

Using Theory of Constraints to increase control in a complex manufacturing environment - Case CandyCo: Make-to-stock production with a broad product offering and hundreds of components

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Abstract

The objectives of this Thesis are to describe the complex manufacturing setup faced by a case company, CandyCo, and to develop suggestions for the case company to increase control and throughput in the factory. CandyCo operates in the confectionery industry and offers several types of products. The motivation for the study for the company's part is to analyze and improve its mixed-component candy bag production. Mixed-component bags are products which contain various types of components, i.e. candies, as opposed to just one type. The production process is analyzed using the Theory of constraints (TOC) –framework. The bottleneck in the production process has been defined as being in the mixing-packaging phase. The Thesis adds to the existing pool of studies on complexity as well as to the pool of case studies using TOC to improve performance. The methods used in this Thesis could be applied by companies facing similar challenges in similar industries, e.g. the snack food industry.

The production process at CandyCo was modeled using the flowchart method. The throughput of the bottleneck resource was analyzed based on the data provided by the case company using Microsoft Excel. The two key analysis techniques were based on TOC: offloading and idle time analysis. The Thesis examines, if offloading possibilities for the bottleneck resource exist and also if the bottleneck resource is ever idle. To determine the root causes for idle time, root cause analysis alongside the five-why method were used. A small simulation model was also built to illustrate the effects of reducing idle time in the bottleneck on throughput and inventory. Finally, the company was involved in generating and assessing improvement ideas for the factory based on initial suggestions.

The analysis revealed that there were offloading possibilities in the bottleneck: around 14% of the end products, i.e. candy bags, handled by the bottleneck were single-component products. This means that the mixing resource of the bottleneck was used to handle components that do not require mixing. The idle time analysis revealed that the bottleneck was idle 52% of the time. 22% of the year was spent on waiting time, of which most consistent of either personnel or component shortages. Together with CandyCo's staff, ideas were generated to reduce component and personnel shortages.

The theoretical result of the Thesis is that the underlying principles of TOC remain sound and applicable in the modern manufacturing environment. The managerial implication is that using TOC-techniques, factory throughput can be increased using small investments and changes in the way things are done instead of resorting to heavy investments in machinery.

Keywords Theory of constraints, TOC, Goldratt, bottleneck, complexity, control, throughput

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1 INTRODUCTION

This Thesis tackles the broadly researched and important theoretical concepts of complexity, throughput and controllability. I will study the topic by using a case company, CandyCo, as an example and illustrating the challenges it faces and some potential solutions to these challenges. I will describe the complexity in the factory's manufacturing environment and introduce techniques and ideas to increase throughput and control in the environment.

1.1 Motivation

Manufacturing companies are facing increasingly difficult challenges in managing their production processes. These challenges can arise from a number of different sources, one of which is complexity. As time has passed and products have become more sophisticated and companies have increased their product offering, modern plants have had to produce various kinds of products with increasing number of components and increasingly complicated production processes compared to those in the past (Mukherjee & Chatterjee, 2007). Thus, plant managers face the challenge of managing and controlling the aforementioned complexity while simultaneously complying with the needs of the organization and the customer. As a result, factories are often required to perform at the edge of their capabilities (Calinescu et al., 1998). Some even go as far as defining all manufacturing systems as complex (Deshmukh et al., 1998).

Inevitably, as complexity increases flexibility must increase as well. When flexibility increases, one of the negative side-effects can be loss of control (Calinescu et al., 1998). Controlling a complex manufacturing environment is essential; otherwise the complexity will lend itself only to make the environment more difficult to manage. A number of philosophies and frameworks have been introduced to help people control manufacturing environments. Examples of such philosophies are e.g. Lean, Total quality management (TQM), Six sigma, Theory of constraints (TOC) and Just-in-time (JIT).

My thesis will examine the production process through the Theory of constraints – methodology (e.g. Goldratt, 1990). TOC-techniques will be used to assess and develop suggestions to improve throughput within the case company. This study is motivated from

the company's part by significant changes in consumer preferences in the confectionery industry and what these changes imply to production in this industry in the future. Ideally, the method of analysis developed and introduced in this Thesis can be used by companies facing similar changing market conditions regardless of their industry.

Over the past ten years, consumer preferences have shifted drastically and companies in the confectionery industry have had to adapt. In terms of sugar bags, the most important shift in demand has been in the preferred component numbers in candy bags. In this context, component means a single type of candy in a bag, such as a hard candy covered with chocolate. In the past, consumers preferred to buy a product, a bag of candies, with only a single type of candy. The demand started to shift when companies began to offer bags with mixed components and consumers preferred these mixes over the traditional products – one could say that the companies managed to create their own monster in this case. CandyCo started manufacturing mixed-component bags in the mid-90s and installed automatized systems to manufacture them in the late 90s. However, at that time, a mixed-component candy bag had only a few different components. At the beginning of the 2000s, the mixed-component bags took off and changed the market landscape for good. Over time, the preferred number of components has increased from a few to as high as over ten.

Currently, mixed bags dominate the candy bag market, accounting for close to 60% of the value. This type of a shift in consumer preferences is drastic and has many implications to the companies in the marketplace. Possibly the biggest changes can be seen in production. The companies have had to change the way the candies are bagged, somehow having to mix the different components together in a controlled way to create a product that has, on average, the same content each time. Together with challenges related to confectionery production, such as that each type of candy requires a specific time to dry before packaging, that the components are perishable, that different components come from different assembly lines and that stores require that most of the candy's potential life cycle is spent in their possession, the confectionery companies face serious production planning challenges.

As previously mentioned, the case company in this Thesis is CandyCo and one of its plants. The plant produces products to stock (i.e. operates under make-to-stock production). The company has identified that the bottleneck in its manufacturing process is the mixing/packaging phase, where boxes of different types of components are combined and poured into mixing machines that create the desirable ratios of components for the mixed

bags, after which the components are put in a bag. This thesis will use the Theory of constraints –framework to analyse the bottleneck and determine possible actions that will increase the throughput of the plant.

The aim is that this case study will add to the already large pool of studies related to complexity, controllability and throughput as well as give a practical example on how the Theory of constraints can be applied in factory settings. It is also my goal that the general tools, techniques and conclusions that are presented in the Thesis can be used by companies in different industries facing similar shifts in consumer demand. It is undoubtedly so that once consumer preferences change as dramatically in the confectionery industry, production will be under a lot of pressure since old production systems must be adjusted or even reinvented to cope with the required changes.

An obvious extension to the confectionery industry is the snack food industry, which could very well face similar challenges in the near future. Lessons from the confectionery industry can most likely be applied when that time comes.

1.2 Research problem and objectives

The general research problem is presenting the complex issues that CandyCo is facing in their day-to-day operations and, using TOC techniques, finding ways to increase controllability and throughput in the process of manufacturing mixed-component candy bags.

Ideally, the objective would be to come up with concrete suggestions that are relatively easy to implement in order to improve performance. Another objective is to add to the literature of complexity and controllability as well as provide the scientific community a case study that uses the TOC-framework.

The specific research questions I will be addressing in the Thesis are:

1. How is the manufacturing process organized? What are the preceding and following steps for the bottleneck resource?

2. What types of components flow through the bottleneck? Can some load be taken off the bottleneck through reorganizing or investments? What is the potential effect on throughput?
3. If the bottleneck resource is ever idle, what are the reasons behind that? Can the reasons be divided into different categories?
4. What are the implications of these findings and what actions could be undertaken to improve performance at the bottleneck resource?

1.3 Methodology

I will analyse the bottleneck using the Theory of constraints –framework (Goldratt & Cox, 1984). According to the Theory of constraints, the capacity of a production plant is ultimately determined by the bottleneck resource and its capacity: if the bottleneck is idle for one hour the plant is idle for one hour. Thus, the bottleneck resource should be utilized at full capacity. Within the TOC-framework, offloading and idle time reduction are the main concepts addressed in the analysis. The main tool for these analyses will be MS Excel, which will be used to conduct statistical analysis.

When analysing idle time, I will add insight into the Excel analysis by interviewing key staff members at CandyCo's factory. The interviews will be structured around the principles of Root cause analysis (RCA) in order to determine the ultimate reasons for idle time in the bottleneck resource.

I will also use flowcharts to illustrate the processes within the factory as well as a simulation software called Simu8 to simulate the component flow to and from the bottleneck.

1.4 Content and progression of Thesis

Following the introductory Chapter where the research problems and objectives are presented and basic concepts defined, I will delve deeper into the relevant literature. I will present the concept of complexity in more detail as well as analyse the Theory of constraints: its history, core concepts, strengths and weaknesses and criticism. Then, I will

look at the literature behind some of the analysis techniques that I will be using, such as Root cause analysis and Qualitative interviewing.

In Chapter 3, I will introduce the methodology that I will be using in my Thesis. This includes describing which theoretical concepts I will be using and which tools and techniques are relevant in each phase of the study.

Chapter 4 will introduce the reader to the case company CandyCo and the plant in more detail and describe the difficulties the plant is facing.

In the next chapter, I will present my findings based on the various analyses that I have conducted during the project. I will synthesize my findings and provide a list of actions and investment suggestions that CandyCo can implement to improve performance at the factory.

Finally, I will conclude the Thesis by discussing its theoretical and practical implications as well as look at the limitations of the study and suggest guidelines for further research on the topic.

1.5 Basic concepts

Throughput

The rate at which the system generate money through sales, not production (Goldratt & Cox, 1984).

Inventory

The total money invested in raw materials and work-in-progress (WIP) items intended to be sold (Goldratt & Cox, 1984).

Operating Expense

The money spent to turn inventory into throughput of sold items (Goldratt & Cox, 1984).

Bottleneck

Bottleneck is the resource that constrains the output of the entire system, the process which has the lowest output per hour ratio and is a necessary step in the production process (Mukherjee & Chatterjee, 2007). It should be noted that, in practice, a bottleneck can move from one location in the production process to another, depending on the loading of the process and the changes in the product variety (e.g. Roser et al. 2002).

Make-to-stock production

A production choice, where end products are made to stock, i.e. according to demand forecasts, as opposed to making products to order.

2 LITERATURE REVIEW

In this chapter I will introduce all the relevant theories, frameworks and tools that I will be using in my Thesis. I will start by looking at the concept of complexity in manufacturing. The bulk of this chapter is focused on introducing and analysing the Theory of constraints, which provides the most important analysis techniques for this study. Developed by Eliyahu M. Goldratt and first introduced in the 1980s, the theory focuses on the role bottlenecks play in manufacturing environments and how to increase the profit generated by a factory.

I will then look at the literature relevant to the other tools, techniques and research methods that I will be using during the research process. I will go through the basics of Root Cause Analysis, Process Modelling and Interviewing, which will, along with the Theory of constraints, form a core part of my research method.

2.1 Complexity in manufacturing

I will begin the literature review by looking at the concept of complexity in manufacturing. One definition of a complex system is that it may refer to a

“[...] [S]ystem which has patterns of connections among subsystems such that prediction of system behaviour is difficult without substantial analysis or computation [...]” (Deshmukh et al., 1998, p. 645)

Thus, according to the definition, manufacturing systems are inherently complex, due to the dynamic nature of the manufacturing environments and system integration. However, complexity can be further divided into two different categories: static and dynamic complexity. Static complexity refers to the complexity of the structure of the system, connective patterns, variety of components and the strengths of interactions. Dynamic complexity refers to the unpredictability in the behaviour of the system over time. (ibid.)

A manufacturing system will quite often exhibit static complexity, even if it does not exhibit dynamic complexity. However, rarely will the processes be so controlled that the behaviour of the system is totally predictable. Therefore, most manufacturing systems will include both static and dynamic complexity.

How does one avoid complexity? In short: by reducing flexibility and thereby also reducing the manufacturing possibilities and alternatives that the system has (Calinescu et al., 1998). Thus flexibility and complexity are necessarily two sides of the same coin and organizations face a trade-off between the two. While flexibility has many benefits, such as increased production and product customization, if not managed properly it can lead the system to being non-predictable, non-controllable, inefficient and ineffective (ibid.).

Calinescu et al. (1998) introduce a list of components that determine manufacturing complexity. These components are:

- (1) the product structure – the number of different items, and for each product: number and type of sub-assemblies, lead and cycle times, lot sizes, type and sequence of resources required to produce it
- (2) the structure of the plant – the number and types of resources (multi-skilled or not; global vs. dedicated), layout, set-up times, maintenance tasks, idle time, performance measures
- (3) the planning and scheduling functions – the planning strategies; the documentation used in planning (volume and content); the decision-making process
- (4) the information flow – internal; intra-plant; external
- (5) the dynamism and variability of the environment – breakdowns, absenteeism etc.
- (6) other functions within the organization – training, politics etc.

2.2 Theory of constraints

This chapter introduces the Theory of constraints. I will first look at the history of the theory and how it is perceived in the scientific community. Then I will introduce the basics of the theory, followed by the tools and techniques that can be used to improve the performance of a factory. Then I will compare Theory of constraints with several similar management philosophies that focus on reducing inventories and improving plant performance. Finally, I will go through some of the critique that the Theory of constraints has received throughout the years.

2.2.1 History, definition and basic concepts

The Theory of constraints (TOC) is an approach developed by the renowned, late Eliyahu Moshe Goldratt. He first introduced the theory in its full form in the 1980s in many well-known books. Since the theory has been introduced, it has generated a lot of interest. Watson et al. (2007) studied the evolution of TOC in their article, where they reviewed over 400 books, dissertations, academic articles, magazine articles, conference proceedings, reports etc. They reported that over half of them had been written since 1998, so the theory has clearly generated more interest as time has passed, suggesting that the philosophy and core concepts are sound. In fact, some authors go as far as suggesting that TOC could serve as a general theory in operations management (Gupta & Boyd, 2008).

The most famous book from Goldratt was written together with Jeff Cox: “The Goal”. The Goal was published in 1984 and it examines the case of a fictional failing American production plant that turns itself from being close to shut down into the best plant in the organization by following the principles of TOC. Another book, published in 1986 and written together with Robert E. Fox called “The Race” goes into more detail about the specific tools and techniques that are part of the TOC, focusing on the difficulties that are likely to surface in the implementation process. It also introduces Goldratt’s logistical system for the material flow called the drum-buffer-rope (DBR) system. A more detailed account on the evolution of TOC can be found e.g. in Watson et al. (2007).

A sidenote on the drum-buffer-rope (DBR) system: DBR evolved from the scheduling software called optimised production technology (OPT), which was first introduced as a commercial system by Goldratt and his associates (Goldratt, 1988). Further, OPT was based on basic rules that were illustrated in The Goal (Goldratt & Cox, 1984) and The Race (Goldratt & Fox, 1986). OPT was criticized heavily since it was first introduced on the grounds that it claims to offer an optimal schedule and because the algorithm that OPT uses was never disclosed by Goldratt to the scientific community. The current TOC approach does not include OPT anymore. (Rahman, 1998)

Boyd and Gupta (2004) categorize TOC as a throughput-oriented view on manufacturing. This view is shared by Goldratt (1990) himself. In the throughput world, there are three dimensions: (1) organizational mindset, (2) performance measurements and (3) decision making and methodology (Boyd & Gupta, 2004). In TOC these three dimensions are expressed in the following way:

- (1) *Organizational mindset*: The main assumption in the TOC is that every for-profit organization has the goal of making as much money as possible, now and in the future. However, while doing this certain conditions cannot be violated, such as satisfying the market demand and providing a good work environment for employees.
- (2) *Performance measurements*: The TOC suggests that traditional accounting measures are inappropriate with respect to the actual goal of the organization and they actually do more harm than good since they distract plant managers from the true goal. These measurements will be described in more detail later on in the Thesis.
- (3) *Decision making and methodology*: The TOC has evolved into a continuous process, emphasizing that change should be embraced. This is important, since constraints tend to shift within the organization as time goes by. These methodologies will be examined in more detail later on. (Gupta & Snyder, 2009)

The premise of TOC

In heart of the TOC lies the idea that most manufacturing organizations were doing many things wrong in the US in the 70s and 80s when trying to compete with the Japanese organizations which used techniques such as Just-In-Time (JIT) to produce quality goods with a lean supply chain. In the US, the manufacturing divisions of companies focused on counting “efficiencies” – such as time or cost per manufactured part – but neglected to look at the bottlenecks in the production process and did not focus on the thing that mattered: the bottom line. The focus of manufacturing organizations should be on maximizing throughput while minimizing inventory and operational expenses, since these three goals together will maximize the ultimate goal: making money. (Goldratt & Cox, 1984)

Goldratt and Cox, highlighted the problem in manufacturing organizations through their business novel, *The Goal* (1984). The authors focused on the facts that actually mattered with respect to making money and communicated these facts through the novel. They argue that the way of looking at production costs in the eighties – and earlier – derived from accounting practices and had little to do with manufacturing. The so called efficiencies that plant managers were obsessed with actually mattered very little, unless the resource in question was a bottleneck, because in effect, a bottleneck resource determines the output of an entire plant. Goldratt and Cox (1984) emphasized that no plant can produce more

products per day than the bottleneck resource can produce, and thus any improvements in production efficiencies in any other resource are “a mirage”, i.e. they do not affect the bottom line. On the other hand, any time lost at the bottleneck resource directly affects the bottom line since it directly reduces the amount of products that can be sold. The opportunity cost of an hour lost on the bottleneck can therefore be calculated as the cost of the entire plant per hour. Thus, there should always be a safety buffer of parts for the bottleneck to work on to account for the inevitable statistical fluctuations that the preceding operations will have. Making the chain too lean will lead to reductions in manufactured products and late deliveries.

The continuous improvement process of TOC

The Theory of constraints advocates a continuous improvement process that enables companies to focus on the bottlenecks of the manufacturing process. The measurements are meant to observe, whether the company is on the right path. The core of the improvement process that TOC suggests comes from five basic steps. These steps are “discovered” gradually by the lead characters in *The Goal* as they try to improve their plant’s performance. Goldratt (1990) also explains the steps in more detail in another book called “What is this thing called the Theory of Constraints and how should it be implemented?” The steps are shown in Figure 1.

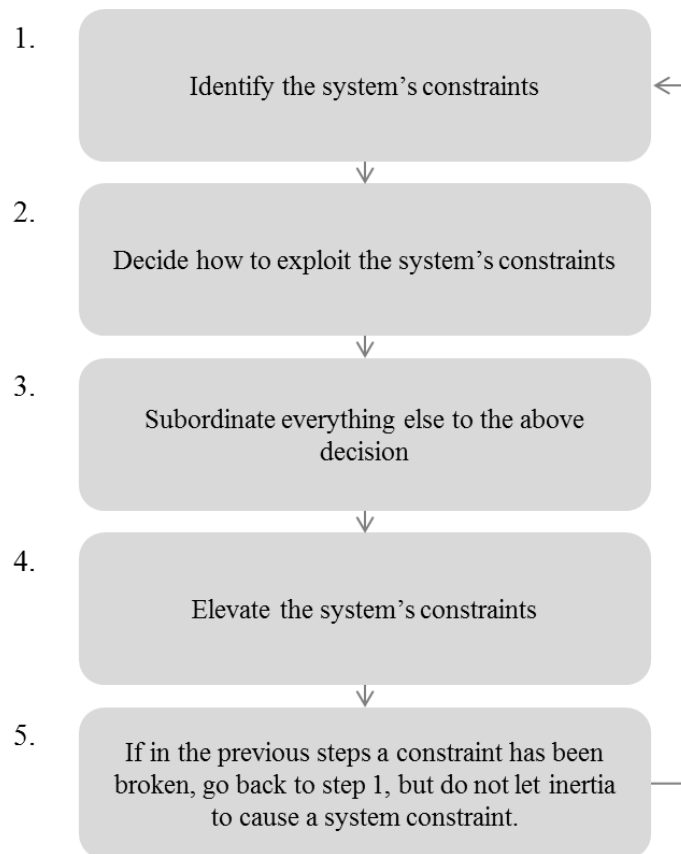


Figure 1 The continuous improvement process of TOC (Goldratt, 1990)

Step 1 means that not only should one analyse and define all existing bottlenecks, one should also rank the bottlenecks according to their importance, i.e. their effect on the “goal” - increase Throughput while reducing Operational Expenses and Inventory. This is where Step 2 comes in: after ranking the bottlenecks, one should choose which ones to focus on. Naturally the focus is on the most restricting bottlenecks first. The third step means that all non-bottleneck resources supply the bottlenecks, which consume all that they are supplied. There is no sense in supplying too much to the bottlenecks since they are, by definition, the most restrictive part of the production process and thus determine the output. However, one should not become constrained too much by the bottlenecks since they are not “acts of God”. They can be elevated: hence Step 4. Step 5 is the step that makes the process continuous. It is intuitively clear that once a constraint is elevated enough, it ceases to be a constraint and the bottleneck shifts within the process. The line: “but do not allow inertia to cause a system constraint” should not be overlooked, however. What Goldratt (1990) wants to emphasize here is that often constraints that seem to be constraints are actually not

constraints at all; rather the constraint derives from some managerial policy within the company. In fact, he asserts that actually it is more often the case that a policy is a constraint rather than anything else. Managerial and policy constraints being so prolific in companies, Goldratt developed a separate technique in identifying them (Goldratt, 1993, cited in Rahman, 1998). The technique is called “current reality tree” (CRT), which is part of Goldratt’s Thinking Process –approach. This approach is explained in more detail in the next chapter.

The Thinking Process

The Thinking Process (TP) is a management tool for understanding where the organization is, what it wants to become and how it intends to get there. It is a higher-level tool than many of the more pragmatic approaches of TOC and clearly aims to elevate TOC from a manufacturing philosophy into a management philosophy.

The Thinking Process has three-steps and it is meant to clarify what an organization needs to do to reach its goals. The steps are (Goldratt, 1990):

- (1) What to change?
- (2) To what to change to?
- (3) How to cause the change?

The first step is simple enough: it is meant to identify the core problems that the company has. This will result in people committing to the improvement, since they understand the severity of the issue. In the second step, simple, practical solutions are developed to achieve the required goals. In the final step, the appropriate people, those who are instrumental in the success of the change, are induced to implement these solutions. (Goldratt, 1990)

To help implement these changes, Goldratt and his associates developed several tools. These tools include the Current reality tree (CRT), the Evaporative cloud (EC), Future reality tree (FRT), Prerequisite tree (PRT), Transition tree (TT) and a set of logic rules called the Categories of Legitimate Reservation (CLR) (Rahman, 2002 and Kim et al., 2008). I will not go into more detail on these techniques, since TP is not the main focus of the Thesis. However, I felt that the method deserved a mention since it is a tool that assists in TOC rising above being “just” a production philosophy. In fact, some experts believe

that of all the concepts of TOC, TP is the one which will have the most lasting impact on business (Rahman, 1998).

New performance measurements

TOC suggests (e.g. Goldratt, 1990) a new set of performance measurements that would help manufacturing organizations to focus on the bottom line. He emphasized that plants should focus on improving Throughput (T) while simultaneously reducing Inventory (I) and Operating Expense (OE). Focusing on these three operational measurements will increase the money generated by the plant. These goals can be translated into financial measurements as follows:

- (1) Net Profit (NP) = Profit expressed in the local currency = $T - OE$
- (2) Return On Investment (ROI) = Relative profit = NP / I
- (3) Cash flow (CF) = Amount of cash that the company has. Not an issue when the company has enough cash, however it becomes a problem when the company starts to run out of it.

Table 1 summarizes the concepts and formulas that TOC defines as important.

Table 1 TOC performance measurement concepts and formulas (Goldratt, 1990)

Concept	Definition	Calculation
Throughput (T)	Sales, i.e. the amount of money that the system generates	Products sold
Inventory (I)	The total money invested in purchasing things intended to be sold	Value of inventory
Operating Expense (OE)	The money spent to turn inventory into throughput	Expenses of running the plant
Net profit (NP)	T is the money generated, OE is the money spent	$T - OE$
Return On Investment (ROI)	NP is the profit generated, i.e. the return, while investment is equal to I	NP / I
Cash flow (CF)	The amount of cash a company has at a given time	Existing cash + cash received - cash paid

Success stories

Up until 2003, very few, if any, studies had been done on the effects of implementing TOC-based practices in organizations (Mabin & Balderstone, 2003). Mabin and Balderstone (2003) changed the situation with their paper, where the authors used a sample of 81 companies and the case survey methodology to look at the realized impacts of TOC in organizations.

The results of the case survey done by Mabin and Balderstone (2003) were encouraging. The authors found that over 50% of the 82 organizations reported improvements in

revenue, throughput or profits. Over 80% reported improvements in lead times, cycle times, due date performance (DDP) or inventory. As a summary of the findings, the authors conclude that:

“[...] [T]he application of TOC techniques yielded substantial reductions in lead time (median 75 per cent); cycle time (median 66 per cent); and inventory (median 50 per cent). Improvements (increases) in DDP (median of 50 per cent) were based on a small sample. Financial improvements were also considerable, with median 39 per cent improvement in revenue.” (Mabin & Balderstone, 2003, p. 586)

For a more thorough evaluation of the case studies used by Mabin and Balderstone (2003), I would suggest in looking at their sources. One of the best reported cases, according to the authors, is a case study by Andrews and Becker (1992), who describe the way the Alkco Lighting Company implemented the TOC philosophy. Among other findings, Andrews and Becker (1992) report that the company increased their sales volume by 20%, profit before tax by 42% and ROA by 39% by applying Goldratt’s methods.

Criticism

Goldratt has been criticized on lack of openness in his theories, an example being him not releasing the algorithm he used for the OPT system (Rahman, 1998). Some view him as unscientific with many of his theories, tools and techniques not being a part of the public domain, rather a part of his own framework of profiting on his ideas. According to Gupta and Snyder (2009), despite being recognized as a genuine management philosophy nowadays, TOC has yet failed to demonstrate its effectiveness in the academic literature and as such cannot be considered academically worthy enough to be called a widely recognized theory. The authors state that TOC needs more case studies that prove a connection between implementation and improved financial performance. Nave (2002) argues that TOC does not take employees into account and fails to empower them in the production process. He also states that TOC fails to address unsuccessful policies as constraints. These objections by Nave (2002) will be examined later on when I compare TOC with similar management philosophies.

In contrast, Mukherjee and Chatterjee (2007) state that much of the criticism of Goldratt’s work has been focused on the lack of rigour in his work, but not of the bottleneck approach

per se, which are two different aspects of the issue. The authors state that even if Goldratt's methods lack rigour, the theory is sound and that further researchers should focus on adding rigour to their work when using the bottleneck approach.

2.2.2 TOC Techniques

It is easy to state that one should “elevate the bottleneck” as the Step 4 in the TOC process instructs us to do. However, what can be done to increase the performance of a bottleneck resource? There are several different techniques which are quite simple to implement and understand, but they can do wonders to the throughput of the factory (Goldratt & Cox, 1984).

Offloading

Offloading means shifting workload off a machine to another machine. When looking at bottleneck resources, one should look for possibilities to share the load of the bottleneck with other machines whenever possible. This might mean shifting certain products off the bottleneck unless it is absolutely critical that they pass through the bottleneck. This may sound difficult; however there are often some management policies or other ancient decisions that are the cause for processing certain products with the bottleneck resource and thus the processing is done by choice. Offloading can also be done with new investments and improvements can be achieved even with small investments. Another alternative is to use a vendor to process components. (Goldratt & Cox, 1984)

Eliminating idle time

Often even bottleneck resources have idle time, for whatever reason. An example could be that employees take breaks at a certain time in the day and they may take the breaks at the same time, resulting in no one performing the bottleneck process. Given that the bottleneck constrains the output of the entire plant, even short breaks may have huge opportunity costs since an hour lost on a bottleneck is lost forever and therefore the plant loses one hour of output. Eliminating as much of the idle time as possible on a bottleneck resource will improve throughput at a factory. (Goldratt & Cox, 1984)

Scheduling and sequencing

Changing the sequences of activities or the work schedules can improve the throughput of a factory. An example is doing quality inspection on products after they've been processed by a bottleneck resource. Discarding products due to poor quality at this stage means that the factory has lost time on a bottleneck. If possible, all processes that can result in time lost on a bottleneck should be done before the bottleneck process. (Goldratt & Cox, 1984)

Priority components

The bottleneck should ideally work only on components and parts that satisfy the current demand, not waste time on creating e.g. spare parts. Components should be prioritized according to how critical it is for them to be processed by the bottleneck. (Goldratt & Cox, 1984)

2.2.3 Comparison with similar philosophies

Goldratt himself recognized (1990) that other management philosophies with similar focus on low inventories and demand-pull mechanisms were coming to the forefront along with the TOC. Examples of such management philosophies are just-in-time production (JIT), total quality management (TQM), manufacturing resource planning (MRP) and lean thinking. More recent similar philosophies are e.g. enterprise resource planning (ERP), six sigma and supply chain management (SCM) (Gupta & Snyder, 2009). Goldratt (1990.) doesn't attack the other methods; instead, he finds that all philosophies try to solve the same problem and that such a "renaissance" where many new theories spring up at the same time to respond to an existing false paradigm is common in science. However, he doesn't equate the philosophies to one another. According to him, the tools and techniques are different. Goldratt (1990, p. 112) states, that:

"It is quite obvious to everybody, that Just-In-Time (JIT), Total Quality Management (TQM) and Theory of Constraints (TOC) all aim towards achieving the same objective, namely; to increase the ability of a company to make more money now, as well as, in the future. [...] [W]hat differs between them is not the basic assumption that they all attack – they all attack the same erroneous assumption. [...] The main difference between them lays more in the realization of the depth change which must stem from the assumption that they use. Thus, of

course, we will find the bigger differences in the techniques they have, or have not, developed to cope with the resulting change.”

According to Goldratt (1990), JIT and TQM are unfinished management philosophies compared to TOC. They both realize the importance of throughput in manufacturing and advocate lower levels of inventories and ways to reduce operating expenses, just as the TOC does. However, he feels that the other two philosophies fall short in establishing a continuous process and a deeper understanding which he claims the TOC offers through the Thinking Process –method. Jones and Dugdale (1998) state that the biggest difference between TOC and JIT and TQM is, that the latter two philosophies aim to eliminate waste, defects and variability, while TOC implicitly accepts that there are defects in the system, as long as they are not a constraint in the system. Thus TOC doesn’t operate in the “zero-defects” world. It is important to note however, that Goldratt does not think quality is unimportant: in fact, he states that customers will never buy a subpar product (Goldratt & Cox, 1984). However, he focuses the quality on the bottleneck resource: the bottleneck should produce close to zero defects, so that no time is lost on the bottleneck (ibid.).

When discussing the merits of TOC compared to other similar philosophies, given that Goldratt is naturally expected to show some bias in evaluating competing philosophies, his comments should perhaps be taken with a grain of salt, despite his reputation.

Nave (2002) compares six sigma, lean thinking and TOC. He concludes that while each method has a different approach and aims for different initial effects, the secondary and tertiary effects of applying the methodology are often similar to the initial effects of the others and the end result thus ends up the same. Selecting the correct methodology, according to him, is dependent on the culture of the organization. Nave (2002, p. 78) argues that TOC is most applicable to company cultures where the “organization values a systems approach where total participation is not desired and if it values the separation between worker and management”, since he feels that TOC includes minimal worker input and does not value data analysis. However, Nave also asserts that none of these methodologies addresses policies, which we know to be untrue at least in TOC from Goldratt’s work (e.g. 1990), so it is possible that he is not completely familiar with the theory. Additionally, Goldratt does recognize employee well-being in TOC (Goldratt, 1994, cited in Gupta & Snyder, 2009), stating that the ultimate goal of “making more money now as well as in the future” cannot violate certain conditions, one of which is providing a satisfying work

environment to employees now and in the future. Nave (2002) might have a point that TOC does not involve employees as much in the process since the theory focuses on constraints; however Goldratt's view on employee well-being should not be overlooked.

Gupta and Snyder (2009) did a literature review on 20 journal articles that compared TOC with MRP and JIT. The authors state that all the articles declare each system independently as good and that, while it might be difficult to assess which system is the best, no system is the worst. Many of the reviewed authors also agree that a common, synergistic theory would be best solution. According to Gupta and Snyder (ibid.) the greatest controversy seems to be between TOC and JIT. However, they feel that the level of the discussion is conceptual and that no advanced simulation studies have been done to suggest one is better than the other. Some studies seemed to suggest that TOC would perform better in plants; however with small improvements the other methods could be tweaked to be as effective as TOC.

Gupta and Boyd (2008) suggest that TOC could be considered as a unifying theory for operations management. They argue that TOC thinking, tools and methodologies contain all aspects of the other proposed popular theories and, as such a comprehensive view should be accepted as the unifying theory. The authors look at areas such as operations strategy, operations management and tools for operations management and find other philosophies such as TQM, Lean and JIT lacking in some departments, while TOC does not and, in fact, includes many of the core concepts of other philosophies, just named differently.

Hines et al. (2004) look at how Lean has evolved through time and assess where the theory stands currently. They see TOC as a much narrower management philosophy as Lean. The authors feel that TOC and Six Sigma can be useful tools in managing wasteful bottlenecks within the Lean thinking –framework and thus implicitly state that they view TOC as a specific methodology for bottleneck control, not a management philosophy that could rival Lean. However, the authors also note that, despite Lean thinking originating from Toyota, the company has since replaced kanbans with an application of TOC called “tie-tie”. This would suggest that TOC offers value to the Lean manufacturing paradigm and cannot simply be included within it.

2.3 Relevant analysis techniques

In this chapter I will look into the existing analysis techniques that will help me define and understand the data and information I will be receiving. Then I will determine which of the techniques suit my study the best. I will first introduce flow charts as a process modelling tool, and then introduce Root Cause Analysis. Finally, I will introduce qualitative interviewing as a research method and define the types of interviews that I will be using.

2.3.1 Flow charts for process modelling

Flow Charts are probably the most commonly used method for describing processes. The strengths of the method are communication ability and flexibility; while its weakness is that the method may be too flexible and thus the boundary of the process may not be clear (Lakin et al., 1996). A Flow Chart is

“[...] a graphical representation in which symbols are used to represent such things as operations, data, flow direction, and equipment, for the definition, analysis, or solution of a problem.” (Aguilar-Savén, 2004, p. 134)

2.3.2 Root Cause Analysis

In this chapter, I introduce the concept of Root Cause Analysis and how it can be used. I will first provide a definition and short history on Root Cause Analysis. Then I will go through the process of Root Cause Analysis and define the one I will be using in my research. Finally, I will introduce the tools and techniques that I will be using when performing the analysis.

Definition

Root Cause Analysis (RCA) is a

“[...] process designed for use in investigating and categorizing the root causes of events with safety, health, environmental, quality, reliability and production impacts.” (Rooney & Vanden Heuvel, 2004, p. 45)

What I am investigating as a part of my Thesis are the root causes for idle time for the bottleneck resource in a manufacturing plant, so it follows that the events have production impacts. There are many definitions for a “root cause”, however I will be using the one

given by Rooney and Vanden Heuvel (2004): (1) Root causes are specific underlying causes, (2) Root causes are those that can reasonably be identified, (3) Root causes are those management has control to fix and (4) Root causes are those for which effective recommendations for preventing recurrences can be generated. This definition helps to weed out the causes which simply occur without any possible control over the matter and helps to focus on the issues that can be addressed. Additionally, if a “force majeure” has caused something, one should not assign blame to this force; rather look for root causes on why the force was overlooked in the first place.

RCA has a long history; while they may not have had the same name, failure prevention and causality analysis methodologies have existed for a long time and some have been commercialized (e.g. Jones, 1983). The technique of RCA is nowadays used in many fields. Having searched for articles on the technique, it seems to me that especially medicine and patient care seem to have embraced RCA as a way of solving the root causes of issues in their respective fields. This observation is backed by e.g. Wald and Shojania (2001) and Wu et al. (2008), though both papers also suggest that the evidence for the effectiveness of RCA in medicine is insufficient. Whatever the case may be, it is clear that the technique has proliferated both within and outside the business community.

RCA is more than just about understanding what happened and how it happened. The key is in understanding why something happened. The why-question should be addressed on a deeper level than simply e.g. “he made a mistake”. Generally, a fundamental reason for making the mistake can be found in the processes and not in the people, such as similar-looking valves at a production plant as a reason for the employee pulling the wrong one (Rooney & Vanden Heuvel, 2004). If the fundamental cause is not rectified, the problem often recurs and this is a sign of the RCA process lacking sufficient depth. In fact, companies tend to stop RCA once the physical issue or item is fixed or replaced but neglect to look at the system causes, resulting in a recurrence of the problem. (Okes, 2008)

The RCA Process

The RCA process is quite similar irrespective of which RCA experts are consulted on the matter. I will introduce two different process frameworks, one by Hughes et al. (2009) and the other by Rooney and Vanden Heuvel (2004). I will examine the similarities and

differences of these two approaches and derive the approach that I will use from these two examples.

Hughes et al. (2009) approach RCA from a risk analysis perspective. The authors define the RCA process to have four major steps: (1) Define the problem, (2) Define a Causal Understanding and Analyze Cause/Effect, (3) Identify Solutions and (4) Design Metrics and Track Effectiveness. Next, I will go through the steps in more detail.

- (1) *Define the problem:* In this step, a formal definition of the risk should be prepared. This definition includes the problem description, when and where it occurred and its significance. The problem's impact on business goals and the potential consequences of recurrence should also be evaluated.
- (2) *Define a Causal Understanding and Analyze Cause/Effect:* In this step, the cause and effect patterns within the system should be identified and a cause-and-effect-chart should be drafted. This will help in finding the root causes and understanding how the system behaves. Ideally, you should be able to identify different types of causes such as common causes (causes which lead to multiple problems) and systemic causes (causes that the system itself creates by its very nature).
- (3) *Identify Solutions:* In this phase, one should create a solution for every cause and not be too critical on costs and on how easy it is to implement them.
 - a. Evaluate Solutions: The first sub-step of the third step is to evaluate the effectiveness of the various solutions relative to the cost of the problem that they are fixing.
 - b. Select the best Solutions: The second sub-step of the third step is to select the best solutions with regards to their cost/benefit ratio and their likeliness to be successfully implemented.
- (4) *Design Metrics and Track Effectiveness:* In the last step one should design the proper metrics to measure the progress of each solution and to monitor the performance of the solution. This ensures that the solution will be implemented correctly and on time and that the organization will immediately know if the solution is not working or if it is performing poorly for some other reason. The

metrics thus work as a type of failsafe mechanism. They also facilitate in communicating the solution to other organizations or divisions.

Rooney and Vanden Heuvel (2004) also advocate a four-step approach to RCA. The four steps in their process model are:

- (1) *Data collection*: This step is relatively simple as the name suggests. You collect all the data on what happened, when and where. The information should be as complete as possible.
- (2) *Causal factor charting*: Causal factor chart is a “sequence diagram with logic tests that describes the events leading up to and occurrence, plus the conditions surrounding these events” (ibid.). The chart helps in understanding the sequence of events, what caused each event and how each event contributed to the eventual outcome.
- (3) *Root cause identification*: All the causal factors have by now been identified. The next step is identifying the root causes. For each causal factor the underlying reason or reasons should be determined.
- (4) *Recommendation generation and implementation*: Once the root causes have been determined, achievable recommendations for preventing the recurrence of the incident should be generated. Finally, the recommendations should be tracked to completion so that the RCA won't be left at the analysis stage.

Looking at the two frameworks, I see more similarities than differences. Both start, logically, with gathering all the relevant data and describing what happened. This is followed by defining the cause and effect relationships in the system or occurrence, and then root causes are determined. Finally, corrective actions are defined and implemented. However, I do feel that the second framework is more apt to my use in this Thesis. The first framework is more applicable in cases, where accidents or severe incidents are analysed. I feel that the second framework can be applied better to finding out the root causes for downtime in a bottleneck resource. However, creating an implementation plan and implementing the recommendations are outside the scope of the thesis and thus are left out of the framework.

The depth of the RCA that will be performed in the Thesis will likely be “Informal” as defined by Vanden Heuvel and Robinson (2005). An informal level of RCA will have a positive impact on the company and be able to find solutions to the causes inspected. However, it will not penetrate the company as deeply as more structured efforts might do. The reason for the level of depth is both effort and complexity: the factory of CandyCo is infinitely complex if broken down to component-level. No solutions could be found within the scope of this Thesis if the analysis would be as detailed as possible. Additionally, since RCA is only used for specific problems within the research process, too much effort on it would sabotage the true purpose of the Thesis. I will heed the advice of Vanden Heuvel and Robinson (2005) and attempt to maximize the return on my problem-solving investment.

The “Five Why” –method

One of the more known approaches to finding the root causes (Step 2 in Hughes et al., Steps 2 and 3 in Rooney & Vanden Heuvel) comes from the car company Toyota. Liker and Meier (2006) documented Toyota’s management practices, among them their approach to RCA, in their book “The Toyota Way Fieldbook”. The Toyota cause-and-effect solving method is based on finding all the causes for a comprehensive analysis. The causes are evaluated through 4Ms: Man, Method, Material and Machine to ensure that the analysis is thorough. The specific tool to actually find the root causes is called the “Five-Why” method. The technique consists of continuously asking why to get deeper and deeper into the problem and simultaneously draw a tree of answers that starts with the observed problem and goes one level deeper after each “Why?” question is asked. The name of the method is a bit misleading: one may find that more than five “whys” must be asked. However, usually five is enough to find the root cause. I will use the “Five-Why”-method as the basis for my RCA interviews. (Liker and Meier, 2006)

2.3.3 Qualitative Interviewing

In the Thesis I will be using interviewing in cases, where data analysis is insufficient. One such example is Root Cause Analysis, where I will interview employees to determine the causes for idle time in the bottleneck resource. In my case, the interviews will be quite open, in the hopes of finding the correct answers to a specific question. The interviews are not structured, as I will not be performing quantitative analysis on the backgrounds and answers of the interviewees.

There are several differences between qualitative interviewing and structured interviewing used in quantitative research. As mentioned above, qualitative interviewing hopes to find the opinions of the interviewee while structured interviewing aims and is designed to answer a specific research question that the researcher has predetermined. This means that in qualitative interviewing, the focus and interest is on the answers and opinions of the interviewee, whereas in structured interviews the focus is on the researcher. Also, qualitative interviewing permits the respondent to ramble a bit and also the interviewer has more liberties: he can e.g. ask previously undetermined follow-up questions. These attributes makes qualitative interviews more flexible than quantitative interviews, which discourage the respondent to answer anything else than the questions presented. (Bryman & Bell, 2003)

There are two major types of qualitative interviews: unstructured and semi-structured interviews. In unstructured interviews the interviewer has almost no agenda for the interview. He may have just one question as a starting point and subsequent questions are thought up as the interview progresses. In semi-structured interviews the researcher has a list of questions to be covered. This list is referred to as an interview guide. Despite the list of questions, the interviewee is given plenty of freedom in answering the question. I will be using the unstructured interview in my Thesis. (ibid.)

2.3.4 Sankey diagram

The Sankey diagram is a tool devised by Riall Sankey at the end of the 1800s to originally analyse the thermal efficiency of steam engines. Since then the Sankey diagram has been used in various fields to illustrate the energy and material balances of complex systems. Examples for its use include car comparison tests, thermal balances of production plants and, more recently, value flows in value chains. (Schmidt, 2006)

In this Thesis, the Sankey diagram will be used to illustrate, how different activities consume the time of the bottleneck. Ideally, it will provide additional insight to the statistical data and aid in illustrating, which activities take up most time in the bottleneck.

3 METHODOLOGY OF THE STUDY

In this chapter I will introduce the framework and the tools and techniques I will be using during the research. I will introduce the methods in the order in which I will perform each analysis.

3.1 Process descriptions

The processes in the factory are quite simple to describe, with clear first and last steps and a process flow from one step to the next. Therefore the flowchart method is used to describe the processes, as it is the most flexible and easiest to understand and create.

It should be noted that the more detailed process descriptions are business secrets of CandyCo and as such, are not presented in this Thesis. However, a higher-level process description will be introduced.

3.2 Offloading and idle time analysis

I will be using some of the techniques that TOC suggests to improve the throughput in the bottleneck. The two main techniques I will be looking at are offloading and idle time reduction (Goldratt & Cox, 1984). These two techniques are most likely the ones that will yield the most practical improvement ideas for CandyCo.

When analyzing the offloading possibilities and the reasons for idle time, I will use standard statistical analysis with Microsoft Excel.

3.2.1 Offloading

I will analyse the different components that are manufactured in the factory during the year as well as look at the components passing through the assumed bottleneck phase. To achieve this, I will use standard statistical analysis techniques with Microsoft Excel.

Combining the statistical analysis with information from CandyCo will allow me to look at offloading possibilities on a component-by-component basis.

3.2.2 Idle time analysis

Idle time analysis will start with statistical analysis using Microsoft Excel, based on CandyCo's data on how time is divided up into different activities in the bottleneck. This time distribution will then be illustrated with a Sankey Diagram.

Interviewing will be used to gain further and deeper understanding into the root causes of the idle time. I will be using qualitative interviews with open-ended questions. The structure of the interview is straightforward: I will ask the interviewees to determine the reasons, why the bottleneck is idle. After writing each high-level reason down, we will then drill down on each. The five-why method together with root cause analysis will be used to dig deeper during the interviews, and after them, to determine the ultimate root causes of idle time.

The interviews will be recorded and details of them will be written out, however they will not be written word-for-word. Subsequently, the interviewees will be given an opportunity to read through the document written about their interview and comment on it. The comments will be noted and the interview notes will be edited based on them, until a consensus is reached.

A simple simulation will be built to determine the effects of increased utilization rate in the bottleneck on the WIP inventory and throughput. The simulation software that will be used is Simul8.

3.3 Generation of improvement ideas

Based on the analysis of offloading possibilities and idle time root causes, a set of improvement ideas will be generated. This idea generation process will start by me coming up with suggestions based on the analysis and interviews. These ideas will then be reviewed with the factory staff.

After reviewing the ideas with the factory staff, I will present the findings at CandyCo's headquarters, where the ideas will be reviewed once again and a definitive list of improvement suggestions will be devised.

4 CASE DESCRIPTION

This chapter will focus on presenting the case company and the issue that the case company wanted to tackle with this study. I will describe the production environment and the production processes that exist within the factory. This description will illustrate the complex challenges that the organization faces in their day-to-day operations. I will also analyse the size of the inventory and what could be done about it, and then I will look at the effectiveness of production planning.

4.1 Case Company (CandyCo)

CandyCo operates in the confectionary industry. Its products are sold worldwide, with Finland being one of the market areas. As explained in the “Introduction”-chapter of my Thesis, the confectionery industry has seen changes in consumer preferences over the past few years.

Companies in the industry have started to offer bags of candy with mixed components, i.e. different types of candy. CandyCo was a pioneer in the industry; the company started offering mixed-component bags in the 90s, before most competitors. CandyCo theorized that demand would exist for such products, even though customers had not explicitly expressed their desire for purchasing them. However, when the company started to manufacture these products, it probably could not anticipate the game-changing effect that it would have. Fast-forward 15 years, and consumer preferences have shifted drastically towards the mixed bags. In fact, mixed bags currently make up for close to 60% of the candy bag market and traditional, one-component bags have had to step aside. Consumers also demand more and more different components within each bag. Currently CandyCo is offering products starting with two different components going up to over ten. Customers are attentive to the number of components in each bag and expect that the ratio is always similar, making it important for CandyCo to get the accuracy of the mixing process just right.

With the advent of mixed-component bags, the production process of candy bags has changed. Not only have companies had to add a new phase within the existing process to mix the bags, they are faced with a host of challenges regarding production planning and

storage. Different types of candies typically have different lead-times to manufacture. The candies are also perishable – of course at different rates; letting them stand around for too long without putting them in bags will result in the candies being spoiled and having to dispose of them. Additionally, mixing will require more storage space since some types of candies have to wait for others before they can all be inserted into the mixing process together. Finally, adding the mixing phase into an existing, traditional manufacturing process is neither an easy nor a cheap task.

The CandyCo factory will provide us with a case example. The manufacturing machines are of various ages at the production facility. Some machines are newer and the mixing phase is naturally quite new in the overall process: it was first automatized in 1997 and has been improved gradually. The company has seen, according to employees, an increase in the WIP inventory levels. As a result, the WIP inventory areas are often full and the factory has been forced to establish new storage areas. The factory makes products to stock according to demand forecasts.

Despite the challenging production setup at the facility, the factory is performing well: production planning is hitting its targets more or less regularly and the facility has an excellent internal delivery success rate. However, with mixed bags still increasing in popularity and consumers demanding more and more different types of candies within each bag, there could be problems ahead if the bottleneck's capacity is not increased

The increased inventory and waiting line in front of the mixing process indicates that mixing is a bottleneck phase in the process of manufacturing mixed bags. This bottleneck phase was analysed and TOC-techniques were used to develop suggestions on how to improve the performance of the bottleneck.

4.2 Problem description and product descriptions

CandyCo is facing a problem of controlling a complex product, which consists of different types of components with different manufacturing lead times. Additionally, the components are perishable and they perish at different rates.

There are four main types of components that are inputs of the mixing process. Each main type consists of several sub-types, each of which has their own manufacturing process. The main types are:

- (1) Molded components
- (2) Caramel components
- (3) Liquorice components
- (4) Granulated components

The first three components are manufactured from start to finish from raw materials. The granulation process receives as input these three types of components – additionally some components are bought from suppliers – and coats the candies with a certain type of a layer. The four different types of components are all sent into mixing and packaging from the manufacturing departments. Figure 2 illustrates the high-level manufacturing process of mixed candy bags at CandyCo.

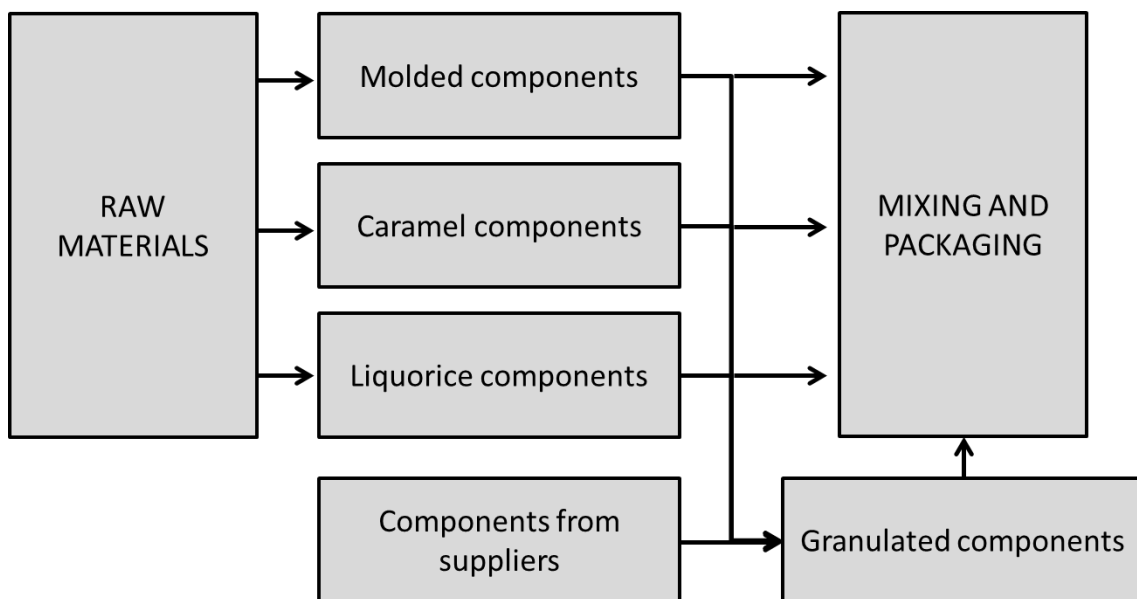


Figure 2 High-level manufacturing process at CandyCo

The main types of components are manufactured at different volumes in the factory. Molded components make up most of the plant's component output.

4.3 Process descriptions

The processes for manufacturing the components are essentially quite similar. For molded, caramel and liquorice components the first steps of the process consists of creating the mixture (i.e. recipe) and forming the candies into the required form. During this process, some components are also filled with chocolate or some other type of filling.

After the components have been formed, they will typically be either sugar coated or polished, based on the recipe. Some components are floured and some are wrapped. After these steps, some components are ready to be sent to the packaging area while some will need further processing, either by drying or moisturizing the components or by granulating the surface.

The granulation process receives inputs, i.e. components, from the other processes. The components are granulated once or twice, depending on the recipe.

The mixing process has multiple phases. The details of the process are a trade secret of CandyCo, however the details are unimportant for the purpose of the Thesis. What is important to note and understand, is that the mixing process combines both the mixing and packaging phases. I.e. components are received as inputs and bags of candy come out as outputs. Thus the case for the mixed-component candy bags is that the mixing and packaging phases are inseparable – they are essentially part of the same overall phase in the manufacturing process.

4.4 Factory layout

The manufacturing units are located in several different floors within the factory. Thus, some components need to be moved via an elevator to the packaging area or to the WIP storage area. The WIP storage area is right next to the main packaging area.

Not all components are packaged in the main packaging area and not all components that are packaged in the main packaging area go through the mixing process. Figure 3 illustrates how throughput is split between different areas and machines within the factory. Of the entire annual throughput, 69% comes from the main packaging area. Of this share, 83% go through the mixing process. This means that annually, 57% of all end products have gone through the mixing process. However, this does not mean that $(69\% * 83\% \Rightarrow) 57\%$ of all

end products consist of products that require mixing. As we will see when studying the data later on, the mixing process is burdened by candy bags that do not require mixing at all. The more detailed focus of the study is on the mixing and packaging phase; however other areas will also be touched upon when they are relevant.

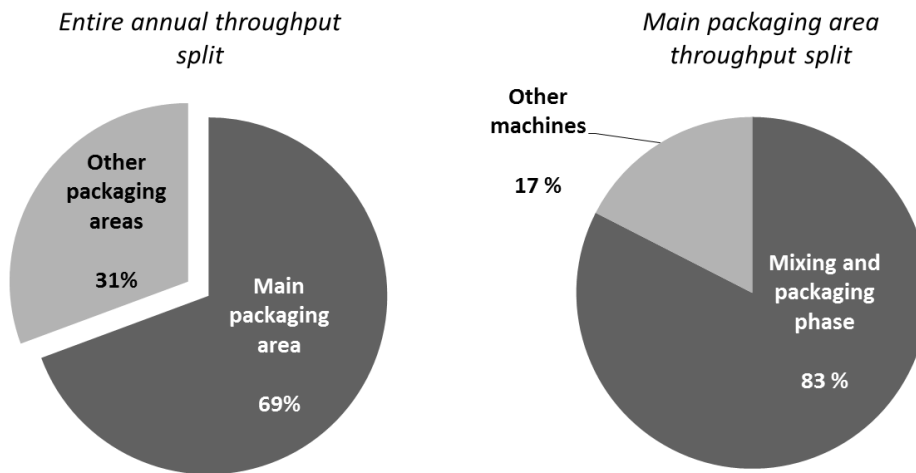


Figure 3 Throughput split between different areas and machines within CandyCo's factory

Most of the mixing is done in the main packaging area, however sometimes some two-component products are mixed manually on other packaging machines to release capacity at the mixing/packaging phase for more complicated mixes.

4.5 Bottleneck efficiency

The average throughput volume per hour (in kilograms) is calculated by assuming that there are 250 days during which the mixing/packaging phase is operational and that the bottleneck runs on three eight-hour shifts, i.e. 24 hours per day.

$$\text{Bottleneck throughput per hour} = \frac{\text{Annual throughput (kg)}}{250 * 24 (h)} \cong 1\,900 \text{ kg/h}$$

Currently, the bottleneck functions at a capacity well below its theoretical maximum: the machines are operational 52% of the time. Given this observation, theoretically the bottleneck could have an output rate of ~3 600 kg/h. However, idle time due to changeovers (product switches) makes up ~13% of the time and one could hardly expect the bottleneck

to churn out just one product all the time. Removing changeover time from the theoretical capacity, we get a new operational efficiency of $52\% / (1 - 13\%) = 60\%$. In volume, this percentage capacity corresponds to an output rate of $\sim 3\,100$ kg/h. During the study, I analysed one week of production, and the average throughput rate was $\sim 2\,300$ kg/h, which is more than the mathematical average calculated from the annual data suggests. This is likely due to maintenance breaks during the year that result in an overall decline of the average rate, since the bottleneck is not operational.

In either case, we can see that the bottleneck is performing far below its theoretical capacity. The causes of this are analysed in the next chapter. Nevertheless, this result indicates that once the efficiency of the bottleneck is improved closer to its theoretical maximum, it is indeed possible that the mixing phase will cease to be the bottleneck in the process.

4.6 Inventory

As mentioned before, CandyCo's WIP inventory has been growing in recent years, and the size of the inventory is a challenge for the factory. The factory has had to establish secondary storage areas due to lack of space in the WIP inventory. A large WIP inventory also ties a lot of capital and affects the bottom line. This is an observation noted also in the new performance measurements suggested by TOC (e.g. Goldratt, 1990).

In the table below, I have calculated the time it would take to package the entire WIP inventory given different throughput speeds. The average throughput speed of the entire factory based on a year's production was observed at around $\sim 2\,300$ kg/h. This indicates that it would take around 150 hours to package all WIP components into end products.

Table 2 Hours and days of inventory with different throughput speeds

Throughput speed (kg/h)	Hours of inventory	Days of inventory*
1500	233	10
1600	219	9
1700	206	9
1800	194	8
1900	184	8
2000	175	7
2100	167	7
2200	159	7
2300	152	6
2400	146	6
2500	140	6
2600	135	6
2700	130	5
2800	125	5
2900	121	5
3000	117	5

* Day calculated as 24-hour work day with 3 shifts

This analysis is slightly biased though: since each component will have a specific place in a candy bag, the components cannot simply be packaged without considering the integrity of the end product. Sometimes less than half of the inventory is ready to be packaged due to lack of specific components. E.g. if a component is meant to be put into a mixed bag and the component batch is for some reason 70% of the expected, the factory can only package 70% of the intended amount and the rest is left in the inventory. There are also a number of components in the WIP inventory waiting for the final component to be delivered into the inventory, after which they are ready to be packaged. Finally, all the boxes are not residing in the WIP inventory; some are drying up while others are waiting for granulation.

Inventory management is done via an Excel sheet, which is manually updated by the employees at the inventory when products enter and leave the area. This system is an error-prone one and it should be investigated, whether the factory should invest in a new, more sophisticated inventory management software.

4.7 Production planning

The production planning department is performing quite well at the factory. Looking at a randomly selected sample week, we see that the actual throughput of the mixing/packaging phase is only 3,4% below the amount planned. However, production planning was forced to make some corrections in the packaging schedule, because of failed component batches. Therefore, some products that should have been sent to the finished goods storage were not delivered. Replacements were made in the schedule and thus throughput was maintained at close to planned levels.

When looking at the effectiveness of production planning, we must remember that the factory is expecting a utilization rate of around 50% of calendar time. Thus, one could argue that matching actual production with planned production will be easier, when planned levels are set low enough.

The production processes are not accurate enough for precise production planning, and almost always a tail is created at the end of each batch (i.e. the batch is larger than required). The size of the tail is not fully proportional to the size of the batch. Rather, the smaller the batch is, the larger the tail will tend to be in relation to the batch size. This means that the production process follows the log-normal distribution, which is a distribution with a tail to the right. This property of log-normality will be used in my simulation of the production processes and throughput.

Production planners attempt to use these tails to reduce losses of components. However, often this can result in component shortages, as the tails are more likely to have inferior quality. An interviewee mentioned that production planners maybe try to use the tails too much.

As mentioned in the previous chapter on inventory, the factory uses Microsoft Excel together with other programs for inventory management. This is not a fully transparent way of working and makes the job for production planning more challenging than it optimally could be.

4.8 Complexity

Looking at the definitions for static and dynamic complexity, the mixed bag manufacturing process has characteristics of both static and dynamic complexity. The system has many subsystems, and sub-processes with variable lead times, which points towards static complexity. Additionally, there are plenty of variables that change over time which create complexities in the process, therefore pointing towards dynamic complexity.

Additionally, based on the list introduced in Chapter 2.1 by Calinescu et al. (1998), the manufacturing process of mixed bags exhibits signs of complexity. The product structure is complex, with varied component numbers, lead times, batch sizes and perishability. Also, the communication and documentation of WIP inventory is not optimal. Finally, there is plenty of dynamism and variability in the environment, creating yet another source of complexity.

5 DATA ANALYSIS

Having laid out the case and described the case company in the previous chapter, this chapter will focus on the data, my analysis of the data and what was uncovered from the data. First I will examine, whether packaging is a true bottleneck. Then I will look at the possibilities of increasing throughput using the TOC techniques that I described earlier on (offloading, eliminating idle time). Next, I will present the key findings from the interviews. Finally, I will combine all these observations to lay out some improvement suggestions both for the short and medium term.

5.1 Is mixing a bottleneck?

First I studied, whether the bottleneck truly existed in the mixing/packaging phase of the mixed-component candy bag manufacturing process. CandyCo assumed that this was the case, given the amount of inventory piled up in front of this phase. However, the amount of inventory could have been a symptom of something else.

To determine whether the process phase was a bottleneck, together with CandyCo's help I piled up and combined the manufacturing data from the different component manufacturing departments and the throughput data. I discovered that the number of components that are sent to the mixing phase exceeded the throughput by 4,8%. This means that the mixing phase is constantly performing slower than the manufacturing phases, which indicates that mixing is indeed a bottleneck in the overall manufacturing process of mixed-component candy bags. However, as we see, the annual difference of 5% is relatively small and this indicates that once efficiency is improved in the bottleneck, it is possible that the factory could see the bottleneck shifting e.g. to the manufacturing of the components or to the market.

As stated above, the analysis confirms that mixing is a bottleneck. Given that the products are packaged at a rate approximately 5% slower than they are produced, components will stack up in inventory as the bottleneck lags behind. According to TOC principles, non-bottleneck operations are supposed to have excess capacity (e.g. Goldratt & Cox, 1984), so that in itself is not a problem. However, in this case the excess capacity has been used in a way that CandyCo's inventories have grown each year. Increased inventory shows as boxes

of candy taking up an increasing share of the factory's floor area. Additionally, whenever there is an unexpectedly long break in the mixing/packaging phase, boxes will tend to run out in the factory and the component manufacturing departments will come to a halt as well.

Having proven that mixing is a bottleneck, the next step was to look at two different techniques to improve the operations of the bottleneck: offloading and eliminating idle time.

5.2 Offloading possibilities

5.2.1 Single-component products

As I mentioned earlier, 57% of all end products go through the mixing/packaging phase. However, the phase is burdened not only by end products that actually require mixing, but there are some bags of candy that actually contain only one component. These types of products are ideal for offloading: they consume the precious resources of the bottleneck, even though most of them do not require the capabilities that the bottleneck resource offers. The data can be seen in Table 3.

Table 3 Single-component products that go through the mixing/packaging phase

Product	Share of bottleneck annual throughput
Single-component product 1	0,26 %
Single-component product 2	0,33 %
Single-component product 3	1,67 %
Single-component product 4	0,59 %
Single-component product 5	0,06 %
Single-component product 6	2,14 %
Single-component product 7	0,49 %
Single-component product 8	1,47 %
Single-component product 9	1,67 %
Single-component product 10	0,62 %
Single-component product 11	1,31 %
Single-component product 12	0,76 %
Single-component product 13	0,25 %
Single-component product 14	1,14 %
Single-component product 15	1,36 %
TOTAL	14,11 %

There are 15 single-component candy bags that together made up of 14,11% of the annual throughput through the bottleneck resource. Given the average throughput rate (calculated in chapter 4.5), this means that ~850 hours a year, i.e. ~110 8-hour shifts, of the precious bottleneck resource is used to process end products that ultimately do not need the capabilities of the bottleneck resource. Thus, this means that mixed-component candy bag production is idle 850 hours in a year. While this may only be a small issue at the moment, as demand of mixed-component product increases, scheduling one-component products to the mixing phase is a waste of the mixing capacity.

We can then conclude that even if no other process improvements happen, 850 hours can be freed for the production of mixed-component products. Naturally, this would mean that there needs to be free capacity at other packaging locations in the factory. This will be addressed in section 5.2.3.

However, there are some possible restrictions. Some components require the packaging machine to have a dust-removing capability, i.e. as the components are packaged, excess sugar dust is removed from the components. Not all machines in the factory have this capability. A bit less than half of the single-component products, 6,21% of the total products do not require the dust removing capability, i.e. they can be moved to other machines directly. The rest, 7,90%, can be moved to other machines, but they will require more organizing, since not all machines can be used.

5.2.2 Two-component products

Occasionally, the factory will package two-component products at other packaging machines by manually mixing the components. Two-component products are relatively easy to mix without the more sophisticated mixing process that is used for most end products that require mixing.

There are 17 two-component products that make up 18,26% of the throughput of the mixing/packaging phase (Table 4). These products can be mixed manually, and this happens occasionally as explained before. These would not be as ideal to be used to decrease the load of the bottleneck as the single-component products. However, as I mentioned above, some single-component products require dust-removal and, if it is difficult to schedule these products to other machines, offloading the two-component products that do not require dust-removal is another option.

Table 4 Two-component products that go through the mixing/packaging phase

Product	Share of bottleneck annual throughput
Two-component product 1	0,49 %
Two-component product 2	0,08 %
Two-component product 3	0,97 %
Two-component product 4	0,49 %
Two-component product 5	2,40 %
Two-component product 6	1,48 %
Two-component product 7	1,64 %
Two-component product 8	0,39 %
Two-component product 9	0,24 %
Two-component product 10	3,81 %
Two-component product 11	0,44 %
Two-component product 12	1,45 %
Two-component product 13	0,39 %
Two-component product 14	2,49 %
Two-component product 15	0,02 %
Two-component product 16	0,33 %
Two-component product 17	1,16 %
TOTAL	18,26 %

Most of the two-component products, 13,37% of the total throughput of the mixing/packaging phase, can be moved to other machines without limitations. 3,56% require dust-removal and 1,34% cannot be moved due to technical limitations of the other packaging machines.

5.2.3 Free capacity

Having analysed the components that could be moved to other packaging machines, the next step would be to determine, whether there actually is any free capacity in the other packaging areas and machines in the factory.

There are two machines that can share the load of the bottleneck. One of these machines is currently used in two shifts and it has around 3-4 shifts of free capacity per week. This machine imposes a restriction however; bags of over 350 grams cannot be packaged in this machine. The other machine is used in three shifts and it has around 2-3 shifts of free capacity per week. If we add a third shift to the first machine, this would free up 8-9 shifts per week to be used for single- or two-component products shifted away from the bottleneck. Given that these machines have an average theoretical capacity of 750 kg/h,

using a 50% utilization rate, which is the same utilization as the bottleneck currently has, we get an annual free capacity of 1,7 million kilograms. The annual throughput of all single-component products is 1,6 million kilograms, therefore we can conclude that there is enough free capacity to shift all single-component products, if the restrictions for dust-removal and bag size can be accounted for.

5.3 Idle time at the bottleneck resource

5.3.1 Time distribution at the bottleneck resource

As mentioned in chapter 4.5, the utilization rate of the bottleneck is 52%. This means that out of 250 business days a year, the bottleneck is operational for 130 days. The 130 days is further divided into slow (due to e.g. special labelling of products or campaigns) and normal production as follows: 37 days of slow production, 93 days of normal production. Below in Figure 4 you can see a Sankey diagram on how time is distributed in the bottleneck resource.

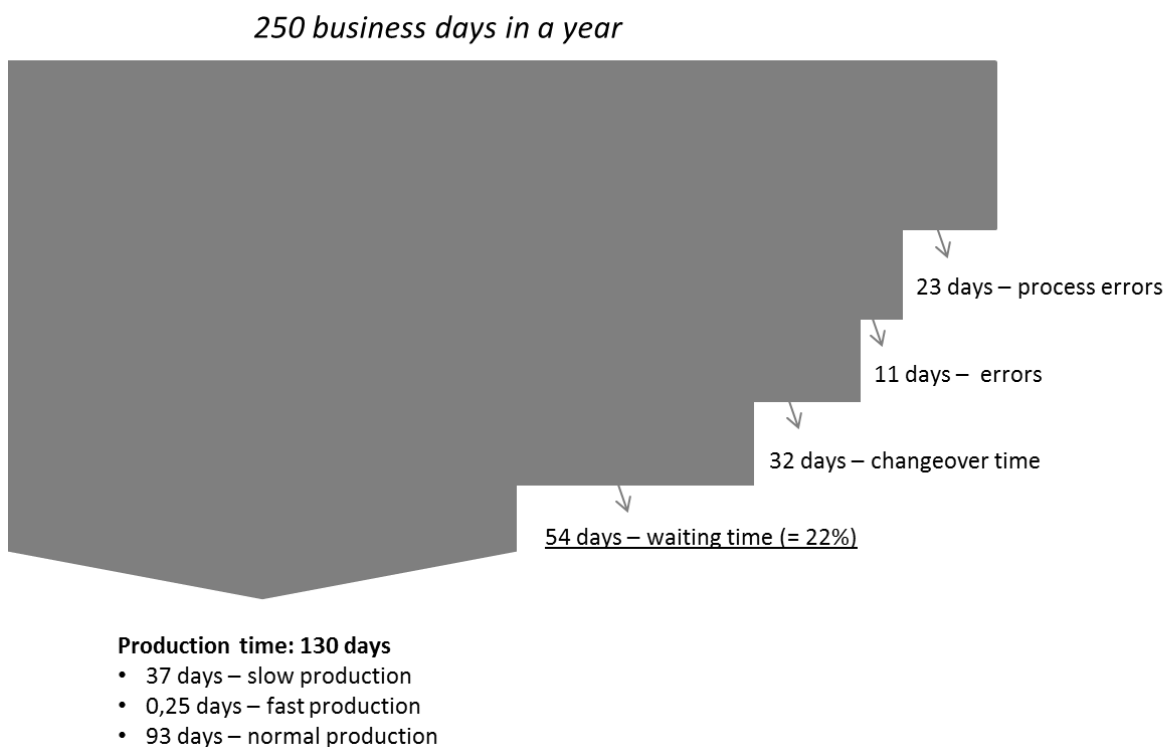


Figure 4 Time distribution in the mixing/packaging phase

As we can see, waiting time, i.e. idle time, takes up over a fifth of the bottleneck's time. Process errors and errors together amount to 34 days, i.e. ~14%. Changeover time is 32 days; however this can only be minimized to an extent: there will always be delays when the settings are changed from one product to the next. Additionally, changeovers can require that the machines are cleaned.

The same data as depicted in the Sankey diagram can be seen in Table 5 below:

Table 5 Time distribution in the mixing/packaging phase

Phase	Share of time	Days
Waiting time	21,70 %	54
Changeover time	12,80 %	32
Error	4,50 %	11
Process error	9,10 %	23
Normal production	37 %	93
Fast production	0,10 %	0
Slow production	14,80 %	37
<i>Annually</i>	<i>100,00 %</i>	<i>250</i>

The data has been compiled from CandyCo's internal monitoring system. The system allows for users to give more detailed reasons for each occurrence. Thus we can dig deeper into the reasons for waiting time to see, which reasons are prevalent and whether they can be addressed. However, given that employees give the causes for the idle time, there are some inconsistencies in the data. The data on the more specific reasons for waiting time can be seen in Figure 5.

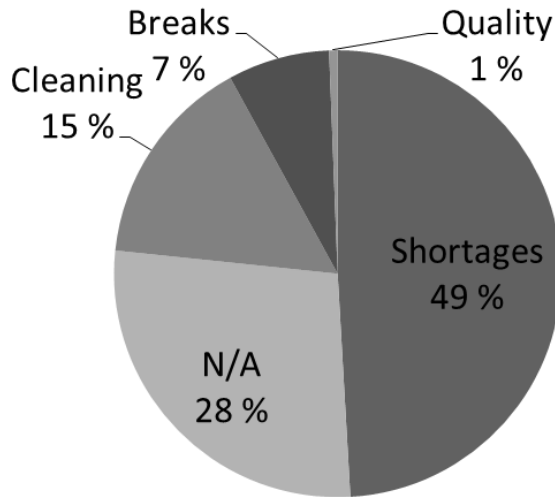


Figure 5 Reasons for idle time

Shortages are clearly the single biggest reason for idle time. Shortages include both component shortages (e.g. not enough components or components available don't match the plan) and personnel shortages (e.g. people are on sick leave). This is separated between the two roughly 50/50, with personnel shortages having a larger share. However, breaks are included as their own section as well and they should be calculated into personnel shortages, as they are sometimes marked in that category. Likewise, quality issues could or should be marked in component shortages, as quality issues effectively create a component shortage.

The analysis is made problematic by the large amount of non-allocated idle time: 28%. Based on interviews, a safe bet would be that a large portion of it should be allocated to personnel shortages, but we have no way to know that for sure.

Nevertheless, this analysis indicates that shortages is the biggest issue in the bottleneck utilization rate, making up of almost 60% of the total waiting time (breaks + shortages + quality = 57%), possibly more. Thus, shortages represent roughly ~30 days of the calendar year, with personnel shortages representing ~17 days (7% of annual business days) and component shortages ~13 days (5% of annual business days).

It is also an observed fact in the organization that more idle time results in more process errors as the machines need to warm up again. Therefore, reducing waiting time would reduce the amount of process errors as well.

5.3.2 Interviews and root cause analysis for shortages

To dig deeper into the root causes for idle time, I interviewed some key employees in the organization. The employees each represented a different phase or department in the process. There were 5 different interviews, and the departments represented were:

1. Molded components
2. Caramel components
3. Liquorice and granulated components
4. Packaging
5. Quality control

The interview was semi-structured, with only one question: “What are the reasons for idle time in the packaging area?” Each respondent naturally focused on their area of expertise more and we discussed the underlying causes for idle time. The “Five-why” –method was used to find the ultimate root causes, instead of stopping at the first cause. Interviewees were also allowed to give other comments. The interviews were somewhat anonymous: it was known, who the five people were that were interviewed, however the specific answers were only known by me.

Based on the interviews, two main reasons for idle time were uncovered: personnel shortages and components shortages. Indeed, these two categories were defined separately based on the data as two of the biggest issues that cause idle time and they were confirmed independently by the interviewees without me leading them on.

The individual root causes for component shortages could be divided into four subcategories. The subcategories can be found below and each subcategory will be analysed more deeply, with suggestions on how each type of cause could be mitigated or removed, if possible.

- a. Mechanical errors – Occur when a machine stops working or starts to show errors. These types of errors are difficult to avoid, since they cannot be affected by employees. Having said that, there is a positive correlation between the age of a machine and the number of errors. These types of investments are expensive though.
- b. Process errors – Occur when there is a mistake in the process. Examples include a mistake in the recipe or a human error during the process. These types of errors can

be prevented in some degree: inevitably people will always make mistakes, however failsafe mechanisms can be created to minimize the number of errors.

- c. Quality errors – Occur when a machine produces poor quality or when components have lost their integrity while waiting to be packaged. Similarly to machine errors, inconsistent quality is correlated with the age of the machines, which are expensive to replace and renew. Component shortages due to deteriorated quality could be avoided by reducing the WIP inventory, allowing components to get packaged more quickly, or by discarding the tails left from production more readily.
- d. Mishaps – Mishaps are entirely preventable. Mishaps include occurrences such as boxes of components going missing, which could be avoided by investing in a tracking system, or having the wrong amount of components in a box, which typically result from lack of scales in certain production areas. Investing in scales would eliminate those errors completely.

For personnel shortages, two main categories could be identified. Fixing personnel shortages would likely impact the idle time more than component shortages, based on statistics.

- a. Breaks are not covered – Breaks make up of 1/8 of working time, i.e. 12,5%. Often, if not always, breaks are not covered in the packaging area, resulting in the bottleneck being idle just from breaks alone for 12,5% of the time, i.e. 1 hour per shift, 3 hours per day. Clearly this is a big issue, which could be mitigated either by recruiting more employees, enforcing the break covering rules or cross-function training, so that employees from other departments could cover the breaks in the bottleneck.
- b. Sick leave rate is high rather high, especially in the packaging area. The root cause for this is difficult to determine and it may indeed be simply a statistical anomaly.

5.3.3 Ideas to decrease idle time at the bottleneck

Several improvement ideas were suggested in the interviews and others were suggestions from my part. These ideas were then reviewed with CandyCo and a shortlist of improvement ideas was developed.

Evidently, the largest impact on reducing the idle time in the bottleneck would be to decrease the shortages: both personnel and component shortages. As component shortages

arise mainly from machine breakdowns and other issues that are less preventable than personnel shortages and since personnel shortages form a larger part of overall shortages, focusing on the latter first could yield larger improvements in the bottleneck's utilization rate.

Ideas to decrease personnel shortages can be seen in Figure 6 below. The ideas have been evaluated on three criteria: investment required (Y-axis), difficulty of implementation (X-axis) and effect on throughput (area of ball).

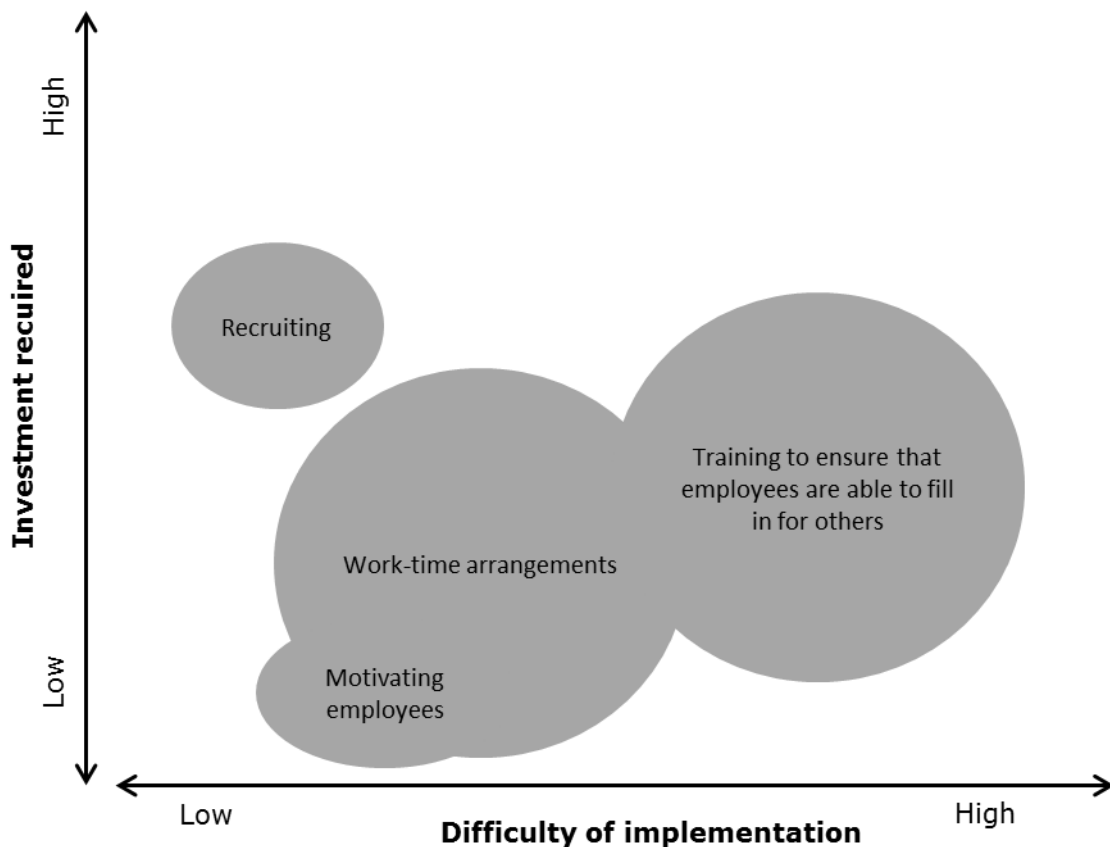


Figure 6 Ideas to decrease personnel shortages

The four best ways to decrease personnel shortages were identified as:

1. Work-time arrangements
2. Training to ensure that employees are able to fill in for others
3. Motivating employees
4. Recruiting new employees

Work-time arrangements refer to arranging work in the factory in such a way that there are always enough people working at the bottleneck. This is heavily related to the second point, training employees so that they can fill in for others, since arranging work will be useless if people cannot operate the machinery properly. These two actions together would yield the largest decrease in personnel shortages, by ensuring that there will always be competent employees in the factory to fill in for the breaks and sick leaves of the packaging area. And there is extra capacity: many of the departments only need a few people to monitor the machines and move some boxes around, when they are producing components. There is extra workforce in some departments and they can, and indeed sometimes do, offer help to other departments.

Other ideas to decrease personnel shortages include recruiting more employees to ensure that there are enough people working at the bottleneck and motivating employees, in case there are some motivational issues in the packaging department.

Ideas to decrease component shortages can be seen in Figure 7 below. The ideas have been evaluated with similar criteria as the ideas to reduce personnel shortages.

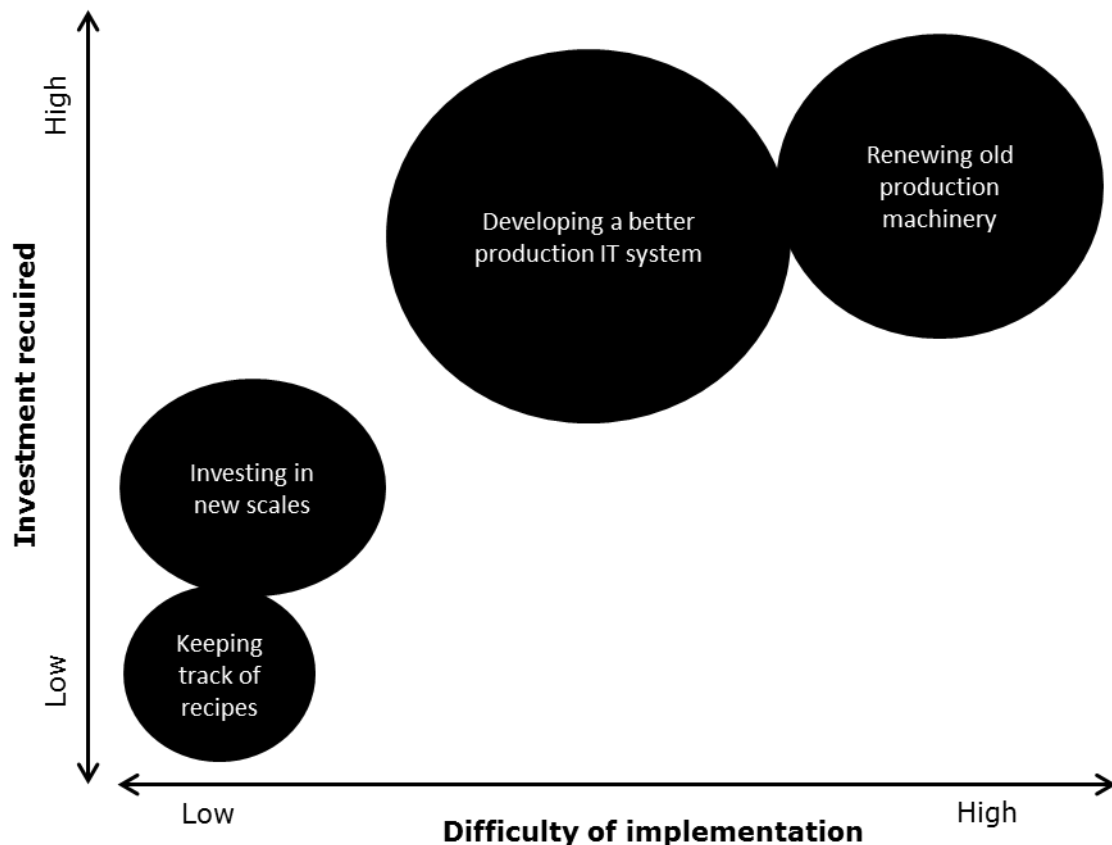


Figure 7 Ideas to decrease component shortages

The four best ways to decrease component shortages were identified as:

1. Developing a better production IT system
2. Renewing old production machinery
3. Investing in new scales
4. Keeping a better track of the recipes for new products

Developing a better production IT system is probably the most pressing issue at the factory. As mentioned before, there is a lack of transparency in the overall production process as the inventory is managed manually through an Excel-sheet. The different IT systems do not communicate well with each other, resulting in disturbances in the information flow in the factory. A part of the new IT system would ideally be devoted to a tracking system, to prevent boxes from being misplaced and disappearing. Renewing old production machinery is also a way to decrease component shortages, albeit a more expensive one. The machines are large and they are not easily nor cheaply renewed.

Minor issues, but cheap to implement, are investing in new scales and keeping a better track of the recipes for new products. As mentioned in Chapter 5.3.2, some production sites do not have scales, which sometimes results in the wrong amount of components in WIP storage boxes. Additionally, it was suggested in the interviews that sometimes the recipes for new products are not confirmed with required precision before they are sent to the factory, resulting in the first few batches being of insufficient quality.

5.3.4 Simulation

To illustrate the effect that reducing idle time in the bottleneck could have on the inventory and throughput, I created a simple simulation model using the software Simul8. The simulation setup has 4 manufacturing departments feeding the WIP inventory with 4 different product types. As a simplification, granulated products are considered as a “manufacturing department”, even though they do not prepare components from scratch. The input speed of each department has been determined by calculating the amount of components that are either components in mixed bags or packaged by the bottleneck. The speed has been determined as the amount of time in hours it takes for a tonne of components to be sent to the inventory, i.e. the inter-arrival time. The speeds used are based

on annual data, which has been averaged out. The throughput speeds of each department can be seen in Table 6 below.

Table 6 Inter-arrival speeds for different product types

Inter-arrival time, in tonnes of kg (hours)	
Product type 1	0,585
Product type 2	12,541
Product type 3	3,045
Product type 4	42,992

The input processes were defined as having a log-normal distribution, as explained earlier in the Thesis. Additionally, the initial setup had an inventory of 280 tonnes, based on an estimate that 80% of the WIP-inventory is attributable to the components that are studied in this simulation. There are two packaging processes: the mixing/packaging phase (bottleneck) and components that require mixing, but are packaged elsewhere (other packaging). The average throughput speed for the bottleneck was defined as the theoretical maximum throughput speed of approximately 3 600 kg/h, but the efficiency was set at 52%. The average throughput speed of the other machines was defined as the actual throughput of 200 kg/h, with an efficiency of 100%, since I wanted to focus on analyzing the bottleneck. The initial conditions have throughput at zero for each packaging phases and the input at zero from each department (product type). The setup can be seen in Figure 8.

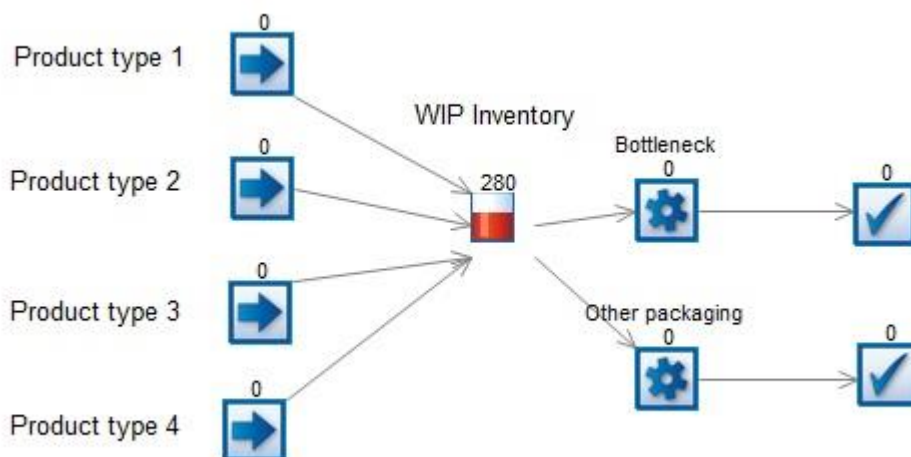


Figure 8 Initial setup for simulation

The simulation runs for 360 hours, i.e. 15 24-hour days which corresponds to three weeks. The first simulation is run using the 52% efficiency for the bottleneck, while the second one uses a 60% efficiency. The results can be seen in Figures 9 and 10.

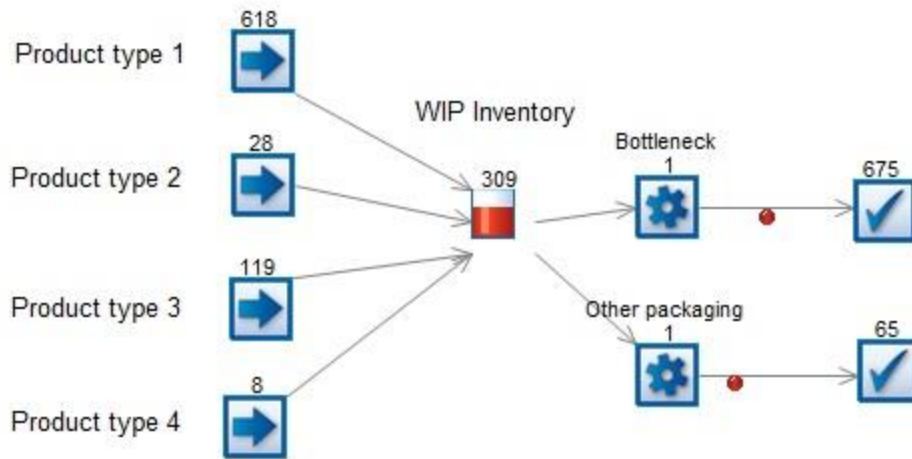


Figure 9 Simulation run with 52% efficiency for the bottleneck

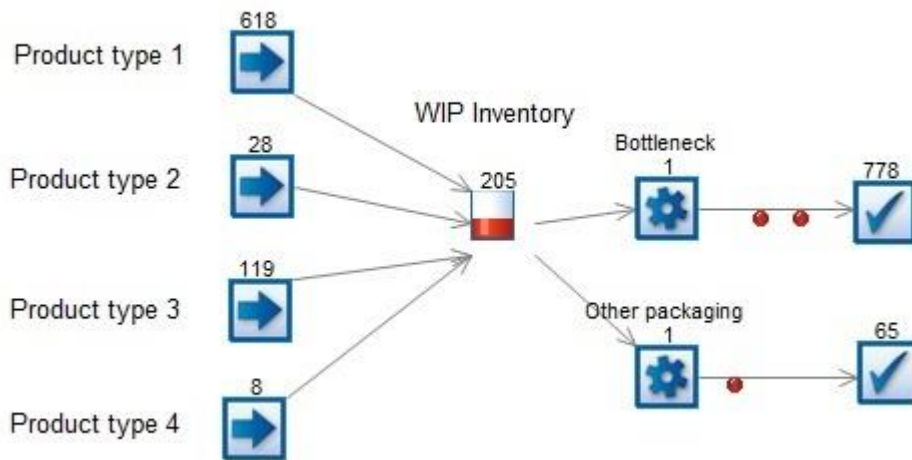


Figure 10 Simulation run with 60% efficiency for the bottleneck

As we can see, the results are drastically different. While the input from the processes is at similar levels, the inventory levels are approximately 50% higher in the first simulation compared to the second one. Average throughput rate in the first simulation is $675\,000\text{kg} / 360\text{h} \approx 1900\text{ kg/h}$, which is the observed average hourly throughput rate from annualized data. The second simulation has the rate at $778\,000\text{kg} / 360\text{h} \approx 2200\text{ kg/h}$.

While the simulation is simplistic compared to the complex reality that the factory faces, it still has a powerful conclusion: increasing the efficiency, i.e. utilization rate, of the bottleneck resource by as much as 8% could have a drastic impact in lowering the inventory levels in the factory. Considering the fact that, mathematically, ensuring that breaks are covered would decrease idle time by 12,5 percentage points, I feel that 8% is not an unrealistic goal. Indeed, it could even be a pessimistic goal, based on the data.

5.4 Actions and investments required

In this chapter, I will synthesize my findings and present the required actions and investments, both short- and long-term, that will improve throughput at the bottleneck. By improving throughput, the factory will reduce its WIP inventories, have less floor space occupied by boxes and crates and be able to produce a greater volume of mixed-component candy bags.

5.4.1 Short-term actions

As we look at the improvement ideas for offloading and idle time reduction, we can clearly see that some of them can be implemented with little or no investment and in a short period of time.

Offloading the bottleneck can be done relatively quickly. There is existing free capacity on other packaging machines to take all or almost all one-component products. This would free up capacity for mixed-component products. Offloading would then require reorganizing and informing the employees more than anything. Additionally, some new shifts should be added to make full use of the other packaging machines.

Work-time arrangements and training new employees could also begin quite quickly, once employees have been heard and a proper training schedule and content devised. Realistically, it will likely take some time to get training started. Motivating the packaging area employees and making sure that breaks are covered are also actions that could be taken up on short notice.

Inspecting new recipes better would require separate “trial run” machinery, which can be expensive. An option to consider would perhaps be investing in common trial run machinery, which could be used by the entire company.

5.4.2 Long-term investments

Most, if not all, the investment ideas are long-term plans. The biggest long-term investments that are suggested in the Thesis are surely both the IT-investment and the investment in new machines. Should these two alternatives be evaluated and compared with each other, the IT-investment would more likely yield in a higher cost/benefit –ratio. The factory is clearly struggling at times with its current IT-system. There is clearly a need of a more transparent process, which smart IT and technology investments could enable.

New production machinery would also impact component shortages, however as numerously stated before, investment in such large machines would not be cheap. Recruiting new employees can also be considered as a long-term investment, since it is not easy to find employees with the proper education and sufficient experience.

6 DISCUSSION AND CONCLUSIONS

In this final chapter I will present the conclusions of my research, analyse its scientific contribution and its managerial implications and suggest areas for further research.

6.1 Summary

The goal of this study was to analyse a case example of a complex manufacturing setup and introduce more control into this setup using the techniques suggested by the Theory of constraints (TOC). The techniques would be simple enough to implement without major investments and they should increase the throughput of the manufacturing setup.

The process analysed was the manufacturing process of mixed-component candy bags at a factory owned by the case company, CandyCo. Increased throughput would aid the factory in its problem of high inventory levels and would increase the capacity to produce mixed-component bags, a category which has shown strong growth within the candy bag market over the past ten years.

To gain deeper insight into the challenges the factory was facing before delving more deeply on the numbers and analysis, I looked at the complexity of the production setup and the manufacturing process of mixed bags as well as the throughput speed of the bottleneck. I also analysed the size of the inventory and looked at how production planning is organized. These insights would also answer my first research question:

1. How is the manufacturing process organized? What are the preceding and following steps for the bottleneck resource?

There are four main types of components that are inputs in the mixed bags: molded, caramel, granulated and liquorice components. Within each main type there are several different specific components. A component is defined as a candy which has the same basic recipe, i.e. it can be manufactured at the same time and in the same production run. The same components can have different colours and shapes, since the machines can produce components with varied colour and shape at the same time.

Three of the main types are manufactured from scratch: molded, caramel and liquorice. Granulated components are components that are manufactured initially in one of these three departments and then coated in granulation drums to create a different surface texture and flavour to the original components. The time it takes for a component to become ready to be put into a bag from raw materials can be vastly varied, from a few days for some components to a few weeks for some.

From these four departments the components are brought into the WIP inventory space for the packaging area, where the mixing/packaging process happens. However, sometimes the components are brought into the mixing/packaging area straight from the manufacturing departments, either due to the components getting finished in the nick of time or due to the space running out in the WIP inventory space. The components are then brought into the mixing area, where the mix is created and the components are packaged into bags. The mixing and packaging phases are inseparable in this setup, thus the phase is called the mixing/packaging phase in the Thesis. This phase is also the bottleneck in the process, initially determined by the large queue in front of the process and later confirmed by my analysis, when I showed that the annual throughput of the mixing/packaging phase is less than the amount of components manufactured during this time period. The throughput speed of the bottleneck based on annual data is approximately ~1 900 kg/h. From the mixing/packaging phase the candy bags are moved to the finished goods inventory, where they are shipped to customers later on. The factory runs on make-to-stock production, so the production schedule is devised based on demand estimates.

With all the variables in the production process of mixed bags, it can safely be concluded that the environment meets the standards for a complex system. The factory does an excellent job at managing this complexity. Production planning is quite accurate: I studied a week of production, where actual production in kilograms was only a few per cent lower than the planned production, even though the production schedule had to be changed on the fly. Having praised production planning, one must also note that they are planning with an expected utilization rate of around 50% of calendar time (60% of available time), so there is definitely room for improvement.

Inventory is very large at the factory. It would take roughly six days to package the entire WIP inventory.

After analysing the initial situation, I started to analyse the components. This analysis answers my second research question:

2. What types of components flow through the bottleneck? Can some load be taken off the bottleneck through reorganizing or investments? What is the potential effect on throughput?

I analysed the types of components that flow through the bottleneck. This analysis revealed that 14% of the products that are packaged by the bottleneck are single-component products, which do not require mixing at all. Using the average annual throughput rate, this means that 850 hours of the bottleneck's time was used to package goods that do not require mixing. There is also free capacity in the factory to shift the 1-component products to other packaging machines, especially if a third shift is added to one of the machines. Additionally, 18% are 2-component products, which only require limited mixing capabilities. If the factory is unable to shift some of the 1-component products away from the bottleneck, 2-component products can be shifted instead. In fact, this is already done in the factory sometimes.

3. If the bottleneck resource is ever idle, what are the reasons behind that? Can the reasons be divided into different categories?

After analysing the offloading possibilities, I looked to analyse the idle time at the bottleneck: whether there is any and if there is, what are the reasons. This phase combined data analysis with interviews to determine the root causes for idle time.

Looking at the bottleneck statistics, we can see that the bottleneck is idle for almost half of the year. The bottleneck is active for 52% of the year. The largest category for idle time is waiting time, which takes up 22% of the year. Waiting time is further divided into separate reasons for the wait, the biggest of which are component and personnel shortages. On an annual level, component shortages represent roughly 5% of time, while personnel shortages represent roughly 7% of time. Together, they contribute to over half of the waiting time, possibly even more (the data was unfortunately not accurate enough to form a more precise estimate).

The main causes for component shortages are machine- or process-related, either resulting from machine or human error. However, some of the component shortages can be

prevented by smart investments. For example, the factory lacks a modern inventory management system and the components are not tracked in a systematic way. Investing in new IT systems would bring transparency to the process and prevent components from being misplaced.

The main causes for personnel shortages are more easily identified: they are caused by employees taking breaks at the same time and by employees being absent due to sick leave. In theory, the employees are instructed not to take breaks at the same time; however it does not work in practice. Also, it was suggested that employees in the packaging area are on sick leave more often than in other departments.

4. What are the implications of these findings and what actions could be undertaken to improve performance at the bottleneck resource?

What my analysis suggests is that there are two different main issues that affect the throughput of mixed bags: the types of bags packaged by the bottleneck and the utilization rate of the bottleneck. The bottleneck can produce more mixed bags, if one-component products are packaged elsewhere. Likewise, the bottleneck can increase throughput by reducing the idle time in the bottleneck resource.

Reducing idle time might seem simple, however it is not. We need to identify the causes for idle time and address those causes, which impact the idle time the most. Ideally, we would like to implement cheap solutions, however it is not always possible. Together with CandyCo's staff, improvement ideas were generated to decrease idle time. The ideas addressed either component or personnel shortages.

The two best ideas to decrease component shortages were investing in a new IT system and investing in new production machinery. Investing in a new IT system would increase the transparency in the manufacturing process and enable employees to track the components in the factory. Additionally, the IT system would need to integrate the various systems that the factory uses, so that production planning has an overview of what is being produced, where certain components are located, what the expected time of various components to become ready for packaging is, what components are in the WIP inventory and if there are errors somewhere, where are they. Renewing old production machinery would decrease the number of errors in component manufacturing and produce more steady quality.

The two best ideas to reduce personnel shortages were work-time arrangements and staff training. Together, these two methods would ensure that the bottleneck is never idle due to lack of staff. The idea is to organize work in the factory in such a way, that there is always someone available to cover for the packaging machines. Of course, this will require that employees are trained to operate the packaging machines, so that the breaks can be covered.

Together these improvement suggestions could decrease inventories in the factory, which at their current state not only require a lot of space but they tie a lot of capital as well. Additionally, the bottleneck's throughput would be increased and capacity for mixed bag manufacturing would increase, should the factory need extra capacity. Based on current market trends, it can be expected that the demand for mixed bag products will continue to increase in the future.

6.2 Theoretical results and managerial implications

The approach of this Thesis is highly practical as it is a case study. However this does not mean that the study is without theoretical merit. What my case study shows is that the underlying principles and techniques of TOC are still, after 30 years, highly practical and easily applicable in factories nowadays and that these techniques can yield in measurable, concrete improvements without huge investments. Additionally this shows, that TOC-thinking has probably not permeated the Finnish manufacturing landscape as widely as it perhaps should have, given the amount of time the theory has been around. The Thesis also adds to the existing body of work on TOC and complexity in manufacturing by introducing a complex manufacturing system, where control and improvements can be added through the application of TOC-thinking.

For managers, my study outlines the need to determine the bottleneck in a production process, where the concept of bottleneck is applicable, such as a streamlined flow from raw materials or components to end products. Once the bottleneck is determined, careful analysis can reveal space for improvement by simple investments or arrangements. The key is to understand the significance of the bottleneck to the overall throughput of the manufacturing system. Even when a system is complex, like the one I have outlined in this Thesis, focusing on elevating the bottleneck can still yield substantial improvements. A complex system does not always require a complex improvement suggestion. However,

managers should not forget thinking in the long-term and only seek the low-hanging fruit; in CandyCo's case, there is certainly room for investments that would impact the overall performance of not only the bottleneck, but of the entire factory as well.

Combining short-term actions with long-term investments will keep managers focused on both viewpoints. There are undoubtedly improvements yet to be uncovered by simple arrangements, yet small improvements and actions can only get you so far. Managers need to be aware of the possibilities that technology offers to their manufacturing and invest smartly.

6.3 Future research – directions and concrete topics

Future research on similar topics could include studying the pervasiveness of TOC in the Finnish manufacturing environment. Philosophies such as Just-in-time (JIT), Total quality management (TQM) and Lean thinking have certainly made their way into the course books of universities and into the training material of managers, however it seems that TOC is less known, despite its rather intuitive thinking process and techniques.

Similar case studies could also be conducted, with different companies and manufacturing environments, to determine whether the process used in this Thesis is applicable elsewhere and whether TOC suits different types of manufacturing environments.

6.4 Limitations of the study

The limitations of the study are also related to its strengths. While simplifying the analysis may lead to powerful conclusions and suggestions, a simplification always leaves a certain factor of truth outside the analysis. Analysing CandyCo's inventory is actually a much more complicated affair than what was done in the Thesis, since the components cannot simply be packaged in a random order, rather certain bags of candy require certain components and certain bag sizes. Thus, the size of the inventory may need to be quite large to accommodate the components waiting for other components to finish.

Additionally, while using annualized data has its upside in representing the actual average throughput rates over a long period and thus representing the performance during a business year, the manufacturing business of CandyCo is actually cyclical, focusing around certain

festivities such as Christmas and Easter. Thus, free capacity is not constant during the year and the reasons that CandyCo uses the bottleneck for processing one-component products could be that there simply is free capacity for it. However, the idle time analysis does not suffer from similar bias as the component analysis. Furthermore, if mixed-component production is to be increased, offloading should surely remain as an option on the table. Some of the one-component products were packaged at the bottleneck for convenience's sake, employees choosing to use the packaging/mixing resource instead of having to reorganize the packaging arrangements.

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