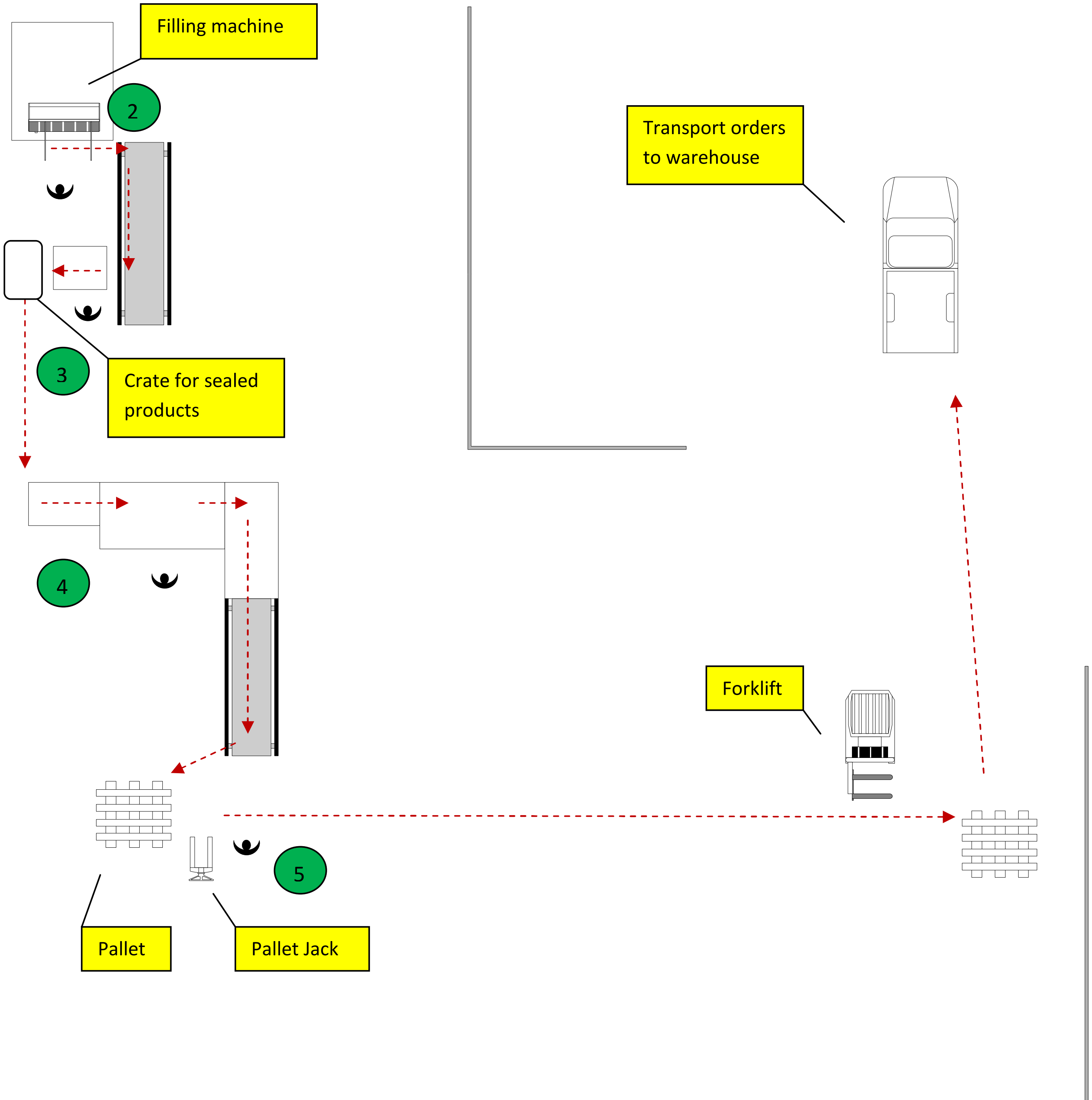
Appendix A – Flow diagram of the flow production line


Filling machine
2
Crate for sealed products
3
4
Transport orders to warehouse
Forklift
5
Pallet
Pallet Jack