

İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

**THE THEORY OF CONSTRAINTS AND ITS
APPLICATION IN A MANUFACTURING FIRM**

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Department : Management Engineering

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**KISITLAR TEORİSİ VE BİR ÜRETİM FİRMASINDA
UYGULANMASI**

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FOREWORD

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ABBREVIATIONS

5FS	: Five Focusing Steps
ABC	: Activity Based Costing
AGI	: Avraham Y. Goldratt Institute
APICS	: American Production and Inventory Control Society
CC	: Core Conflict
CCC	: Core Conflict Cloud
CCR	: Capacity-Constrained Resources
CF	: Cash Flow
CI	: Continuous Improvement
CLR	: Categories of Legitimate Reservation
CM	: Constraint Management
CPCM	: Contribution Per Constraint Minute
CPCRM	: Contribution Per Constraint Resource Minute
CPM	: Critical Path Method
CPU	: Contribution Per Unit
CRD	: Conflict Resolution Diagram
CRT	: Current Reality Tree
DBR	: Drum-Buffer-Rope
DE	: Desirable Effects
ECE	: Effect-Cause-Effect
FRT	: Future Reality Tree
GPE	: General Production Expenditure
I	: Inventory
IP	: Integer Programming
IT	: Information Technologies
JIT	: Just-In-Time
LP	: Linear Programming
MRP	: Materials Requirements Planning
NBR	: Negative Branch Reservation
OE	: Operating Expense
OPT	: Optimized Production Timetables
POOGI	: Process Of OnGoing Improvement
PRT	: PreRequisite Tree
QC	: Quality Control
ROI	: Return on Investment
SO	: Strategic Objectives
T	: Throughput

TA	: Throughput Accounting
TCA	: Traditional Cost Accounting System
TO	: Tactical Objectives
TOC	: Theory of Constraints
TP	: Thinking Process
TPS	: Toyota Production System
TQ	: Total Quality
TQM	: Total Quality Management
TT	: Transition Trees
UDE	: UnDesireable Effects
WIP	: Work in Process

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LIST OF SYMBOLS

P_j	: The selling price of product j
p_i	: The unit contribution of product j
c_j	: The cost of materials j
a_{ij}	: The amount of resource i required to produce product j
x_j	: The number of product j produced
b_i	: The maximum amount of resource i available
d_j	: The forecasted market demand for product j
m	: The number of products
n	: The number of resources

THE THEORY OF CONSTRAINTS AND ITS APPLICATION IN A MANUFACTURING FIRM

SUMMARY

The Theory of Constraints is an organizational change method that is focused on profit improvement. The essential concept of TOC is that every organization must have at least one constraint. A constraint is any factor that limits the organization from getting more of whatever it strives for, which is usually profit. For most manufacturing and service organizations the goal of the organization is to make a larger profit now and in the future. Theory of Constraints (TOC), accepts the organization as a whole, not the manufacturing department, or one plant, or one department within the plant. Local optimums are not concerned with.

The Theory of Constraints defines a set of tools that change agents can use to manage constraints, thereby increasing profits. Most businesses can be viewed as a linked set of processes that transform inputs into saleable outputs. TOC conceptually models this system as a chain, and advocates the familiar adage that a "chain is only as strong as its weakest link." Goldratt defines a five-step process that a change agent can use to strengthen the weakest link, or links.

The purpose of the research is to provide and apply a model for product mix and the effect of the results to the profitability of the firm by using Theory of Constraint approach. In this frame, descriptive and exploratory case studies had been made in a ring spun cotton yarn manufacturing firm. In this research the traditional cost accounting system and the throughput accounting system of TOC were compared. For this reason, optimum product mixes determined and the results of the profitabilities compared. It was seen that the maximum profit was of throughput accounting system. To sum up, the firms which are in textile manufacturing business and have similar conditions, could be achieve more profitable product mix solutions by throughput accounting of TOC.

KISITLAR TEORİSİ VE BİR ÜRETİM FİRMASINDA UYGULANMASI

ÖZET

Kısıtlar Teorisi (KT), kâr artırmaya odaklanan bir organizasyonel değişim metodudur. Kısıtlar teorisinin başlıca konsepti, her organizasyonun en az bir adet kısıta sahip olmasıdır. Kısıt, organizasyonun uğruna çabaladığı her ne ise – genellikle kârdır- bunu sınırlayan herhangi bir faktördür. Üretim ve servis organizasyonlarının çoğunluğu için amaç, şimdi ve gelecekte yani sürekli ve artarak daha fazla kâr sağlamaktır. Kısıtlar teorisi, organizasyonları bir bütün olarak ele alır, sadece üretim departmanını ya da sadece tek bir fabrikayı ya da fabrikanın bir departmanını değil. Lokal optimumlarla ilgilenilmez.

Kısıtlar Teorisi, kısıtları yönetip bu sayede kârı artırmaya yarayan araçlar seti tanımlar. Firmalar, girdileri çıktılara çeviren, birbirine bağlanmış süreçler olarak görülebilir. KT, konsept olarak bu sistemi zincir olarak modeller ve bunu “ zincir, en sayıf halkası kadar güçlüdür” teziyle savunur. Goldratt, en zayıf halka ya da halkaları güçlendirmede kullanılacak beş odaklanma adımını tanımlar.

Bu çalışmanın amacı, kısıtlar teorisi yaklaşımını kullanarak ürün karması ve sonuçlarının firma karlılığı üzerindeki etkilerini ortaya koyacak bir model kurabilmek ve uygulayabilmektir. Bu çerçevede, pamuk ipliğinden ring iplik üretimi yapan bir firmada tanımlayıcı ve keşifsel olay çalışmaları yapılmıştır. Bu çalışmada, geleneksel maliyet muhasebesi sistemi ile Kısıtlar teorisinin katkı payı muhasebe sistemi karşılaştırılmıştır. Bu nedenle, optimum ürün karmaları ve bu ürün karmalarının firma kârlılıklarının sonuçları karşılaştırılmıştır. Analizler sonucunda görülmüştür ki, Kısıtlar teorisinin katkı payı muhasebe sistemi maksimum kârı sağlayan sistemdir. Buradan yola çıkılarak, tekstil üretiminde ve benzer koşullardaki firmalar için, kısıtlar teorisinin katkı payı muhasebe sistemi kullanılarak daha kârlı ürün karması çözümlerine ulaşılabilir.

1. INTRODUCTION

Theory of Constraints (TOC), as a management approach, has been around for almost two decades, and its creator, Eliyahu M. Goldratt, has been applying the basic principles even longer than that. Consultants have been expending a lot of effort in helping their clients use TOC to effect real change-quantum improvements-in the performance of their organizations. Visionary people within client organizations have been trying to apply what they have learned about TOC toward the same end. The question is: Why? Interestingly, that basic question - Why? - is at the heart of TOC itself. The thinking process created by Goldratt is designed to answer “why” types of questions. And when the “why” question is posed about an undesirable system outcome using the thinking process, the inevitable answer - whatever that may be - is the system’s core problem, or critical root cause (Caspari and Caspari, 2004).

Two paradigms of business strategy can be identified. The first, known as the cost world, emphasizes the reduction of existing costs as the means to bottom-line improvement. The second, called the throughput world, emphasizes the expansion of throughput as the means to bottom-line improvement (Caspari and Caspari, 2004).

The Theory of Constraints is an organizational change method that is focused on profit improvement. The essential concept of TOC is that every organization must have at least one constraint. A constraint is any factor that limits the organization from getting more of whatever it strives for, which is usually profit (Dettmer, 1997).

In the second part of the thesis, from the literature review, the concept of system constraints, change and The Theory of Constraints (TOC) will be defined in detailed. Throughput Accounting, the TOC tools, Drum-Buffer-Rope and Thinking Process will be explained.

The third part of the thesis will be the case study of the comparison of TOC accounting (Throughput accounting) with traditional cost accounting system in a textile manufacturing firm.

In the fourth part of thesis, the results of the case study and the advantages of the Theory of Constraints and its accounting system throughput accounting will be discussed.

2. THEORY OF CONSTRAINTS

The Theory of Constraints is an organizational change method that is focused on profit improvement. The essential concept of TOC is that every organization must have at least one constraint. A constraint is any factor that limits the organization from getting more of whatever it strives for, which is usually profit. *The Goal* focuses on constraints as bottleneck processes in a job-shop manufacturing organization. However, many non-manufacturing constraints exist, such as market demand, or a sales department's ability to translate market demand into orders (Dettmer, 1997).

The Theory of Constraints defines a set of tools that change agents can use to manage constraints, thereby increasing profits. Most businesses can be viewed as a linked set of processes that transform inputs into saleable outputs. TOC conceptually models this system as a chain, and advocates the familiar adage that a "chain is only as strong as its weakest link." Goldratt defines a five-step process that a change agent can use to strengthen the weakest link, or links. In *The Goal*, Goldratt proves that most organizations have very few true constraints. Since the focus only needs to be on the constraints, implementing TOC can result in substantial improvement without tying up a great deal of resources, with results after three months of effort (Dettmer, 1997).

2.1 The System's Goal

The people create systems to achieve a goal. There is only one goal, no matter what the company. It's simple logic is what it is. Goldratt (2006) says, the people can find the answer with their own mind.

Theory of Constraints (TOC), accepts the organization as a whole, not the manufacturing department, or one plant, or one department within the plant. Local optimums are not concerned with (Goldratt, 2006). The Constraint Management (CM) heuristic does not guarantee optimumity, but in many situations it does return the optimum solution (Qiu et al., 2002). For most manufacturing and service

organizations the goal of the organization is to make a larger profit now and in the future (Siha, 1999).

2.1.1 The Manager and The Goal

The essence of management is recognizing the need for change, then initiating, controlling, and directing it, and solving the problems along the way. Of it were not so, managers would not be needed (Dettmer, 1997).

Everyone is a manager of something in different arenas, perhaps, but a manager nonetheless. In a general sense, the Theory of Constraints (TOC) is about management (Dettmer, 1997).

As said in the, Spencer's Laws of Data:

- Anyone can make a decision, given enough facts
- A good manager can make a decision without enough facts
- A perfect manager can operate in perfect ignorance

Dettmer (1997) claims that one of the hallmarks of effective managers is that they deal less with the present and more with the future. In other words, they concentrate on "fire prevention" rather than "fire fighting". If you are more focused on the present than the future, you will always be in a time lag following changes in your environment-a reactive rather than a proactive mode.

Most of the managers are not running as efficient a plant as they think they are. They are running exactly the opposite. They are running a very in-efficient plant, says Goldratt (2006) in *The Goal*. No manager can hope to succeed without knowing three things (Dettmer, 1997):

- What the ultimate goal is
- Where he or she currently stands in relation to that goal
- The magnitude and direction of the change needed to move from the status quo to where he or she wants to be (the goal).

They determine the difference between what *is* and what *should* be, and they change things to eliminate that deviation (Dettmer, 1997). The goal is not to reduce operational expense by itself. The goal is not to improve one measurement in isolation. The goal is to reduce operational expense and reduce inventory while simultaneously increasing throughput. The goal is, to make money by increasing net

profit, while simultaneously increasing return on investment, and simultaneously increasing cash flow (Goldratt, 2006).

2.1.2 Goal or Necessary Condition

Frequently a system's managers - and perhaps even the owners - have different ideas about the system's goal. In a commercial enterprise, the stockholders (owners) usually consider that the system's goal is "to make more money" (Dettmer, 1997).

The managers in a system might see the goal a little differently. While they acknowledge the need to make money for the stockholders, they also realize that other things like competitive advantage; market share; customer satisfaction; a satisfied, secure workforce; or first-time quality of product or service important too. Factors like these often show up as goals in strategic or operating plans. But are they goals or necessary conditions (Dettmer, 1997)?

Dettmer (1997) emphasized, because of this interdependency, no matter what factor you designate to be the goal, all other related factors become conditions necessary to achieve that goal.

Dettmer (1997) and Goldratt (2006) explains the goal and necessary condition in an example: Your stockholders might decide that "increased profitability" is the company's goal. In this case, cost-effective purchasing, employing good people, high technology, producing products, producing quality products, selling quality products, capturing market share, communications, customer satisfaction might all be necessary conditions that you can not ignore without the risk of not attaining the profitability goal. But you might just as easily consider the goal to be "customer satisfaction" as many quality-oriented companies do these days. In this instance, "profitability" becomes a necessary condition without which you can not satisfy customers. Why? Because unprofitable companies do not stay in business very long, and if they are not in business, they can not very well satisfy customers.

2.1.3 Manufacturing Environment

If the goal is to make money, then an action that moves toward making money is productive and an action that takes away from making money is nonproductive (Goldratt, 2006).

Goldratt (2006) proclaims that **productivity** is meaningless unless you know what your goal is, when you are productive you are accomplishing something in terms of your goal. Productivity is the act of bringing a company closer to its goal. Every action that brings a company closer to its goal is productive. Every action that does not bring a company closer to its goal is not productive.

Goldratt (2006) explains that, most of the time, companies struggle for high **efficiencies** is taking you in the opposite direction of your goal. A plant in which everyone is working all the time is very inefficient. The company which everybody is working nearly all the time can not make money. The only way the companies can create excess inventories is by having excess manpower. The tendency for most managers is to trim capacity wherever they can, so no resource is idle, and everybody has something to work on.

Balanced plant is a plant where the capacity of each and every resource is balanced exactly with demand from the market (Goldratt, 2006).

The focus is on maximizing efficiency on each operation. Unlike MRP-based scheduling that essentially “counts backward” from the end of the production line to determine workstation schedules and material releases, TOC-based scheduling “count backward” from the bottleneck process to determine workstation schedules and material releases, in order to maximize the productivity of the bottleneck process. This approach is commonly termed Drum-Buffer-Rope, or DBR. The aim of TOC is to maximize the productivity of the entire system (Polito et al., 2006).

When capacity is trimmed exactly to marketing demands, no more and no less, throughput goes down, while inventory goes through the roof. And because inventory goes up, the carrying cost of inventory - which is operational expense - goes up. Accordingly it is questionable whether company can even fulfill the intended reduction in its total operational expense, the one measurement expected to improve (Goldratt, 2006).

Dependent event is an event, or a series of events, must take place before another can begin. The subsequent event depends upon the ones prior to it (Goldratt, 2006).

As Goldratt (2006) says: “You can imagine what happens when companies have got dependency running through ten or fifteen operations, each with its own set of fluctuations, just to make one part. A mathematical principle says that in a linear

dependency of two or more variables, the fluctuations of the variables down the line will fluctuate around the maximum deviation established by any preceding variables”.

2.2 The Concept of System Constraints

Goldratt likens systems to chains, or Networks of chains (Dettmer, 1997). The theory of constraints views manufacturing processes/organizations as “chains”, wherein the entire system is only as strong as its weakest link. The purpose of TOC is to identify the weak link (constraint) within an organization and to strengthen this link to the point where it is no longer the limiting factor in determining the strength of the chain (or organization). Expanding on this line of thinking, no matter how strong the chain has become, it will always have at least one link that is not quite as strong as the others. For this reason, TOC can be thought of as a continuous improvement process, because no matter how well an organization performs, there will always be at least one constraint that limits the organization from becoming a little better (Watrous and Pegels, 2005). The chain might have only one “weakest link”. It will fail first at only one point, and that weakest link is the constraint that prevents the chain (systems) from doing any better at achieving its goal (transmission of force) (Dettmer, 1997). The chain will not be stronger unless the weakest link be strengthened. The way of strengthening the chain is to strengthening the weakest link. Consequently, the weakest link is the key controlling the entire system. Weakest link might be called as bottleneck and might be explained by the analogy of an hourglass.

According to the APICS (American Production and Inventory Control Society) Dictionary, a constraint is “any element or factor that prevents a system from achieving a higher level of performance with respect to its goal” (Blackstone and Cox, 2004). While constraints generally take one of three forms: physical (resource capacity less than demand), market (demand less than resource capacity), and policy (formal or informal rules that limit productive capacity of the system); DBR is intended to address market or physical constraints (Watson et al., 2006).

2.2.1 Constraints and Nonconstraints

Goldratt contends that there is only one constraint in a system at any given time. That one constraint limits the output of the entire system. The chain would still create the

weakest link, no matter how strong we made the others. In other words, no efforts on nonconstraints will produce immediate, measurable improvement in system capability (Dettmer, 1997).

Dettmer (1997) explains the strength of the systems: “Now, let us assume we are smart enough to figure out which link is the weakest, and let us say we double the strength. It is not the weakest link anymore. What has happened to the chain? It has become stronger, but is it infinitely stronger? No. Some other link is now the weakest one, and the chain’s capability is now limited by the strength of that link. It is stronger than it was, but still not as strong as it could be. The system is still constrained, but the constraint has migrated to a different component”.

The TOC philosophy essentially states that every firm must have at least one constraint. Goldratt and Cox (1992) define a constraint as any element or factor that limits the system from doing more of what it was designed to accomplish (i.e. achieving its goal). The owner of a system is assumed to establish its goal. The goal of any business entity is to make money now and in the future (Simatupang et al., 2004). Distinguish between two types of resources in a plant. One type is called a bottleneck resource. The other is a non-bottleneck resource. A bottleneck is any resource whose capacity is equal to or less than the demand placed upon it. And a non-bottleneck is any resource whose capacity is greater than the demand placed on it (Goldratt, 2006).

Goldratt (2006) explains the bottleneck as: To increase the capacity of the plant is to increase the capacity of only the bottlenecks. The bottlenecks stay bottlenecks. What we must do is find enough capacity for the bottlenecks to become more equal to demand. On any non-bottleneck machine in your plant, no problem. Because, after all, some percentage of a non-bottleneck’s time should be idle. On a bottleneck, if you lose one of those hours you have lost it forever. You cannot recover it someplace else in the system. Your throughput for the entire plant will be lower by whatever amount the bottleneck produces in that time. And that makes an enormously expensive lunch break.

The nature of a constraint can be either physical or non-physical and its location can be either internal or external. Physical constraints can take the form of raw material shortages, limited capacity resources, limited distribution capacity, and lack of

customer demand. Non-physical constraints include obsolete rules, procedures, measures, training and operating policies that guide the way in which decisions are made. The location of a constraint can be either internal or external. Internal constraints – such as the raw material constraint, the capacity constraint, and the distribution constraint – are located inside the supply chain. External constraints include the market constraint (Simatupang et al., 2004). Different types of constraints are interrelated with each other. Physical constraints are often driven by human behaviour (i.e. habits, decisions, and actions). Besides outdated policies and inappropriate metrics, flawed mental models and past training can be constraints that affect human behaviour (Simatupang et al., 2004). After eliminating internal constraints which keeps the system from doing better in relation to its goal, is now outside the system, but it is a constraint nonetheless. If the company going to attack this constraint, it will need a different set of task skills and knowledge (Dettmer, 1997).

Insufficient demand is a managerial or policy constraint rather than a physical constraint. Policy constraints are generally difficult to identify and evaluate, and frequently require involvement and cooperation across functional areas. Goldratt developed the Thinking Process (TP) methodology to address policy constraints and create breakthrough solutions using common sense, intuitive knowledge and logic (Rahman, 2002).

2.2.2 Relation of Constraints to Continuous Improvement

“There is no such thing as staying the same. You are either striving to make yourself better or allowing yourself to get worse.”

Unknown

Success is inherently a cooperative effort. Most organizations having formal improvement efforts include employees, usually in teams, in the process (Dettmer, 1997). Goldratt has developed the approach to continuous improvement called the “Theory of Constraints” (Dettmer, 1997). One of the newer and lesser-known OM (Operations Management) concepts that is finding increasing acceptance is the TOC (Polito et al., 2006).

For many organizations, projects are “what we do for a living”. Projects are their business. In such environments, changing how people manage projects is tantamount

to changing the basic fabric of the business. Clearly, one must approach such change with great care. The right people must be brought into the picture at the right time, in just the right way. The process must move slowly enough to permit identification of essential changes, yet fast enough that it does not lose the momentum that is necessary to sustain continued progress (Jacob, 2001).

2.3 The Concept of Theory of Constraints

The Theory of Constraints (TOC) is a relatively new managerial philosophy that has been steadily evolving since the early 1980s. This systems-based approach to management, primarily credited to Eliyahu M. Goldratt, seeks to understand the underlying cause-effect relationships that are responsible for an organization's performance. Goldratt has documented his conceptual framework, ideas, and illustrated their applications through several books (Reid, 2007).

As a systemic management philosophy, TOC is based on three interrelated premises (Reid, 2007):

- Every system has a goal and a set of necessary conditions that must be satisfied if its goal is to be achieved;
- The overall system's performance is more than just the sum of its component performances; and
- Very few factors or constraints, often only one, limit a system's performance at any given time.

2.3.1 TOC Development

Over the last four decades implementation of operations management principles and strategies, such as materials requirements planning (MRPI and MRPII) (Orlicky, 1975), just-in-time (JIT) (Monden, 1981), total quality management (TQM) (Deming, 1986; Juran, 1992), Toyota production system (TPS) (Ohno, 1984), lean thinking (Womack and Jones, 1996), six sigma (Smith, 1986) and theory of constraints (TOC) (Goldratt, 1988) have helped companies to reduce manufacturing costs as much as practically possible (Rahman, 2002). Among both practitioners and academicians alike, there has been much discussion about their similarities and differences along with their relative applicability in various types of organizations. TQM is often implemented using the Deming plan-do-check-act cycle and uses many of the data summarization and team facilitation Total Quality (TQ) tools for

describing and analyzing problems that are embedded within organizational processes. Both JIT and TPS are historical antecedents to TQM that were developed and extensively used for improving processes in Japan prior to arriving in the West. With few additions, this same tool set is used to implement a new five-step structured process variability reduction effort under the auspices of Six Sigma. Moreover, many of these same improvement tools are also used in Lean Thinking initiatives that acknowledge its historical links to TPS and seek to improve the entire system's overall performance. Although TOC is also systemically-oriented, it has a generic set of logic tools, known as the Thinking Process (TP), that help a manager identify the source of an organization's problems, create improvement strategies, and implement desired changes (Reid and Cormier, 2003). In short, the data-driven and team-centered initiatives such as TQM, JIT, TPS, and Six Sigma are primarily focused on improving work-performing processes in organizations. They are most effective when the goal of the process being improved is aligned with the goal of the organization as a whole. While not rejecting data collection and summarization, the system-based improvement paradigms associated with Lean and TOC do not require a concerted effort to gather and analyze it formally. Instead, they require a healthy intuition about and keen understanding of the relationships between and among study system activities and processes. Whereas Lean seeks to reduce costs through the minimization of waste and non-value-added in every system activity or process, TOC strives to better manage the single activity or process that constrains the system's throughput (Reid and Cormier, 2003). Moreover, the theory of constraints (TOC) provides a suitable framework for maintenance management in modern manufacturing environments. TOC focuses on capacity-constrained resources (CCR) as the machines/operations which determine manufacturing system performance. Having determined the CCR, via linear programming for example manufacturing system management is centred on the CCR (Ribeiro et al., 2005).

The problem is to create a schedule that uses the capacity during the periods in the planning horizon to meet demand while minimizing work in process (WIP) inventory. This differs from the traditional discrete lot-sizing and scheduling problems because it allows more than one item to be produced in any period if capacity constraints are not violated (Qiu et al., 2002).

The conventional view of constraints in the financial management literature is that they are determinants of short-run tactical operations in a decoupled environment. That was as the following quotations reveal, it is still widely held today (Caspari and Caspari, 2004):

“The assumptions of TOC are an excellent approximation of reality for the problem TOC has been designed to solve: short-term product mix and scheduling of bottleneck resources.”

This short-run view of usefulness of constraints is no longer appropriate, however. The constraint theory, evolving over the last two decades, has expanded beyond a bottleneck production scheduling system into a comprehensive management philosophy (Caspari and Caspari, 2004).

2.3.2 TOC Evolution

TOC is an overall management philosophy that recognizes constraint on any system restricts the maximum performance level that the system can obtain in relation to its goal. For most manufacturing and service organizations the goal of the organization is to make a larger profit now and in the future (Siha, 1999).

TOC has gained much of its notoriety through Goldratt’s initial business novel, *The Goal* (Goldratt and Cox, 1984), a realistic, yet fictionalized, story in which many of the TOC concepts are applied to rescue a medium-sized manufacturer from being shutdown by its corporate management (Reid and Cormier, 2003).

Developed by Goldratt in the mid-1980s, TOC evolved from the Optimized Production Timetables (OPT) system (Goldratt, 1980) and was later known under the commercial name of Optimized Production Technology (OPT). As part of a marketing tool for the OPT system, Goldratt illustrated the concepts of OPT in the form of a novel, *The Goal* (Goldratt and Cox, 1984), in which the theory is gradually unravelled through the context of an everyday production situation. A second book, titled *The Race* (Goldratt and Fox, 1986), was written to overcome difficulties encountered in the implementations and, gradually, the focus of the concept has moved from the production floor to encompass all aspects of business. By 1987, the overall concept became known as TOC, which Goldratt viewed as “an overall theory for running an organisation” (Rahman, 2002).

The TOC philosophy could be applied to every day operations decisions as well as to continuous improvement effort. The TOC consists of two main branches; logistics (every day operations) and continuous improvement (Siha, 1999). The TOC comprises a set of three separate but interrelated areas – namely, logistics, performance measurement, and logical thinking. The TOC applications to logistics include the drum-buffer-robe scheduling method, buffer management, and the VAT analysis. Measurements are required to determine whether or not the system is accomplishing its goal of making money. Performance measurement includes operating measures (i.e. throughput, inventory, operating expenses) and local performance measures (i.e. throughput-dollar-days and inventory-dollar-days). Logical thinking comprises the five-step-focusing process and the thinking process (Simatupang et al., 2004).

To clearly focus on the development of principal TOC concepts, Watson et al. (2006) have segmented the evolution of TOC into five eras, Figure 2.1:

1. The Optimized Production Technology Era – the secret algorithm.
2. The Goal Era – articulating drum-buffer-robe scheduling;
3. The Haystack Syndrome Era – articulating the TOC measures.
4. The It's Not Luck Era – thinking processes applied to various topics.
5. The Critical Chain Era – TOC project management.

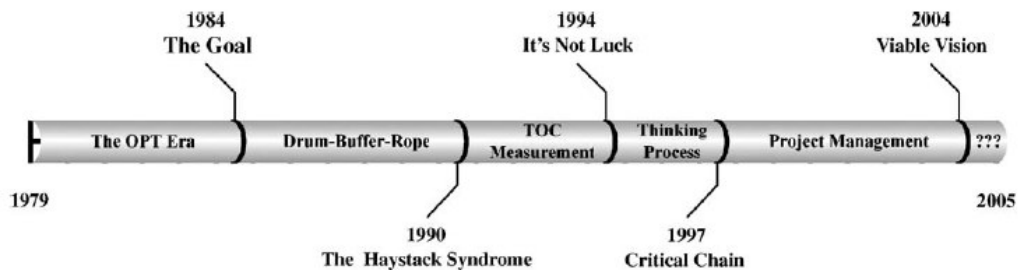


Figure 2. 1: Timeline of Major Eras In The Development of TOC

2.3.2.1 Era 1: Optimized Production Technology

The distinguishing characteristic of OPT/TOC is that the operation needs some form of bottleneck around which to focus its efficiencies. This bottleneck usually takes the form of some type of machine with limited capacity. Driving this bottleneck to efficiency optimizes the usage of the bottleneck which, according to OPT philosophy

(but not satisfactorily proven), optimizes the throughput and profitability of the entire plant (Plenert, 1988).

Therefore, workers would sometimes ignore the schedule and produce parts for inventory in an attempt to stay busy and avoid unfavorable performance appraisals. These actions created unsynchronized material flows through the plant, scrambling the schedule and endangering the success of OPT itself. To combat this behavior, Goldratt decided to educate managers and workers addressing first the fallacy of efficiency as the prime measure of worker productivity. To compel activation of non-constraint resources at 100% of their capacity does not increase output, it only serves to create excess inventory (Watson et al., 2006).

2.3.2.2 Era 2: The Goal

Failing to elicit a response through presentations at industry meetings, Goldratt changed tactics. In 1984, he and Jeff Cox wrote *The Goal*, a manufacturing novel in which the protagonist, Alex Rogo, saves his plant with the help of some pointed questions by his mentor, Jonah. *The Goal* was written largely to educate workers at facilities employing OPT in an effort to have them follow OPT schedules; however, it became a business best seller with numerous companies attempting to implement the concepts found in the book. *The Goal* outlines the Five Focusing Steps (5FS), the process by which TOC concepts are implemented. The 5FS have evolved into what is now called the Process Of OnGoing Improvement (POOGI), an amalgamation of the Five Focusing Steps and the two prerequisites for implementation. The first prerequisite for implementation is to define the system under investigation and identify its purpose. Having defined the purpose of the system, the second prerequisite is to define measurements that align the system to that purpose. TOC systems produce greater numbers of product while reducing inventory, manufacturing lead time, and the standard deviation of cycle time (Watson et al., 2006).

2.3.2.3 Era 3: The Haystack Syndrome

Goldratt proclaimed that “cost accounting is public enemy number one to productivity”. According to Goldratt, cost accounting principles when applied to local performance measurement, product cost, and capital investment decisions provide misleading or incorrect information to decision makers, which may cause

implementation of policies or practices that are incongruent with company goals (Watson et al., 2006).

Watson et al. (2006) quote by Smith (2000) that “the theory behind financial accounting is valid for the purpose of reporting past activities; however, the actions necessary to maximize throughput and cash flow now and in the future are not the same as minimizing local unit cost and maximizing short-run reported net income”.

The overriding goal in a TOC system is to make money now and in the future. In order to ascertain whether an organization is obtaining that goal, three global performance measures are utilized: Net Profit (NP), Return on Investment (ROI), and Cash Flow (CF). Goldratt and Cox introduce three plant level performance measurements: throughput (T), inventory (I), and operating expense (OE) (Watson et al., 2006).

The first and perhaps most important difference is based on a philosophical difference between TOC and traditional accounting. While TOC considers cost reduction important, the focus is on increasing throughput; therefore, OE in TOC plants is not stressed to the extent that would be found in a traditional environment. Second, TA (Throughput Accounting) is conservative in terms of recognizing throughput; revenue is recognized only when a sale to the consumer, not a downstream member of the supply chain, has taken place. The most important TA concept is contribution per constraint minute (CPCM) (Watson et al., 2006).

The PQ problem addresses cost accounting's failure to identify the disproportionate impact of the constraint by calculating the opportunity cost of production of a particular product at the constraint, providing a reliable measure for exploitation of the constrained resource. The widest application of PQ, and CPCM, is to the make-or-buy decision; however, it has also been used to (1) determine retail product mix based on opportunity cost of limited shelf space, (2) identify strategic linkages between the operations and purchasing functions, (3) direct preventative maintenance efforts, and (4) prioritize set up time improvement efforts. Showing that throughput accounting consistently produces optimum decisions while traditional cost accounting, direct costing, and activity based costing generally produce suboptimum decisions (Watson et al., 2006).

2.3.2.4 Era 4: It's Not Luck

Watson et al. (2006) proclaimed that Goldratt, in keeping with his preference for the Socratic Method and directed self discovery, rather it presents a roadmap for discovering novel solutions to complex unstructured problems: the Thinking Processes (TP). While The Goal clearly identifies management policies as a significant source of potential constraints, most academicians believed TOC to be synonymous with drum-buffer-rope.

2.3.2.5 Era 5: Critical Chain

Watson et al. (2006) explains that “At the 1990 International Jonah Conference, a method for scheduling and controlling projects based on TOC logic, critical chain project management (CCPM), was introduced. The logic of CCPM is best explained in Newbold’s Project Management in the Fast Lane. At its most basic, CCPM is the application of the Five Focusing Steps to project management, employing buffers at critical control points to leverage greater project performance by protecting against and proactively managing task completion time variation. CCPM is similar to critical path project management; however, three major differences exist: the method of assigning activity times, the use of buffers, and the elimination of resource conflicts”.

To insure that non-critical activities do not impact the start of critical chain tasks, “feeding” buffers are scheduled where the non-critical and critical activities converge. Based on infinite capacity logic, traditional project management techniques such as critical path method (CPM) do not consider resource conflicts. Thus it is likely that CPM schedules contain at least one resource scheduled to perform two different activities simultaneously rendering the project schedule infeasible. CCPM protects against this problem by using a Gantt chart approach to avoid and resolve resource conflicts. The effect of this procedure is to create a dynamic critical path through the project, allowing the critical chain to jump between linear project paths to reflect resource contention. In practice, this means that the critical chain reflects not only the longest aggregate project completion time, but also the completion time considering resource contention. Results achieved with CCPM are impressive; Leach describing CCPM successes in the information technology sector states that “companies such as Texas Instruments, Lucent Technologies, Honeywell and Harris Semiconductor complete projects in one half or less the time

of previous or concurrent similar projects, or as compared to industry standards’’ (Watson et al., 2006).

2.4 Change and The Theory of Constraints

“It is not necessary to change; survival is not mandatory.”

W.Edwards Deming

Goldratt’s Theory of Constraints is essentially about change. Applying its principles and tools answers the three basic questions (Table 2.1) about change that every manager needs to know: These are system-level, not process-level questions (Dettmer, 1997).

Table 2.1: Thinking Process Tools and Their Roles

Generic questions	Purpose	TP tools
What to change?	Identify core problems	Current reality tree
What to change to?	Develop simple, practical solutions	Evaporative cloud
How to cause the change?	Implement solutions	Future reality tree Prerequisite tree Transition tree

Rather than reacting to external change, or being subjected to random internal change, many organizations have concluded that a process of on-going improvement is an absolute necessity. For an organization to have a process of on-going improvement, certain basic questions need to be answered faster and more effectively. Those fundamental questions are (Burton-Houle, 2001):

- What to change? (Where is the constraint?)
- What to change to? (What should we do with the constraint?)
- How to cause the change? (How do we implement the change?) (Dettmer, 1997).

2.4.1 What to Change?

From a list of observable symptoms, cause-and effect is used to identify the underlying common cause, the core problem, for all of the symptoms. In organizations, however, the core problem is inevitably an unresolved conflict that keeps the organization trapped and/or distracted in a constant tug-of-war

(management versus market, short term versus long term, centralize versus decentralize, process versus results). This conflict is called a Core Conflict (Burton-Houle, 2001).

Burton-Houle (2001) arranges in order the TOC Processes:

Identify the Core Conflict (CC)

Causing the symptoms or UnDesireable Effects (UDEs) of the chosen subject using the *Three-Cloud Process* (Burton-Houle, 2001).

Build a Current Reality Tree (CRT)

CRT validates the identification of the Core Conflict, helps us understand the existing cause-and-effect relationships of the subject and identifies the conspiring formal and informal policies, measurements and behaviors that support the existence of the UDEs. The TOC Processes Core Conflict Cloud (CCC) and CRT, related to What to Change question is shown in Figure 2.2 (Burton-Houle, 2001).

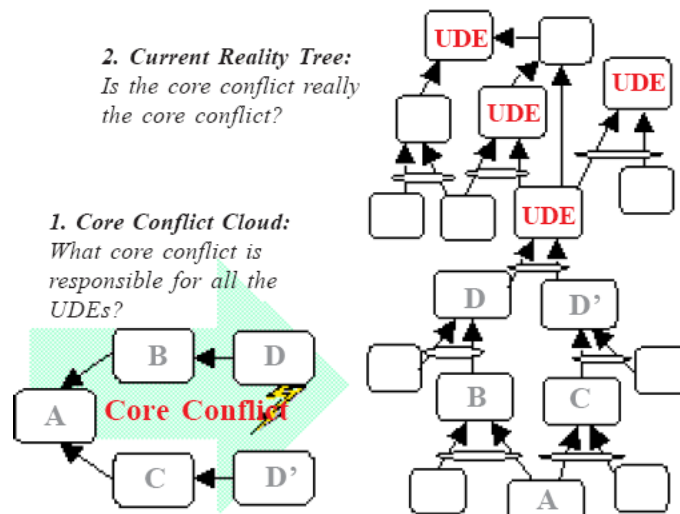


Figure 2.2: What to Change Application Tools

2.4.2 To What to Change?

The strategy must also include the changes that must be made alongside the solution to the Core Conflict to ensure that the solution works and that the organization is restored to its “best possible health.” Respectively, these are often the changes to the policies, measurements and behaviors identified in *What to Change?* as well as the organization’s strategic objectives. Lastly, the strategy is not complete until all

potential negative side-effects of the strategy have been identified (Burton-Houle, 2001).

Identify Core Conflict

Identify and break the assumptions that allow the *Core Conflict* to persist (Burton-Houle, 2001).

Construct a Future Reality Tree (FRT)

FRT lays out the complete solution/strategy that (Burton-Houle, 2001):

- Resolves all of the UDEs by making their opposites, the Desirable Effects (DE), exist
- Ensures alignment with the Strategic Objectives (SO) of the bigger system that the subject is a part
- Ensures that no new negative side effects (Negative Branches) will occur from implementing the solution/strategy
- Identifies what changes in the culture (formal and informal policies, measurements and procedures) of the system and/or sub-system must be made to ensure the symptoms are resolved
- Leverages the existing TOC applications that are needed to make the solution/ strategy work
- Quantifies the “bottom line” value of achieving those DEs and SOs. The TOC Processes CC and FRT, related to “to What to Change” question is shown in Figure 2.3 (Burton-Houle, 2001).

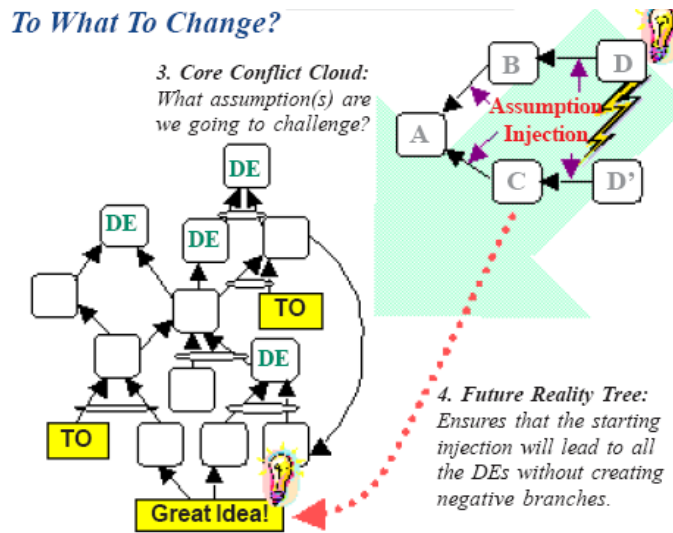


Figure 2.3: to What to Change Application Tools

2.4.3 How to Cause a Change?

A plan for successfully implementing the strategy is created, including what actions must be taken, by whom and when. Because resistance to change can block even the most perfectly laid strategies and plans, building active consensus and collaboration, or buy-in is crucial (Burton-Houle, 2001).

Build a Tactical Objectives (TO) Map

TO that charts the overall course for getting from the current reality to the future reality, where the solution/strategy is fully implemented (Burton-Houle, 2001).

Create detailed task interdependency diagram, using Transition Trees (TTs)

Create TT when necessary to flesh out crucial actions. The TOC Processes TT and PreRequisite Tree (PRT), related to “to What to Change” question is shown in Figure 2.4 (Burton-Houle, 2001).

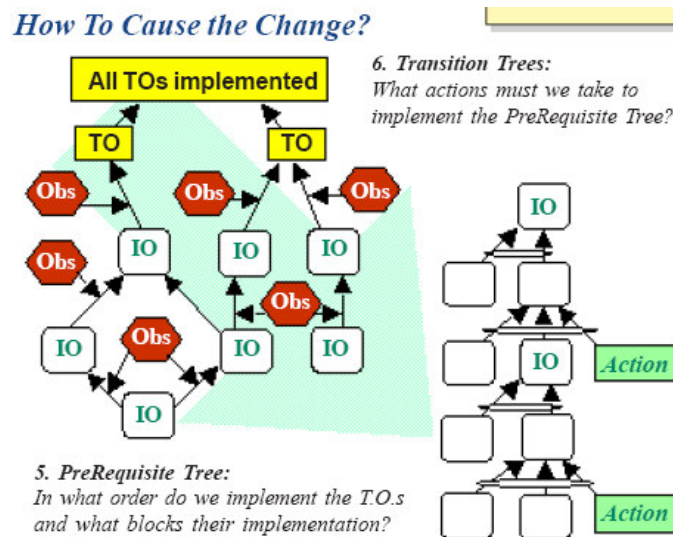


Figure 2.4: How to Cause the Change Application Tools

2.4.4 Overcoming Resistance To Change (Burton-Houle, 2001):

- Is the right problem being addressed - mine?
- Is the general direction that the solution is heading a good one?
- Will the solution really work to solve the problems and what is in it for me?
- What could go wrong? Who might get hurt?
- How the check are we going to implement this thing?

- Are we really up to this? Do we have the leadership and the commitment to pull this change off successfully?

2.5 Systems Thinking and TOC

Goldratt (2006) says in his novel *The Goal*: “We should not be looking at each local area and trying to trim it. We should be trying to optimize the whole system. Some resources have to have more capacity than others. The ones at the end of the line should have more than the ones at the beginning, sometimes a lot more”.

2.5.1 TOC Principles

Theory of Constraints has some principles as being a theory to improve systems. Dettmer (2006) puts in order the most important principles in the aspect of systems thinking:

- Systems thinking is preferable to analytical thinking in managing change and solving problems.
- An optimum system solution deteriorates over time as the system's environment changes. A process of ongoing improvement is required to update and maintain the effectiveness of a solution.
- If a system is performing as well as it can, not more than one of its component parts will be. If all parts are performing as well as they can, the system as a whole will not be. The system optimum is not the sum of the local optimum.
- Systems are analagous to chains. Each system has a “weakest link” (constraint) that ultimately limits the success of the entire system.
- Strengthening any link in a chain other than the weakest one does nothing to improve the strength of the whole chain.
- Knowing what to change requires a through understanding of the system's current reality, its goal, and the magnitude and direction of the difference between the two.
- Most of the undesirable effects within a system are caused by a few core problems.
- Core problems are almost never superficially apparent. They manifest themselves through a number of undesirable effects (UDEs) linked by a network of cause and effect.
- Elimination of individual UDEs gives a false sense of security while ignoring the underlying core problem. Solution that do this are likely to be short-lived. Solution of a core problem simultaneously eliminates all resulting UDEs.

- Core problems are usually perpetuated by a hidden or underlying conflict. Solution of core problems requires challenging the assumptions underlying the conflict and invalidating at least one.
- System constraints can be either physical or policy. Physical constraints are relatively easy to identify and simple to eliminate. Policy constraints are usually more difficult to identify and eliminate, but removing them normally results in a larger degree of system improvement than the elimination of a physical constraint.
- Inertia is the worst enemy of a process of ongoing improvement. Solutions tend to assume a mass of their own that resists further change.
- Ideas are not solutions.

2.5.2 Undesirable Effects and Core Problems

Dettmer (1997) explains that “Nearly all of what we see in a system that we do not like is not problems, but indicators. They are the resultant effects of underlying causes. Treating an undesirable effect is like putting a bandage on an infected wound: It does nothing about the underlying infection. So its remedial benefit is only temporary. Eventually the indication resurfaces because the underlying problem causing the indication never really goes away. Eliminating undesirable effects gives a false sense of security. Identifying and eliminating the core problem not only eliminates all the undesirable effects that issue from it, but it prevents them from returning”.

The TOC precept is to identify and focus on bottlenecks in any operation because they are the source of interference in any attempt at improving productivity and throughput. By eliminating the bottlenecks in any operation, substantial improvements will therefore follow automatically. So the relatively simple approach of TOC is to identify the bottleneck and then take whatever action is necessary to remove that bottleneck (Watrous and Pegels, 2005).

Mostly, internal bottlenecks are not maintaining a flow sufficient to meet demand and make money. In this case, more capacity should be found. If a plant has excess capacity and if the source work to the maximum, there will be excess inventory. This time, there will no excess work-in-process, there will excess finished goods. The constraint here is not in production. The constraint is marketing's ability to sell (Goldratt, 2006).

Goldratt (2006) claims that the level of utilization of a non-bottleneck is not determined by its own potential, but by some other constraint in the system.

Activating a non-bottleneck to its maximum is an act of maximum stupidity. We must not seek to optimize every resource in the system. A system of local optimums is not an optimum system at all; it is a very inefficient system. The numbers are meaningless unless they are based upon the constraints of the system. With enough raw materials, you can keep one worker busy from now until retirement. But should you do it? Not if you want to make money.

The capacity of the plant is equal to the capacity of its bottlenecks. Whatever the bottlenecks produce in an hour is the equivalent of what the plant produces in an hour. Due to this reason, an hour lost at a bottleneck is an hour lost for the entire system. The true cost is the cost of an hour of the entire system (Goldratt, 2006).

2.5.3 Solution Deterioration

Dettmer (1997) quotes from Goldratt “Yesterday’s solution becomes today’s historical curiosity”.

A principal tenet of TOC is that the production capacity and availability of a CCR (Capacity Constraint Resource) should be maximised. This may be achieved by a number of actions such as setup reduction, maintenance planning, and insertion of a buffer between the CCR and the predecessor machine/operation (Ribeiro et al., 2005).

Qui (2002) explains if a product is moved to an alternate machine, some slack capacity on the machine to which it was originally assigned will result. Here we have to be careful because a product assigned to an alternate machine may take longer to produce and that may more than offset the “savings” in reduced setup costs. Next, we must determine whether there is any unsatisfied demand that can be filled by increasing the production time of that product because no additional setup is required. All other products should be considered in the descending order of the T day ratio.

Burton-Houle (2001) presents a process of a healthcare analogy for solution:

a. Diagnosis: a list of observable symptoms and uses cause and effect to seek out the underlying common cause for all of them, the “disease” or core problem.

b. Design of a Treatment Plan: a treatment plan is developed that first and foremost treats the disease (e.g., surgery), but also suggests what other things must be done alongside that “cure” to ensure the treatment will work.

c. Execution of the Treatment Plan: a plan is developed for how to implement the treatment.

2.6 The Process of Managing The Constraints, The Five Focusing Steps

This is the beginning of the prescriptive part of the Theory of Constraints. Goldratt has developed five sequential steps to concentrate improvement efforts on the component that is capable of producing the most positive impact on the system (Dettmer, 1997). Goldratt and Cox developed a heuristic consisting of five steps to manage capacity and schedule a manufacturing facility (Qiu et al., 2002).

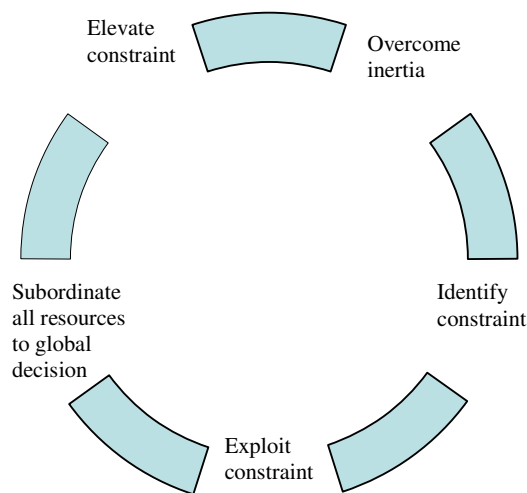


Figure 2.5: The Process of On-going Improvement

2.6.1 Identify the System Constraint

What part of the system constitutes the weakest link (Dettmer, 1997)? These may be physical (e.g. materials, machines, people, demand level) or managerial. It is important to identify these constraints and also necessary to prioritise them according to their impact on the goal(s) of the organization (Rahman, 2002). A system can not be maintained at maximum performance unless we know what constrains the system so we can design control mechanisms appropriate to the constraints (Siha, 1999).

2.6.2 Decide How to Exploit the Constraint

By "exploit," Goldratt means we should wring every bit of capability out of the constraining component as it currently exists. In other words, "What can we do to get the most out of this constraint without committing to potentially expensive changes or upgrades?" (Dettmer, 1997). We must make the best possible use of the constraints. For example, physical constraints within the system must be scheduled to produce the most profitable products (Siha, 1999). A managerial constraint should not be exploited but should be eliminated and replaced with a policy which will support increased throughput (Rahman, 2002).

2.6.3 Subordinate Everything Else

Dettmer (1997) explains this step as "Once the constraint is identified (Step 1) and we have decided what to do about it (Step 2), we adjust the rest of the system to a "setting" that will enable the constraint to operate at maximum effectiveness. We may have to "de-tune" some parts of the system, while "revving up" others. Once we have done this, we must evaluate the results of our actions: Is the constraint still constraining the system's performance? If not, we have eliminated the constraint, and we skip ahead to Step 5. If it is, we still have a constraint and we continue with Step 4".

2.6.4 Elevate the Constraint

If a company is doing this, it means that Steps 2 and 3 were not sufficient to eliminate the constraint and the company have to do something more. It is not until this step that the company entertain the idea of major changes to the existing system, reorganization, divestiture, capital improvements, or other substantial system modifications. This step can involve considerable investment in time, energy, money, or other resources, so the company must be sure it is not able to break the constraint in the first three steps. "Elevating" the constraint means that the company takes whatever action is required to eliminate the constraint. When this step is completed the constraint is broken (Dettmer, 1997). As the performance of the constraints improves, the potential of nonconstraint resources can be better realised, leading to improvements in overall system performance. Eventually the system will encounter a new constraint (Rahman, 2002).

2.6.5 Go Back to Step 1, But Beware of “Inertia”

If, at Steps 3 or 4, a constraint is broken, we must go back to Step 1 and begin the cycle again, looking for the next thing constraining our performance. The caution about inertia reminds us that we must not become complacent; the cycle never ends. We keep on looking for constraints, and we keep breaking them. And we never forget that because of interdependency and variation, each subsequent change we make to our system will have new effects on those constraints we have already broken. We may have to revisit and update them, too (Dettmer, 1997).

The implementation of the five focusing steps to a typical production environment can yield rapid and substantial improvements in operations as well as profits (Rahman, 2002).

Dettmer (1997) proclaims and summarizes that The Five Focusing Steps have a direct relationship with the three management questions pertaining to change: what to change, what to change to, and how to cause change. They tell us how to answer those questions. To determine what to change, we look for the constraint. To determine what to change to, we decide how to exploit the constraint and subordinate the rest of the system to that decision. If that does not do the complete job, we elevate the constraint. The subordinate and elevate steps also answer the question "how to cause the change".

2.7 TOC Accounting

The TOC process emphasizes the need to maximize throughput and focuses on identifying and managing the constraints that can reduce the amount of throughput a company is able to achieve. Using the TOC process, the objective of management is reaching a point where the system's constraint lies outside the production arena. An example of such a situation occurs when all orders are completed on time and there is a shortage of incoming orders. In this case, the system's constraint is in the sales area rather than in the production area (Watrous and Pegels, 2005).

Goldratt(2006) developed measurements which express the goal of making money perfectly. They also permit to develop operational rules for running plant. Their names are throughput, inventory and operational expense:

Throughput (T): The rate at which the entire system generates money through sales. Another way of looking at Throughput is “all the money coming into the system” (Dettmer, 1997).

Throughput (T) per pound is calculated by taking the difference between the selling price and the raw materials cost per pound of product. If we multiply by the production rate in pounds per day we are able to determine the throughput per day to produce the product (Qiu et al., 2002).

Inventory (I): Inventory is all the money the system invests in things it intends to sell, or all the money tied up within the system. Obviously, raw materials, unfinished goods, purchased parts, and other “hard” items intended for sale to a customer spring to mind. But Inventory also includes the investment the organization makes in equipment and facilities (Dettmer, 1997).

Operating Expense (OE): All the money the system spends turning Inventory into Throughput. In other words, it is the money going out of the system. Direct labor, utilities, consumable supplies, and the like are examples of Operating Expense, because it constitutes the value of a fixed asset expended or “used up”, in turning Inventory into Throughput (Dettmer, 1997).

Dettmer (1997) emphasizes, if the same sales revenues can be produced with less Inventory and spending less on Operating Expense, the money will increase coming into the company (net profit).

Dettmer (1997) asks to improve your system, what would you, as a manager, try to do? Obviously, increase Throughput, while decreasing Inventory and Operating Expense. As you decide what action to take, ask yourself these questions:

- Will it increase Throughput? If so, how?
- Will it decrease Inventory? If so, how?
- Will it decrease Operating Expense? If so, how?

Of the answer to these questions is “yes”, go ahead with your decision, confident that the overall system will benefit from it. If you are not sure, perhaps you had better reevaluate. The bottom line is that if it does not result in increased Throughput, you are wasting your time-and probably your money (Dettmer, 1997).

Which is Most Important:T, I, or OE?

As can be seen in the Figure 2.5, note that the theoretical limit in reducing OE and I is zero. Obviously, a system can not produce many outputs with no Inventory and no Operating Expense, so the practical limits of I and OE are somewhat above zero. Theoretically, there is no upper limit to how high the company can increase T, but from a practical standpoint there is a limit to the size of the market. However, it is highly probable that the potential for increasing T is always likely to be much higher than the potential for decreasing I and OE. Accordingly, it would make sense to expend as much effort as possible on activities that tend to increase T primarily, and make reduction of I and OE a secondary priorities. But what is the normal priority of most companies in a competitive environment? Cut costs (Operating Expense) first. Then, maybe, reduce Inventory (usually without a lot of consideration for how far it can be reduced without hurting Throughput). And finally, try to increase Throughput directly (Dettmer, 1997).

The key dilemma facing many manufacturing operations is the apparent trade-off between manufacturing throughput and production lead times. To obtain and maintain high throughput, it is thought that high levels of work in progress (WIP) are necessary to avoid starvation of machines. Thus all machines are fully utilised and throughput is at a maximum. Organizations should work to increase overall system T while simultaneously reducing I and OE (Siha, 1999).

2.8 TOC Tools, Philosophy and Organisations

Continuous improvement is the key factor to understand TOC philosophy. The tools which Goldratt has developed are being very effective tools with Thinking Process. The concepts continuous improvement, service organisations, supply chain are easily understood with drum-buffer-rope approach.

2.8.1 Tools

Being comprehensive in scope, the change sequence typically involves the use of the six logic tools and the "rules of logic" that govern their construction to effect system change. These six TOC TP tools or logic diagrams are the current reality tree (CRT), evaporating or conflict cloud (CC), future reality tree (FRT), negative branch reservation (NBR), prerequisite tree (PRT), and the transition tree (TT). The rules are

called the Categories of Legitimate Reservation (Dettmer, 1997; Reid and Cormier, 2003).

2.8.1.1 The Current Reality Tree

The Current Reality Tree (CRT) is a problem-analysis tool. It helps us examine the cause-and-effect logic behind our current situation. The CRT begins with the undesirable effects we see around us and helps us work back to identify a few root causes, or a single core problem, that originate all the undesirable effects we are experiencing. The core problem is usually the constraint we are trying to identify in the Five Focusing Steps. The CRT tells us what to change the one simplest change to make that will have the greatest positive effect on our system (Dettmer, 1997).

The first major step in the Thinking Process is the construction of a CRT. The CRT is, in essence, a causal flowchart of the current system state as described by the facts of the case. The CRT is constructed by first identifying the Undesirable Effects (UDEs) noted in the case and posting them near the top of the diagram. Next, those facts of the case that appear to immediately cause the UDEs are posted to the diagram and connected to the appropriate UDEs with arrows, thereby illustrating the causal relationship. Next, those causes are looked upon as effects, and then their causes are extracted from the facts of the cases and subsequently diagrammed. This process is repeated until the CRT converges upon a root cause that, once identified, can be further acted upon by the decision-makers (Polito et al., 2006). The CRT identifies cause-and-effect relationships in a system. It is constructed from the top-down by identifying undesirable effects (UDEs), and depicting probable causes for those effects (effect-cause). It is, however, read from bottom-up (cause-effect), when the construction is complete (Rahman, 2002). The CRT is constructed with “sufficient cause” reasoning and is used to establish a stream of cause and effect logical relationships that link the core conflict with the UDEs. Sufficient cause logic uses *if ... , then ...* relationships in one of two forms: *if ... , then ...* or *if ... , and if ... , then ...* (Reid and Cormier, 2003).

The CRT is used to logically validate that the core conflict revealed in the CCC is the primary cause of those aspects of our existing situation that are deemed detrimental to meeting the stated goal(s). The CCC is used as the base for the CRT and rational

connections were derived to logically link the entities in the core conflict with the various UDEs (Reid and Cormier, 2003).

2.8.1.2 The Conflict Resolution Diagram: The “Evaporating Cloud”

Dettmer(1997) explained that Goldratt designed the Conflict Resolution Diagram (CRD) (which he referred to as an "evaporating cloud") to resolve hidden conflicts that usually perpetuate chronic problems. The CRD is predicated on the idea that most core problems exist because some underlying tug-of-war, or conflict. Prevents straightforward solution of the problem: otherwise, the problem would have been solved long ago. The CRD can also be a "creative engine," an idea generator that allows us to invent new, "breakthrough" solutions to such nagging problems. Consequently, the CRD answers the first part of the question, what to change to.

Once the root cause has been identified through the Current Reality Tree, the next major step in The Thinking Processes is the construction of an “Evaporating Cloud” diagram. The Evaporating Cloud diagram is, in essence, a flowcharting of the faulty and/or incomplete logic regarding the root cause. The Evaporating Cloud is constructed by the first posting the identified root cause at the left of the diagram and is labeled as the system objective. Next, the two key opposing elements that are required to meet the objective are posted to the right of each of the two requirements is placed the prerequisite condition for the requirement; each is also connected in the diagram by a causal arrow (Polito et al., 2006). The pattern of *in order to ... , we must do ... , because ...* is the prevalent format for the logical thought process involved in creating CCs (Reid and Cormier, 2003).

A major premise underlying the TOC management philosophy is that there is a single basic conflict or cause that is precluding managers from attaining significant system performance improvement. This core conflict is the root cause of the UDEs. The rationale is that if the core conflict is identified and if managerial action is taken to eliminate it and if it is successfully eliminated, then most, if not all, of the UDEs will cease to exist. Thus, the next step is to isolate this conflict for the current situation. A recently developed approach for synthesizing the information revealed in the three clouds into a general or CCC is called the three-cloud process. By definition, a valid CCC is responsible for a significant majority of the identified UDEs (Reid and Cormier, 2003).

2.8.1.3 The Future Reality Tree

As a tool for logically visualizing the future, the Future Reality Tree (FRT) is often created through a transformation of the CRT. The transformed CRT or FRT presents the results from the planned implementation of some action that will eliminate or mitigate the core conflict. This action, often labeled an injection, can be introduced at any point in the CRT. It can be in the form of a new entity or it can describe a proposed change to an existing entity. By definition, an injection logically provides a change in the sufficient cause relationship to a subsequent entity, and therefore, all ensuing entities will need to be modified. The goal is to design an injection that would ultimately cause all UDEs to be invalidated, thus converting them into DEs (Desirable Effects). More than one injection may be required to convert all the UDEs (Reid and Cormier, 2003).

Dettmer (1997) claims that The Future Reality Tree (FRT) serves two purposes. First, it allows us to verify that an action we would like to take will, in fact, produce the ultimate results we desire. Second, it enables us to identify any unfavorable new consequences our contemplated action might have, and to nip them in the bud. These functions provide two important benefits. We can logically "test" the effectiveness of our proposed course of action before investing much time, energy, or resources in it, and we can avoid making the situation worse than when we started. This tool answers the second part of the question what to change to by validating our new system configuration. The FRT can also be an invaluable strategic planning tool.

Future Reality Tree (FRT) is, in essence, a causal flowchart of the future system state that is now intended by the decision-makers, given their more complete understanding of the root cause/objective (Polito et al., 2006).

The general appearance of the Future Reality Tree is extremely similar in nature to the Current Reality Tree. The FRT is constructed by first posting the root cause/objective, given that more complete understanding, are posted to the diagram and connected with arrows to represent the casual relationship. Next, those effects are looked upon as causes, and then their desired effects are subsequently diagrammed. This process is repeated until the FRT represents the future system state as desired by the decision-makers (Polito et al., 2006).

2.8.1.4 The Negative Branch Reservation

Dettmer (1997) explains that associated with any proposed change is the possibility that a Negative Branch Reservation (NBR) would result. A NBR is a logic diagram for specifying the causal relationships between an injection that is designed to overcome existing UDEs and any resulting new negative effects that could logically materialize.

From a managerial perspective, anticipating any negative effects and being able to neutralize them with additional planned changes or secondary injections is highly desirable (Reid and Cormier, 2003).

The process of creating a *negative branch* begins by reviewing the FRT for the purpose of developing a comprehensive listing of the potential undesirable impacts that could result from the injections or obstacles to overcome if the injection is to be effectively implemented (Schragenheim and Dettmer, 2001). That is, the improvement team generates a list of new UDEs that might occur when the injection is activated or reasons why the injection may not work (Reid and Cormier, 2003).

2.8.1.5 The Prerequisite Tree

Dettmer (1997) explains the Prerequisite Tree (PRT) once we have decided on a course of action helps us implement that decision. It identifies obstacles to what we want to do and the best ways to overcome those obstacles. It also tells us in what sequence we need to complete the major milestones in implementing our decision. The PRT provides the first half of the answer to the last question, how to change.

2.8.1.6 The Transition Tree

The last of the five logical tools is the Transition Tree (TT). The TT can give the detailed step-by-step instructions for implementing a course of action. It provides both the steps to take (in sequence) and the rationale for each step. The TT is essentially the detailed road map to the objective, and it answers the second half of the question, how to change (Dettmer, 1997).

2.8.1.7 The Categories Of Legitimate Reservation

To be logically sound, a tree must be able to pass all of these tests. The eight Categories of Legitimate Reservation (CLR) include (Dettmer, 1997): Clarity, entity

existence, causality existence, cause sufficiency, additional cause, cause-effect reversal, predicted effect existence, tautology.

CLR usage explained by Dettmer (1997) that we use the CLR as we construct our trees, to be sure our initial relationships are sound. We use the CLR after the tree is built, to review it as a whole. We use the CLR to scrutinize and improve the trees of others. And, most important, we use the CLR to communicate disagreement with others in a nonthreatening way, which promotes better understanding rather than animosity (Dettmer, 1997).

2.8.2 The Logical Tools As A Complete “Thinking Process”

Each of Goldratt's five logical tools can be used individually, or they can be used in concert, as an integrated "thinking process". TOC is discussed as a methodology for managing change. The three basic questions a manager must answer about change (what to change, what to change to, and how to cause the change) can be answered using the five logical tools as an integrated package (Dettmer, 1997). Nonquantifiable problems of broad scope and complexity are particularly prime candidates for a complete thinking process analysis (Dettmer, 1997).

Polito et al. (2006) informs that Goldratt developed and presented The Thinking Processes in his book *It's Not Luck*. The Thinking Processes are intended as a set of structured steps that lead decision-makers to identify the root cause of “undesirable effects” to identify the faulty and/or incomplete logic regarding the root cause and to develop an improved logic regarding the root cause that, in turn, leads to more desirable effects. In fact, much of the benefit of The Thinking Processes is derived from the decision makers' direct involvement in the diagram development.

Polito et al. (2006) explains The Thinking Processes assumption that many effects can be traced to few causes may well have been influenced by the Pareto Principle. In 1954 Juran, based on his observations and data, adapted the concept to usage in the discipline of quality, stating that 80 percent of quality losses are effected by 20 percent of all root cases. Juran called that 20 percent of root causes “the vital few” and the rest “the trivial many”. The Pareto Principle, or “The 80:20 Rule”, implies that managemet resources are best allocated toward modification of “the vital few” root causes.

As this case demonstrates, The Thinking Processes can be employed as an effective and valuable tool in the diagnosis and improvement of organizational systems toward an increased competitive posture. While in this case competitive advantages in the specific areas of cost and service level were obtained, The Thinking Processes technique is not specific to any particular type of competitive advantage or organizational issue, and so can be an appropriate application toward improvement of competitive position in a wide variety of scenarios (Polito et al., 2006).

2.8.3 Drum Buffer Rope

The TOC has two major components. First, a philosophy which underpins the working principles of TOC. This is often referred to as TOC's "logistics paradigm" and consists of five steps for on-going improvement, the drum-buffer-rope (DBR) scheduling methodology, and the buffer management information system. This philosophy suggests that the main constraint in most organizations may not be physical, but in fact managerial-policy related. To address the policy constraints and effectively implement the process of on-going improvement, Goldratt developed a generic approach called the TP. This is the second component of TOC. Experts believe that it is the TP which will ultimately have the most lasting impact on business (Rahman, 2002).

The TOC has a unique method of scheduling process with constraints, called Drum-Buffer- Rope or DBR. To maintain a system at maximum performance we must design the system so that capacity constraints within the system are always operating at peak capacity. The Drum is the capacity constraint. The capacity constraint sets the pace for the system as a drum sets the pace for marching soldiers. The Buffer isolates the capacity constraint from negative effects of the rest of the system. The Rope ties raw material release to the capacity constraint buffer to assure that inventory is at the lowest level that will maintain capacity constraint performance at maximum (Siha, 1999). Flowing directly from the Five Focusing Steps, The Goal develops the scheduling methodology employed under TOC: drum-buffer-rope (DBR) (Watson et al., 2006).

The constraint, or drum, determines the pace of production. The rope is the material release mechanism; releases material to the first operation at a pace determined by the constraint. Material release is offset from the constraint schedule by a fixed

amount of time, the buffer. Buffers are strategically placed to protect shipping dates and to prevent constraint processes from starvation due to a lack of materials (Watson et al., 2006).

Watson et al. (2006) describes the term “buffers” is often synonymous with work-in-process or finished goods inventory; however, TOC makes use of three distinct buffer types: time, shipping, and capacity. Shipping buffers maintain a small amount of finished good inventory used to protect due date performance. Further, shipping buffers increase responsiveness to market demand by allowing the system to deliver an item in less than the manufacturing lead time. Capacity buffers exist in a TOC system to the extent that non-constrained resources have extra capacity. Releasing inventory to the production system based on the rate of consumption at the constraint. The “length” of the rope, hence the amount of inventory in the system, is determined by the protection to the constraint provided by the buffer.

Buffer management is a related TOC application that assists in managing tradeoffs between protection of the constraint and lead times. First, it allows management to identify possible problems in the manufacturing system before they impact the schedule. Second, buffer management can be used to focus improvement efforts on those processes that have the greatest negative impact on schedule performance, simplifying the management of continuous improvement activities (Watson et al., 2006).

2.8.4 Continuous Improvement

The practice of continuous improvement (CI) embraces the fundamental idea that whatever success in satisfying customers that an organization may have had in the past, it must do better in the future. This belief is based on the proposition that the needs and wants of a firm’s customers are in a constant state of flux, and that ongoing success requires a proactive commitment to implementing frequent improvements. Competition and continuously escalating standards of customer satisfaction have proven to be endlessly drivers for seeking to increase organizational performance (Reid and Cormier, 2003). The definition of these terms might be dependent on the service. Since system constraint is at the heart of TOC, the recognition of the nature of organization constraint is the first step towards continuous improvement (Siha, 1999).

The continuous improvement branch has two elements: effect-cause-effect (ECE) diagrams and the five-step focusing process. The process of developing these ECE diagrams forces managers to think about the true causes of problems. Utilizing critical thinking and Socratic methods, the root cause of a problem is identified. A plan is developed for eliminating the root cause rather than treating symptoms of the problem. This approach answers three questions, what to change, what to change to, and how to change (Siha, 1999).

2.8.5 Service Organisations

Some management techniques developed for manufacturing organizations may not be appropriate for service organizations. There are clear differences between manufacturing organizations and service organizations that make manufacturing management techniques inappropriate for service management. Manufactured goods can be inventoried to provide products during times when demand exceeds capacity. Services cannot be pre-produced and held in inventory (Siha, 1999).

TOC principles have been successfully applied to a variety of manufacturing organizations. Since manufacturing and service organizations have significant differences, application of TOC principles to service organizations may require some modifications (Siha, 1999).

Another approach involves translation of a successful classification scheme from manufacturing to service. In manufacturing, a method for classification is the product process matrix. Analogous to the product-process matrix in manufacturing is the service process matrix developed by Schmenner (1986) (Table 2.2). Two key elements are used to classify service delivery processes, labor intensity, and customer interaction and service customization. A two-by-two matrix can be generated from these two classification categories (Siha, 1999).

Table 2.2: The Service Process Matrix

		Degree of Interaction & Customization	
		Low	High
Degree of Labor Intensity	Low	Service Factory: Airlines Trucking Hotels Resorts & Recreation	Service Shop: Hospitals Auto Repairs Other Repair Services
	High	Mass Service: Retailing Wholesaling Schools Retail Aspects of Commercial Banking	Professional Service: Doctors Lawyers Accountants Architects

Applying the theory of constraints requires identifying the performance measures (Table 2.2). Inventory here is the unused “service”, e.g. a seat on a flight, a room in a hotel or resort or a space in a truck. Inventory is physical in nature. The throughput is the money generated from selling the “service”. Operating expense has the standard TOC definition. The five-step focusing process requires a multi-stage or multi-process system (Table 2.3) to be applied meaningfully (Siha, 1999).

Table 2.3: Applying TOC to The Four Types of Service Organizations

Service Type	Constraints	Inventory	Throughput
Service factory	Scheduling-balancing capability and demand	The “unused” services, e.g. unsold seats in airlines	The income generated from selling the “service”, e.g. tickets, rental,.. etc
Service shop	Handling the customization of the service and the stochastic processing time	The turnover rate, e.g. tables in restaurant or space in repairing shop	The income generated from offering the “right” service to customers
Mass service	Controlling the policies and processes	The “delay” in delivering services, e.g. insurance policy not issued on time	The income generated from “adequate” utilization of the “workforce”
Professional service	Matching “workforce” and demand	The initialized human resource capacity, e.g. doctors need to keep their Schedule full	The income generated from “adequate” utilization of the “workforce”

2.8.6 Supply Chain

Supply chain collaboration amongst independent firms often provides larger benefits from effectively satisfying end customer needs than working in isolation. However, a lack of awareness about the existence of constraints along the supply chain prevents the benefits of collaboration from being fully realised. Supply chain collaboration

can be defined as two or more independent firms jointly working to align their supply chain processes so as to create value to end customers and stakeholders with greater success than acting alone (Simatupang et al., 2004).

The core problem appears to be with management . Owing to their limited vision, the management of many organizations fails to see and appreciate the importance of system-wide performance measures. Several other factors (causes) which may affect the performance of supply chains are (Rahman, 2002):

- communication;
- trust among channel participants;
- investment and usage of IT;
- common goals;
- coordination;
- product-process design without supply chain consideration;
- lack of appreciation for supply chain wide performance measures;
- sharing risks and rewards;
- supply base orientation, inadequate definition of customer service (Rahman, 2002).

Rahman (2002) explained “Many empirical and case studies have identified these factors. For instance, Power *et al.* (2001) found that “more agile” supply chains are more customer focused, have greater involvement with suppliers and better utilise information technologies (IT) compared to the “less agile” supply chains. Many have suggested channel-wide management of inventories, coordination, shared visions, reduced supplier base (Cooper and Ellram, 1993; Shin *et al.*, 2000), and fair sharing of risks and rewards (Handfield and Nichols, 1999) as characteristics of integrated supply chain management”.

There are two ways in which the constraint-based approach can help managers improve the supply chain: first, by providing reliable global performance measures that help the chain members to measure the progress of accomplishing the total revenue of the supply chain, and second, by focusing on improvement efforts that have a dramatic impact on the supply chain performance (Simatupang et al., 2004).

Throughput is comprised mainly of the revenue a supply chain generates through sales of its product, less the truly variable cost of generating the sale. For many supply chains, truly variable costs include the material costs, sales commissions,

markdowns, consumable supplies, and so on. Investment (I) is all the money the supply chain invests in things it intends to sell. The larger portion of this investment for a supply chain is raw materials or purchased parts. This definition excludes the contribution of labour and overheads. In a supply chain, investment comes in three forms: raw materials, finished products not as yet sold, and things somewhere in between (work-in-process). Operating expense (OE) is all the money the supply chain spends in turning investment into throughput. This includes direct labour and overheads and other fixed expenses that would be incurred even it never produced a single product (Simatupang et al., 2004).

2.9 TOC Measures, Applications and Results

Theory of Constraints has many application areas in manufacturing, services, supply chain and even in daily life of the people. Measures should be done to apply and to get positive results of TOC are can be reached by 5FS and throughput accounting. The results of the applications of TOC to companies sometimes might be as miracle to imagine.

2.9.1 TOC Measures

In general, the reduction of allocated costs is not a part of the CM (Constraint Management) heuristic. Instead, the CM rationale for investigating a lower number of setups would be aimed at providing more throughput potential, greater flexibility, or both. Often, the CM approach gives greater weight to customer responsiveness and therefore is willing to incur more setups to achieve better due-date performance. That is often the case in situations in which setups for nonconstraints are being considered. In this study we addressed the reduction of costs for two reasons (Qiu et al., 2002):

1. Extra setups affect output quality
2. They reduce available production time because off-line setups are not possible.

We know that to improve means we must (Burton-Houle, 2001):

- Provide products and services that solve customers' problems
- Release products and services consistent with market demand
- Reduce variability in our processes

- Have measurements that indicate success relative to achieving our goal
- Reward people for their contribution to change

Goldratt (2006) gives most critical measures to increase the capacity of the bottlenecks in his novel, the Goal:

Putting quality control (Q.C.) in front of the bottlenecks, training people to give special care to bottleneck parts, activating the three machines to supplement the bottleneck, the new lunch rules, assigning certain people to work only at the bottlenecks...

First, make sure the bottlenecks' time is not wasted. How is the time of a bottleneck wasted? One way is for it to be sitting idle during a lunch break. Another is for it to be processing parts which are already defective or which will become defective through a careless worker or poor process control. A third way to waste a bottleneck's time is to make it work on parts you do not need.

Because what happens when you build inventory now that you will not sell for months in the future? You are sacrificing present money for future money; the question is, can your cash flow sustain it? You are making your bottlenecks work on parts that will not contribute to throughput?

Where you do quality inspection on bottleneck parts? Do you realize what the rejection by Q.C. has done to you? We lost the time on the bottleneck. Make sure the bottleneck works only on good parts by weeding out the ones that are defective. If you scrap a part before it reaches the bottleneck, all you have lost is a scrapped part. But if you scrap the part after it is passed the bottleneck, you have lost time that cannot be recovered.

One way to increase the capacity of the bottlenecks is to make the bottlenecks work only on what will contribute to throughput today. The other way you increase bottleneck capacity is to take some of the load off the bottlenecks and give it to non-bottlenecks.

Do all of the parts have to be processed by the bottleneck? If not, the ones which do not can be shifted to non-bottlenecks for processing.

And the result is you gain capacity on your bottleneck. A second question: do you have other machines to do the same process? If you have the machines, or if you have a vendor with the right equipment, you can offload from the bottleneck. And, again, you gain capacity which enables you to increase throughput.

2.9.2 TOC Applications

Theory of Constraints techniques were, for the most part, developed by Dr. Eli Goldratt, beginning with his best-selling book *The Goal* (Goldratt, 2006). The most widely known Theory of Constraints technique is scheduling and managing operations centered upon those operational activities that constrain, or bottleneck, the entire system (Polito et al., 2006).

TOC systems produce greater levels of output while reducing inventory, manufacturing lead time, and the Standard deviation of cycle time. TOC techniques have been applied at a number of Fortune 500 companies; 3M, Amazon, Boeing, Delta Airlines, Ford Motor Company, General Electric, General Motors, and Lucent Technologies have publicly disclosed significant improvements achieved through deployment of TOC solutions. Additionally, a number of adopting companies state an unwillingness to disclose improvements for competitive reasons. Application of TOC is not limited to for-profit companies; not-for-profit organizations and government agencies such as Habitat for Humanity, Pretoria Academic Hospital, British National Health Service, United Nations, NASA, United States Department of Defense (Air Force, Marine Corps, and Navy), and the Israeli Air Force all have successfully employed TOC solutions (Watson et al., 2006).

2.9.3 TOC Results

The goal was to elevate the capacity of the system's constraint to the point that the constraint no longer fell within the manufacturing environment. Stated differently, the goal of the plant was to reach a point where all customer orders could be filled on time (Watrous and Pegels, 2005).

Simatupang et al. (2004) emphasized The TOC solutions initially attempted to resolve core problems in production systems using methods such as the drum-buffer-rope scheduling, constraint-focused performance measurement, and buffer

management. Further development of the TOC incorporates solutions for marketing and sales, project management, and supply chain management.

Some usages of TOC Thinking Processes by AGI(Avraham Y. Goldratt Institute)'s customers (Burton-Houle, 2001):

- Design of Manufacturing Systems
- New product development
- New market entry
- Pipeline Management
- Segmentation of existing markets
- Strategic Planning
- System of Systems Design

Results reported by customers using the TOC Thinking Processes (Burton-Houle, 2001):

- 41 percent reduction in cycle time = \$7 million savings in capitalization
- New Product Introduction cycle times reduced 50 percent
- 21 percent increase in Net Sales Dollars
- Tripled development capacity with no staffing increases
- 80 percent increase in Operating Profit
- New job startup in 60 percent less time
- 100 percent on-time delivery
- 40 percent growth in revenues
- \$5.5 million dollars growth in revenue per year
- First to market five weeks ahead of schedule eliminates competitors' entry of new products
- 300 percent increase in net profit
- Annual inventory turns up from four to twelve
- Gross Margin increase from 29 to 41 percent
- Pre-tax profit improvement in excess of 3,500 percent

2.9.4 TOC Assumptions

TOC assumes that for most manufacturing and service organizations the goal of the organization is to make a larger profit now and in the future.

The essential concept of TOC is that every organization must have at least one constraint. Goldratt defines a five-step process that a change agent can use to

strengthen the weakest link, or links. TOC assumes that the main cause of physical constraint is policy constraint.

For most manufacturing and service organizations the goal of the organization is to make a larger profit now and in the future.

As a systemic management philosophy, TOC is based on three interrelated premises (Reid, 2007):

- Every system has a goal and a set of necessary conditions that must be satisfied if its goal is to be achieved;
- The overall system's performance is more than just the sum of its component performances; and
- Very few factors or constraints, often only one, limit a system's performance at any given time.

TOC assumes that system optima are not the sum of all local optima. Under these principles, TOC assumed that the optimum performance of the system as a whole is not the sum of all the local optima. In other words, an organization that maximizes the output of every machine will not perform as well as one that ensures optimization of the flow of materials and value created through its linked set of activities.

The TOC process emphasizes the need to maximize throughput and focuses on identifying and managing the constraints that can reduce the amount of throughput a company is able to achieve. Using the TOC process, the objective of management is reaching a point where the system's constraint lies outside the production arena.

Throughput accounting considered direct labor cost and overhead cost is irrelevant, and thus should be omitted from the calculations of either the purchased material cost or total variable cost. Throughput accounting assumes that direct labor cost and overhead cost can not be changed and thus it will not be worthwhile to spent much of our attention for such cost (Hutagalung, 2003).

Value added concept which is revealed in direct labor and overhead cost to be accumulated in determining the work in process and finished good inventory, is not pertinent in Throughput accounting. According to the throughput, the value creation of business can only be happened when product or services have been rendered to customers and therefore generates revenue for the system (Hutagalung, 2003).

2.10 Related Concepts

TOC presents an alternative view in evaluation of the economic results of the decisions about production to the traditional accounting (Unal, 2006). Product-mix decision through theory of constraints (TOC) should take into account considerations like the decisionmaker's level of satisfaction in order to make product-mix decision a robust one. Sensitivity of the decision made, needs to be focused for a bottleneck-free, optimal product-mix solution of TOC problem (Bhattacharya and Vasant, 2006). Product-mix decision-problem under TOC could be mathematically tackled as a linear programming (LP) model (Bhattacharya and Vasant, 2006).

2.10.1 Case Study Method

Case study method is a kind of research method type which is used in social science and especially cost and management researches frequently. It categorizes into five groups as descriptive, sample projector, experimental, heuristic and illuminating. Case study provide to examine the fact deeply and establish the problem and to find improving the solution methods as suitable all that. The high trustworthiness of the method provide the generalizable results for the similar events and constitute a basic or the other workings. In this study, with descriptive and heuristic event works (Unal, 2006).

2.10.2 Optimum Product Mix

In traditional approach, product mixed namely how many amounts will be produced is decided with using the product addition which considered variable costs or unit contributions that identified the all costs about the production. But according to the TOC, product mixed is established with consider the raw material costs that is accepted as a unique variable (Unal, 2006).

If there is a capacity constraint in the company, it is not possible to produce all the demanded products. Therefore company ought to focus on producing the maximum profitable product or products. The better product mixed should be known for increasing the profitability and management need to exact knowledge about the bottleneck and the optimum product mixed (Unal, 2006).

When a firm has more demand than capacity, managers must determine which product to produce in a given period. The product mix decision typically attempts to

maximize profit. However, researchers have some disagreement about the best method of determining the product mix and the best management accounting system to use. Some researchers contend that the theory of constraints (TOC) product mix algorithm and TOC's accounting system (i.e., throughput accounting) perform as well or better than linear programming (LP) and activity based costing (ABC), respectively. For example, some researchers suggest that throughput accounting be used for short-term decisions, while ABC should be used for long-term decisions (Lea and Fredenhall, 2002).

As restricted resource other profitable products could be produced until the capacity limit with given the priority to the maximum profitable product hourly (Unal, 2006).

2.10.3 Integer Programming

Integer programming (IP) is an extension of linear programming which all or some of decision variables have to be integer. Integer programming is divided three groups as absolute integretal programming, double (binary) integretal programming and mixed integretal programming. All variables have to be integer in absolute integral programming. As double programming, variables have to be "1" or "0". The models are called mixed integral programming which some variables have to be integer and the others have to be all values (Unal, 2006).

The main hypothesis of the linear programming is all variables are continuous and decision variables have integer and fractional values. However, there is no economic meaning of the decision variables is not integer in some problems. The indivisibility problems of the inputs and the outputs requires that the decision variables should be integer. Capital budgeting, electric generator units, instruments and devices, machines and people are the examples for that. If the most suitable value for the decision variable which is achieved by linear programming is not integer, and want to the decision variables as integer, the other solution method which is an integer programming method could be used (Unal, 2006).

In analysis, integer programming is going to use to define the product mixed. Some computer programs which is suitable with solution algorithm is going to used during the integer programming model solution. Working results could have a basic for the other studies and could generalized for the firms in the same conditions in the same sectors (Unal, 2006).

Manufacturing involves the conversion of raw materials into finished products through the efforts of workers and the use of production equipment.

A product mix problem can be formulated as (Lea, 2007):

$$\text{Maximize } Z = \sum_{j=1}^n (P_j - c_j)x_j \quad (2.1)$$

Subject to:

$$\sum_{j=1}^n a_{ij}x_j \leq b_i \quad i = 1, 2, \dots, m \text{ (resource / capacity constraints)} \quad (2.1a)$$

$$\sum_{j=1}^n x_j \leq d_j \quad j = 1, 2, \dots, m \text{ (market demand constraints)} \quad (2.1b)$$

$$x_j \geq 0 \quad j = 1, 2, \dots, n \quad (2.1c)$$

Where P_j – the selling price of product j ; c_j – the cost of product j ; a_{ij} – the amount of resource i required to produce product j ; x_j – the number of product j produced; b_i – the maximum amount of resource i available; d_j – the forecasted market demand for product j ; m – the number of products; n – the number of resources. As shown in the product mix formulation above, product mix decisions are influenced by the selling prices of products (P_j), costs of products (c_j), resource requirement/consumption of products (a_{ij}), capacity of resources (b_i), and market demand of products (d_j). As management accounting systems are used to determine product costs in order to reasonably represent the cost of input resources, such as workers and equipment, which are used during the production process, cost of products (c_j) is determined by the management accounting system used. However, different management accounting systems determine product cost differently and result in different product mix decisions that lead to different manufacturing performance when a manufacturing firm has insufficient production capacity to meet market demand (Lea, 2007).

Most effective laboratory research involves quantifying the effect of a change in one variable by holding all the others constant-or as nearly so as possible. This is **sensitivity analysis**, and it is particularly useful in determining how much of an outcome is attributable to a particular cause (Dettmer, 1997).

Integer programming model gives the optimum product mix solution paying attention the capacities of all sources of the company. Integer programming model can be used while determining the constraint which limits the production and increase inputs. Sensitivity analysis is using in the estimation of the expected profit coming with the increase in production and with the elimination of the constraint. The sensitivity analysis of the model can be used also determining the new constraint after the existing constraint eliminated and determining the effect of the elimination of this constraint to the profit (Unal, 2006).

2.10.4 Simulation

Simulation modeling and analysis is the process of creating and experimenting with a computerized mathematical model of a physical system. The simulation modeling and analysis of different types of systems are conducted for the purposes of (Chung, 2003):

- Gaining insight into the operation of a system
- Developing operating or resource policies to improve system performance
- Testing new concepts and/or systems before implementation
- Gaining information without disturbing the actual system

In production and manufacturing industries nowadays computer simulation has been adopted and emerged as an advanced, sophisticated and flexible management analysis tool which is able to take account of the complexities and dynamic changes within the production environment. It mimics and analyzes the stochastic behaviour of the production system for measuring its performance in terms of its overall strategy with a view to assisting the management in arriving at a better decision after evaluation of various alternative results obtained from the simulation (Khan, 1999).

3. APPLICATION OF TOC IN A MANUFACTURING FIRM

Companies give the product mix decisions traditionally according to full cost accounting system considering unit profits. However, the decisions which are taken by considering unit profits can be deceptive. For this reason, companies might give the product mix decisions according to changeable costing systems considering contribution shares. But, in case of having capacity constraints, the decisions which are taken by considering the contribution shares will be deceptive. For this reason, product mix decisions are taken considering the capacity constraint source, giving priority to the products which are the most profitable per unit source in the capacity constraint source. The result of the product mix decisions of process contribution approach while there is a capacity constraint source existing, is much more profitable than changeable costing systems considering contribution shares.

According to TOC, all costs except raw material cost are fixed costs which are out of control.

3.1 The Goal, Scope and Importance of the Research

Product mix determination is very important in the profitability of the company and there are some systems determination of this. Traditional cost accounting system is considering unit contribution shares. In traditional cost accounting system priority is given to the products which are the most profitable per unit source. In TOC, accepting only raw material cost as a changeable cost, product mix decisions are taken considering the capacity constraint source, giving priority to the products which are the most profitable process contribution in the capacity constraint source.

At this direction, the aim of this work is to emphasize the importance of the product mix decisions and to present the importance of TOC instead of traditional systems in determination of the correct product mix decisions. In this frame, by doing a case study in a manufacturing firm, we tried to answer below questions:

- Is there any constraint in manufacturing system of the firm

- Does the firm determine the product mix decisions according to the traditional accounting system
- Will the firm create more profitable results by TOC comparing traditional cost accounting system

A case study in a textile firm was done to answer these questions. Therefore, firstly the descriptive case study was done and in this frame, manufacturing and costing systems of the firm were presented. Afterwards, an exploratory study was done and the impact in the firm profitability of the product mix decisions was made by TOC. In the frame of exploratory case study, the advantages of the integer programming was used. Besides using Excel tables, The program WinQSB was used to solve the integer programming problems because of the difficulty of solving the iterations which were had lots of variables and constraints.

3.2 General Information About the Firm

Firm is a textile manufacturing firm which manufactures the ring spun cotton yarn located in Lüleburgaz, Kırklareli. Raw material of the firm is cotton which are provided from Urfa and/or from Greece. The products which are produced by combing process are: Ring ring spun combed 16 cotton yarn, ring spun combed 20 cotton yarn, ring spun combed 24 cotton yarn, ring spun combed 30 cotton yarn, ring spun combed 40 cotton yarn and. The products which are produced by carding process are: Ring spun carded 16 cotton yarn, ring spun carded 20 cotton yarn, ring spun carded 24 cotton yarn.

Firm is working 24 hours / 7 days by 3 shifts a day. Top management of the firm is making feasibility of increasing existing capacity to meet the demand of the customers.

Customers of the firms are mostly domestic textile and clothing firms.

3.3 Production Systems

The combed and carded yarns are being produced in the firm. These kind of yarns are using in the textile and clothing sectors. All kind of yarns which are producing in the firm, considered to determine product mix selection.

Cotton accounts for almost 50% of the worldwide consumption of textile fibre. China, the United States, the Russian Federation, India and Japan are the major

cotton-consuming countries. Consumption is measured by the amount of raw cotton fibre purchased and used to manufacture textile materials. Worldwide cotton production is annually about 80 to 90 million bales (17.4 to 19.6 billion kg). China, the United States, India, Pakistan and Uzbekistan are the major cotton-producing countries, accounting for over 70% of world cotton production. The rest is produced by about 75 other countries. Raw cotton is exported from about 57 countries and cotton textiles from about 65 countries. Many countries emphasize domestic production to reduce their reliance on imports (www.oit.org).

Yarn manufacturing is a sequence of processes that convert raw cotton fibres into yarn suitable for use in various end-products. A number of processes are required to obtain the clean, strong, uniform yarns required in modern textile markets. Beginning with a dense package of tangled fibres (cotton bale) containing varying amounts of non-lint materials and unusable fibre (foreign matter, plant trash, motes and so on), continuous operations of opening, blending, mixing, cleaning, carding, drawing, roving and spinning are performed to transform the cotton fibres into yarn.

Even though the current manufacturing processes are highly developed, competitive pressure continues to spur industry groups and individuals to seek new, more efficient methods and machines for processing cotton which, one day, may supplant today's systems. However, for the foreseeable future, the current conventional systems of blending, carding, drawing, roving and spinning will continue to be used. Only the cotton picking process seems clearly destined for elimination in the near future (www.oit.org).

Yarn manufacturing produces yarns for various woven or knitted end-products (e.g., apparel or industrial fabrics) and for sewing thread and cordage. Yarns are produced with different diameters and different weights per unit length. While the basic yarn manufacturing process has remained unchanged for a number of years, processing speeds, control technology and package sizes have increased. Yarn properties and processing efficiency are related to the properties of the cotton fibres processed. End-use properties of the yarn are also a function of processing conditions (www.oit.org).

3.3.1 Yarn Manufacturing Process

3.3.1.1 Opening, blending, mixing and cleaning

Typically, mills select bale mixes with the properties needed to produce yarn for a specific end-use. The number of bales used by different mills in each mix ranges from 6 or 12 to over 50. Processing begins when the bales to be mixed are brought to the opening room, where bagging and ties are removed. Layers of cotton are removed from the bales by hand and placed in feeders equipped with conveyors studded with spiked teeth, or entire bales are placed on platforms which move them back and forth under or over a plucking mechanism. The aim is to begin the sequential production process by converting the compacted layers of baled cotton into small, light, fluffy tufts that will facilitate the removal of foreign matter. This initial process is referred to as “opening”. Since bales arrive at the mill in various degrees of density, it is common for bale ties to be cut approximately 24 hours before the bales are to be processed, in order to allow them to “bloom”. This enhances opening and helps regulate the feeding rate. The cleaning machines in mills perform the functions of opening and first-level cleaning (www.oit.org).

3.3.1.2 Carding and combing

The card is the most important machine in the yarn manufacturing process. It performs second- and final-level cleaning functions in an overwhelming majority of cotton textile mills. The card is composed of a system of three wire-covered cylinders and a series of flat, wire-covered bars that successively work small clumps and tufts of fibres into a high degree of separation or openness, remove a very high percentage of trash and other foreign matter, collect the fibres into a rope-like form called a “sliver” and deliver this sliver in a container for use in the subsequent process (www.oit.org).

The latter distribute opened and cleaned tufts of fibres to cards pneumatically through ducts. This action contributes to processing consistency and improved quality and reduces the number of workers required (www.oit.org).

A small number of mills produce combed yarn, the cleanest and most uniform cotton yarn. Combing provides more extensive cleaning than is provided by the card. The purpose of combing is to remove short fibres, neps and trash so that the resulting sliver is very clean and lustrous. The comber is a complicated machine composed of

grooved feed rolls and a cylinder that is partially covered with needles to comb out short fibres (www.oit.org).

3.3.1.3 Drawing and roving

Drawing is the first process in yarn manufacturing that employs roller drafting. In drawing, practically all draft results from the action of rollers. Containers of sliver from the carding process are staked in the creel of the drawing frame. Drafting occurs when a sliver is fed into a system of paired rollers moving at different speeds. Drawing straightens the fibres in the sliver by drafting to make more of the fibres parallel to the axis of the sliver. Parallelization is necessary to obtain the properties desired when the fibres are subsequently twisted into yarn. Drawing also produces a sliver that is more uniform in weight per unit of length and helps to achieve greater blending capabilities. The fibres that are produced by the final drawing process, called finisher drawing, are nearly straight and parallel to the axis of the sliver. Weight per unit length of a finisher-drawing sliver is too high to permit drafting into yarn on conventional ring-spinning systems (www.oit.org).

The roving process reduces the weight of the sliver to a suitable size for spinning into yarn and inserting twist, which maintains the integrity of the draft strands. Cans of slivers from finisher drawing or combing are placed in the creel, and individual slivers are fed through two sets of rollers, the second of which rotates faster, thus reducing the size of the sliver from about 2.5 cm in diameter to that of the diameter of a standard pencil. Twist is imparted to the fibres by passing the bundle of fibres through a roving “flyer”. The product is now called “roving”, which is packaged on a bobbin about 37.5 cm long with a diameter of about 14 cm (www.oit.org)..

3.3.1.4 Spinning

Spinning is the single most costly step in converting cotton fibres to yarn. Currently, over 85% of the world's yarn is produced on ring-spinning frames, which are designed to draft the roving into the desired yarn size, or count, and to impart the desired amount of twist. The amount of twist is proportional to the strength of the yarn. The ratio of the length to the length fed can vary on the order of 10 to 50. Bobbins of roving are placed onto holders that allow the roving to feed freely into the drafting roller of the ring-spinning frame. Following the drafting zone, the yarn passes through a “traveller” onto a spinning bobbin. The spindle holding this bobbin

rotates at high speed, causing the yarn to balloon as twist is imparted. The lengths of yarn on the bobbins are too short for use in subsequent processes and are doffed into “spinning boxes” and delivered to the next process, which may be spooling or winding (www.oit.org).

In the modern production of heavier or coarse yarns, open-end spinning is replacing ring spinning. A sliver of fibres is fed into a high-speed rotor. Here the centrifugal force converts the fibres into yarns. There is no need for the bobbin, and the yarn is taken up on the package required by the next step in the process (www.oit.org).

Considerable research and development efforts are being devoted to radical new methods of yarn production. A number of new spinning systems currently under development may revolutionize yarn manufacturing and could cause changes in the relative importance of fibre properties as they are now perceived. In general, four of the different approaches used in the new systems appear practical for use on cotton. Core-spun systems are currently in use to produce a variety of specialty yarns and sewing threads. Twistless yarns have been produced commercially on a limited basis by a system that bonds the fibres together with a polyvinyl alcohol or some other bonding agent. The twistless yarn system offers potentially high production rates and very uniform yarns. Knit and other apparel fabrics from twistless yarn have excellent appearance. In air-vortex spinning, currently under study by several machinery manufacturers, drawing sliver is presented to an opening roller, similar to rotor spinning. Air-vortex spinning is capable of very high production speeds, but prototype models are particularly sensitive to fibre length variations and foreign matter content such as trash particles (www.oit.org).

3.3.1.5 Winding and spooling

Once the yarn is spun, the manufacturers must prepare a correct package. The type of package depends on whether the yarn will be used for weaving or knitting. Winding, spooling, twisting and quilling are considered preparatory steps for weaving and knitting yarn. In general, the product of spooling will be used as warp yarns (the yarns that run lengthwise in woven fabric) and the product of winding will be used as filling yarns, or weft yarns (the yarns that run across the fabric). The products from open-end spinning by-pass these steps and are packaged for either the filling or warp. Twisting produces ply yarns, where two or more yarns are twisted together before

further processing. In the quilling process yarn is wound onto small bobbins, small enough to fit inside the shuttle of a box loom. Sometimes the quilling process takes place at the loom (www.oit.org).

3.3.1.6 Waste handling

In modern textile mills where control of dust is important, the handling of waste is given greater emphasis. In classical textile operations, waste was collected manually and delivered to a “wastehouse” if it could not be recycled into the system. Here it was accumulated until there was enough of one type to make a bale. In the present state of the art, central vacuum systems automatically return waste from opening, picking, carding, drawing and roving. The central vacuum system is used for cleaning of machinery, automatically collecting waste from under machinery such as fly and motes from carding, and for returning unusable floor sweeps and wastes from filter condensers. The classical baler is a vertical upstroke press which still forms a typical 227-kg bale. In modern wastehouse technology, wastes are accumulated from the central vacuum system in a receiving tank which feeds a horizontal bale press. The various waste products of the yarn manufacturing industry can be recycled or reused by other industries. For example, spinning can be used in the waste spinning industry to make mop yarns, garnetting can be used in the cotton batting industry to make batting for mattresses or upholstered furniture (www.oit.org).

Manufacturing processes of the two kind of ring spun yarns are below. Raw materials (cotton) are being bought from Urfa and imported from Greece. This raw materials processing following process: Firstly, bales are opening, blending, mixing and cleaning and then carding and combing. After these processes, drawing and roving, spinning and winding the last process spooling.

The products which are produced by combing process are: Ring spun combed 16 cotton yarn, ring spun combed 20 cotton yarn, ring spun combed 24 cotton yarn, ring spun combed 30 cotton yarn, ring spun combed 40 cotton yarn. The products which are produced by carding process are: Ring spun carded 16 cotton yarn, ring spun carded 20 cotton yarn, ring spun carded 24 cotton yarn. In this study, products will qualified as: Combed 16 (X1), combed 20 (X2), combed 24 (X3), combed 30 (X4), combed 40 (X5), carded 16 (X6), carded 20 (X7), carded 24 (X8).

Manufacturing processes of the combed and carded yarns are shown in Fig. 3.1 and the product mix layout of the firm is shown in Fig. 3.2.

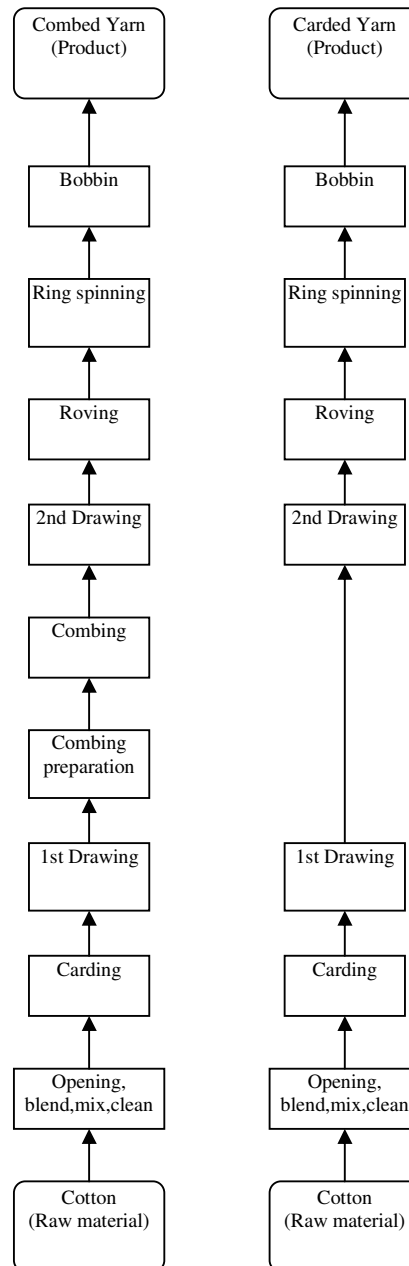


Figure 3.1: Manufacturing Process of Ring Yarn

3.4 Accounting System

Sales of the firms are mostly for domestic customers. The production is mostly for customer orders. Plant is working continuously 24 hours / 7days per week. Daily production reports are containing final products (including wastages). The

accounting system of the firm is traditional cost accounting considering source usage to distribute General Production Expenditure (GPE).

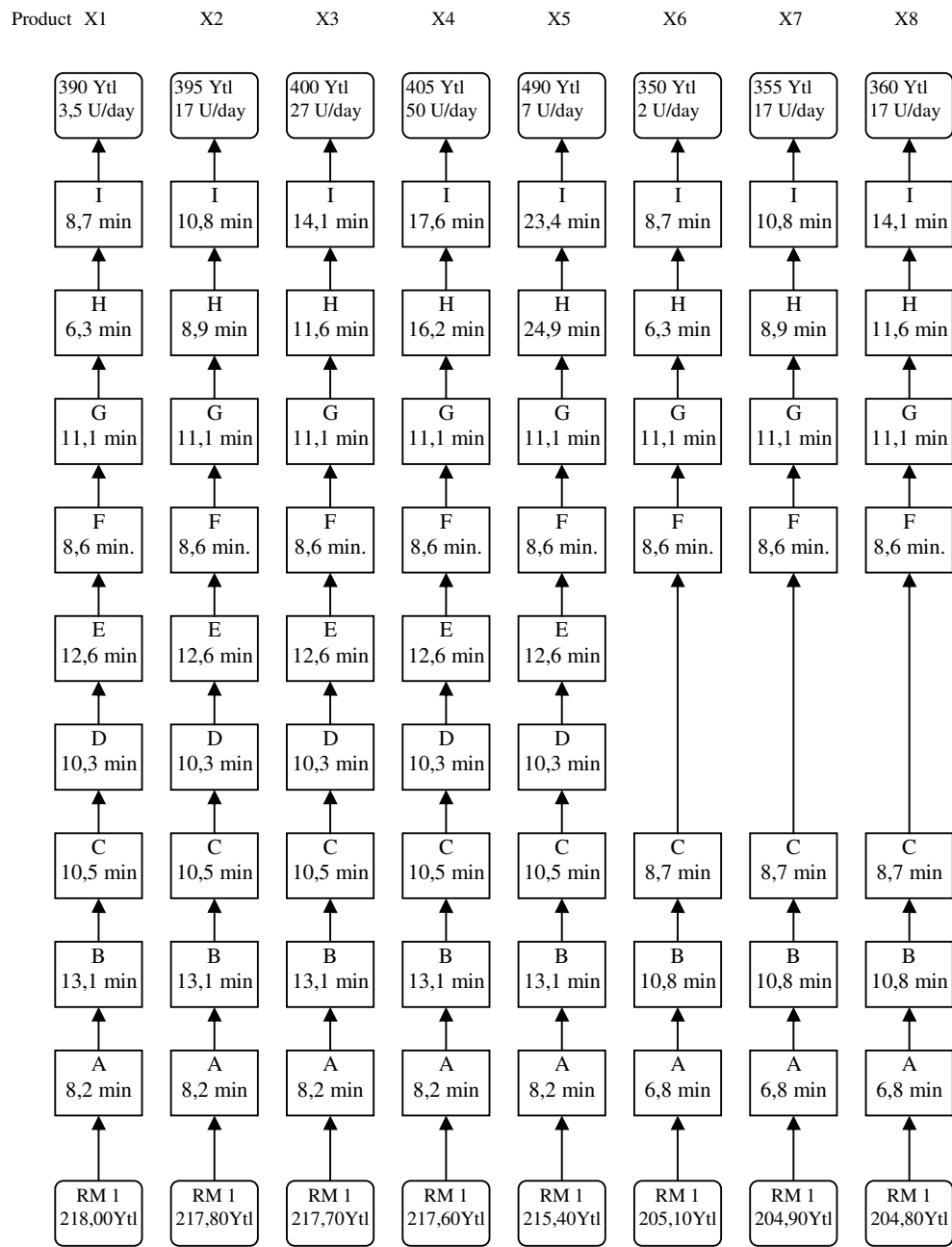


Figure 3.2 Product Mix of the firm

3.4.1 Assumptions of The Model

Assumptions of the model are:

- Demand is much more than the capacity.
- Each resource has 1440 min/day capacity.

- Plant is working continuously 24 hours / 7days per week, there is no break, lunch time etc.
- Demands, selling prices, material costs and process times are given.
- Eight different types of products, X1, X2, X3, X4, X5, X6, X7 and X8 are produced. There are nine different resources, A-I.
- One unit means 100 kgs product.
- Operations expense for Traditional Cost Accounting (TCA) and for Traditional Cost Accounting Contribution Per Constraint Resource Minute are 1.050 Ytl/day.
- Operations expense for Throughput Accounting of TOC is 9.500 Ytl/day.
- The terms which are used in the analysis explained below:

Contribution Per Unit = Revenue Per Unit – Variable Cost Per Unit

Throughput Per Unit = Revenue Per Unit – Materials Costs Per Unit

Total Profit for TCA = Total Contribution – Total Operating Expense

Total Profit for TOC = Total Throughput – Total Operating Expense(!)

3.5 Collecting and Analysing the Data

Eight different types of products, X1, X2, X3, X4, X5, X6, X7 and X8 are produced. There are nine different resources, A-I. Each resource has a capacity of 1440 minutes per day. The datas were collected from production manager of the firm.

Table 3.1 shows the loads required for producing one unit (100kgs) of products of X1-X8.

Table 3.1: Load Requirements for Producing Products

Products	Daily market potential (100 kgs)	Selling price (ytl/100kg)	Processing time per 100kgs (minutes)									Material cost per 100kgs (ytl/100kgs)
			A	B	C	D	E	F	G	H	I	
X1	3,5	390	8,2	13,1	10,5	10,3	12,6	8,6	11,1	6,3	8,7	218,00
X2	17	395	8,2	13,1	10,5	10,3	12,6	8,6	11,1	8,9	10,8	217,80
X3	27	400	8,2	13,1	10,5	10,3	12,6	8,6	11,1	11,6	14,1	217,70
X4	50	405	8,2	13,1	10,5	10,3	12,6	8,6	11,1	16,2	17,6	217,60
X5	7	490	8,2	13,1	10,5	10,3	12,6	8,6	11,1	24,9	23,4	215,40
X6	2	350	6,8	10,8	8,7	0	0	8,6	11,1	6,3	8,7	205,10
X7	17	355	6,8	10,8	8,7	0	0	8,6	11,1	8,9	10,8	204,90
X8	17	360	6,8	10,8	8,7	0	0	8,6	11,1	11,6	14,1	204,80

To answer the question of “Is there any constraint in manufacturing system of the firm”, the analysis of source load was done. In the frame of source load analysis, the constraints were determined by determination of existing capacity of sources and

needed capacity to cover the demands and capacity usage proportions. Table 3.2 shows loads on each resource.

Table 3.2: Load Calculations and Constrained Resources

Products	Daily market potential (100 kgs)	Capacity per 100kgs for resources (minutes)								
		A	B	C	D	E	F	G	H	I
X1	3,50	28,70	45,85	36,75	36,05	44,10	30,10	38,85	22,05	30,45
X2	17,00	139,40	222,70	178,50	175,10	214,20	146,20	188,70	151,30	183,60
X3	27,00	221,40	353,70	283,50	278,10	340,20	232,20	299,70	313,20	380,70
X4	50,00	410,00	655,00	525,00	515,00	630,00	430,00	555,00	810,00	880,00
X5	7,00	57,40	91,70	73,50	72,10	88,20	60,20	77,70	174,30	163,80
X6	2,00	13,60	21,60	17,40	0,00	0,00	17,20	22,20	12,60	17,40
X7	17,00	115,60	183,60	147,90	0,00	0,00	146,20	188,70	151,30	183,60
X8	17,00	115,60	183,60	147,90	0,00	0,00	146,20	188,70	197,20	239,70
Total load(minutes)		1.101,70	1.757,75	1.410,45	1.076,35	1.316,70	1.208,30	1.559,55	1.831,95	2.079,25
Available capacity (min)		1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00
Overload (minutes)		-338,30	317,75	-29,55	-363,65	-123,30	-231,70	119,55	391,95	639,25
Capacity utilization (%)		76,5%	122,1%	97,9%	74,7%	91,4%	83,9%	108,3%	127,2%	144,4%
										CCR1

The capacity utilization proportions above 100 % mean that the capacities needed were more than existing capacities. From Table 3.2 it was clear that resources A, C, D, E and F were underutilized while resources B, G, H and I were overloaded. Resource I was the capacity constraint resource (CCR) as it was the most overloaded and the said CCR was indicated in Table 3.2 using CCR1.

The Drum-Buffer-Rope approach of TOC was shown in Fig. 3.3. Bobbin machine was the drum which determines the maximum output of the system. Buffers were formed by the ring spinning machine's output stocks. Rope was the feedback and communication of the bobbin as a drum with the opening,blending,mixing,cleaning machine and with the market.

It was seen that there was not any product mix determination in the firm while answering the question of "Does the firm determine the product mix decisions according to the traditional accounting system". But if there was, it would be the profitability to consider. While discussing with top management of the firm, they informed that the main aim of the firm is to customer satisfaction and mostly for the sake of long-term profits, they manufacture the products which are requested by customers even they have poor profitability. Such situation can be to manufacture poor profitable products with high profitable products due to the reason of the customers would like to receive their requirements from the same firm. For this

reason, the firm does not determine optimum product mix and it manufactures without considering the poor profitability.

The terms which are used in the analysis explained below:

Contribution Per Unit = Revenue Per Unit – Variable Cost Per Unit

Throughput Per Unit = Revenue Per Unit – Materials Costs Per Unit

Total Profit for TCA = Total Contribution – Total Operating Expense

Total Profit for TOC = Total Throughput – Total Operating Expense(!)

In throughput accounting, the cost accounting aspect of Theory of Constraints (TOC), operating expense is the money spent turning inventory into throughput. In TOC, operating expense is limited to costs that vary strictly with the quantity produced, like raw materials and purchased components. Everything else is a fixed cost, including labour.

The profitability of the combed and carded yarn products according to traditional cost accounting system (TCA) contribution per unit (CPU) were shown in table 3.3. The profitability of the combed and carded yarn products according to traditional cost accounting system (TCA) contribution per constraint resource minute were shown in table 3.4. The product mix determination is not exist in the firm but if there is, it would be the profitability to consider in ordering as showed in the Table 3.3. If the firm would like to determine the optimum product mix, it is possible to manufacture by considering the order of the profits and capacities.

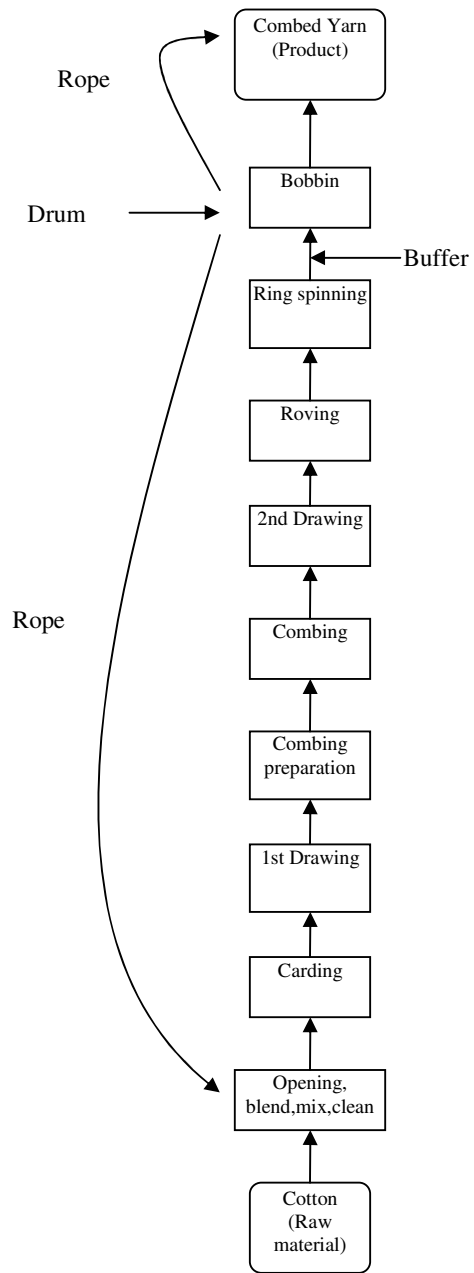


Figure 3.3 Drum-Buffer-Rope Mechanism of Manufacturing Firm

Table 3.3: Product Mix Ordering According to Traditional Cost Accounting (TCA) Contribution Per Unit (CPU)

Products	Daily market potential (100 kgs)	Selling Price per 100kgs (ytl/100kgs)	Variable Cost per 100kgs (ytl/100kgs)	Contribution per 100kgs (ytl/100kgs)	Product mix ranking
X1	3,50	390,00	297,90	92,10	4
X2	17,00	395,00	297,70	97,30	2
X3	27,00	400,00	303,64	96,36	3
X4	50,00	405,00	316,54	88,46	5
X5	7,00	490,00	367,84	122,16	1
X6	2,00	350,00	272,77	77,23	7
X7	17,00	355,00	272,57	82,43	6
X8	17,00	360,00	290,74	69,26	8

Table 3.4: Product Mix Ordering According to Traditional Cost Accounting (TCA) Contribution Per Constraint Resource Minute (CPCRM)

Products	Daily market potential (100 kgs)	Selling Price per 100kgs (ytl/100kgs)	Variable Cost per 100kgs (ytl/100kgs)	Contribution per 100kgs (ytl/100kgs)	Constraint resource minute	Contribution per constraint resource minute (ytl/100kgs)	Product mix ranking
X1	3,50	390,00	297,90	92,10	8,70	10,59	1
X2	17,00	395,00	297,70	97,30	10,80	9,01	2
X3	27,00	400,00	303,64	96,36	14,10	6,83	5
X4	50,00	405,00	316,54	88,46	17,60	5,03	7
X5	7,00	490,00	367,84	122,16	23,40	5,22	6
X6	2,00	350,00	272,77	77,23	8,70	8,88	3
X7	17,00	355,00	272,57	82,43	10,80	7,63	4
X8	17,00	360,00	290,74	69,26	14,10	4,91	8

Table 3.5: Product Mix Ordering According To TOC

Products	Daily market potential (100 kgs)	Selling Price per 100kgs (ytl/100kg)	Material cost per 100kgs (ytl/100kgs)	Throughput per 100kgs (ytl/100kgs)	Constraint resource minute	Throughput per constraint resource minute (ytl/100kgs)	Product mix ranking
X1	3,50	390,00	218,00	172,00	8,70	19,77	1
X2	17,00	395,00	217,80	177,20	10,80	16,41	3
X3	27,00	400,00	217,70	182,30	14,10	12,93	5
X4	50,00	405,00	217,60	187,40	17,60	10,65	8
X5	7,00	490,00	215,40	274,60	23,40	11,74	6
X6	2,00	350,00	205,10	144,90	8,70	16,66	2
X7	17,00	355,00	204,90	150,10	10,80	13,90	4
X8	17,00	360,00	204,80	155,20	14,10	11,01	7

Throughput per constraint resource minute (refer to Table 3.5) is to be calculated for finding out the required number of products to be produced within the available capacity of each resource per day. The main difference of the TOC from TCA is considering throughput per constraint resource minute while ordering the product mix. The product mix ordering according to TOC was shown in Table 3.5.

When the firm manufactures till the end of the capacity (1440min.) for each of the systems, the capacities (units to be produced at CCR) of the product mix according to TOC was 104,18 unit (Table 3.8), according to TCA CPCRm was 100,80 unit (Table 3.7) and according to TCA CPU was 93,22 unit (Table 3.6).

Table 3.6: Product Mix According to TCA CPU Ordering

Products	Units(100kgs) to be produced at CCR	Constraint resource minute	Resource usage at CCR (I)(min)	Resource capacity at CCR (I)(min)
X5	7,00	23,40	163,80	163,80
X2	17,00	10,80	183,60	347,40
X3	27,00	14,10	380,70	728,10
X1	3,50	8,70	30,45	758,55
X4	$(1440-758-55)/17,6=38,72$	17,60	681,45	1.440,00
93,22				

Table 3.7: Product Mix According to TCA CPCRm Ordering

Products	Units(100kgs) to be produced at CCR	Constraint resource minute	Resource usage at CCR (I)(min)	Resource capacity at CCR (I)(min)
X1	3,50	8,70	30,45	30,45
X2	17,00	10,80	183,60	214,05
X6	2,00	8,70	17,40	231,45
X7	17,00	10,80	183,60	415,05
X3	27,00	14,10	380,70	795,75
X5	7,00	23,40	163,80	959,55
X4	$(1440-959,55)/17,6=27,30$	17,60	480,45	1.440,00
100,80				

Table 3.8: Product Mix According to Theory of Constraints

Products	Units(100kgs) to be produced at CCR	Constraint resource minute	Resource usage at CCR (I)(min)	Resource capacity at CCR (I)(min)
X1	3,50	8,70	30,45	30,45
X6	2,00	8,70	17,40	47,85
X2	17,00	10,80	183,60	231,45
X7	17,00	10,80	183,60	415,05
X3	27,00	14,10	380,70	795,75
X5	7,00	23,40	163,80	959,55
X8	17,00	14,10	239,70	1.199,25
X4	$(1440-1199,25)/17,6=13,68$	17,60	240,75	1.440,00
104,18				

While answering the question of “Will the firm creates more profitable results by TOC comparing traditional cost accounting system”, the product mix determined by setting the model up with integer programming and analysing the algorithm of the

solution by computer program. Afterwards, the product mix determined by setting the model up with traditional cost accounting system and analysing. Consequently, the results were compared product mix which were determined by two models. Notations are below which were used in the models of integer programming.

Product mix model according to Theory of Constraints (Lea, 2007):

In case of determination of throughput according to Theory of Constraints, considering the order of the products, the production will continue till the end of the capacity.

Considering the throughput, product mix model is as below:

$$\text{Maximize } Z = \sum_{j=1}^n (P_j - c_j)x_j \quad (3.1)$$

Subject to:

$$\sum_{j=1}^n a_{ij}x_j \leq b_i \quad i = 1,2,\dots,m \text{ (resource / capacity constraints)} \quad (3.1a)$$

$$\sum_{j=1}^n x_j \leq d_i \quad j = 1,2,\dots,m \text{ (market demand constraints)} \quad (3.1b)$$

$$x_j \geq 0 \quad j = 1,2,\dots,n \quad (3.1c)$$

Notations:

- | | |
|-------------------------------------|------------------------------|
| j : product index (kind) | i : production process index |
| 1 : ring spun combed 16 cotton yarn | 1 : Opening, blend,mix,clean |
| 2 : ring spun combed 20 cotton yarn | 2 : Carding |
| 3 : ring spun combed 24 cotton yarn | 3 : 1st Drawing |
| 4 : ring spun combed 30 cotton yarn | 4 : Combing preparation |
| 5 : ring spun combed 40 cotton yarn | 5 : Combing |
| 6 : ring spun carded 16 cotton yarn | 6 : 2nd Drawing |
| 7 : ring spun carded 20 cotton yarn | 7 : Roving |
| 8 : ring spun carded 24 cotton yarn | 8 : Ring Spinning |
| | 9 : Bobbin |

- P_j : the selling price of product j
- p_i : the unit contribution of product j
- c_j : the cost of materials j
- a_{ij} : the amount of resource i required to produce product j
- x_j : the number of product j produced

b_i : the maximum amount of resource i available
 d_j : the forecasted market demand for product j
 m : the number of products
 n : the number of resources

As shown in the product mix formulation above, product mix decisions of TOC are influenced by the selling prices of products (P_j), costs of materials (c_j), resource requirement/consumption of products (a_{ij}), capacity of resources (b_i), and market demand of products (d_j).

Product mix model according to Traditional Cost Accounting (Unal, 2006):

In case of determination of unit contributions according to traditional cost accounting system, considering the order of the products, the production will continue till the end of the capacity.

Considering the unit contributions, product mix model is as below:

$$\text{Maximize } Z = \sum_{j=1}^n (p_j x_j) \quad (3.2)$$

Subject to:

$$\sum_{j=1}^n a_{ij} x_j \leq b_i \quad i = 1, 2, \dots, m \text{ (resource / capacity constraints)} \quad (3.2a)$$

$$\sum_{j=1}^n x_j \leq d_i \quad j = 1, 2, \dots, m \text{ (market demand constraints)} \quad (3.2b)$$

$$x_j \geq 0 \quad j = 1, 2, \dots, n \quad (3.2c)$$

As shown in the product mix formulation above, product mix decisions are influenced by the unit contribution of products (p_j), resource requirement/consumption of products (a_{ij}), capacity of resources (b_i), and market demand of products (d_j).

While models setting up, the maximum of the demands were considered. At this direction, the condition that the the number of products produced in the model could not above of the demand or below of the zero. Nonetheless, if there was a situation that the determination of minimum number of the products produced, the

solution to this could be achieved by adding the minimum number of the requested products to the model.

Table 3.9: Net Profit of Product Mix According to TCA CPU

Traditional Cost Accounting (Ytl / 100kgs)									
	X1	X2	X3	X4	X5	X6	X7	X8	Total
Selling Price	390,00	395,00	400,00	405,00	490,00	350,00	355,00	360,00	
Variable Costs	297,90	297,70	303,64	316,54	367,84	272,77	272,57	290,74	
Contribution	92,10	97,30	96,36	88,46	122,16	77,23	82,43	69,26	
Product Mix Order	4	2	3	5	1	7	6	8	
Units Produced	3,50	17,00	27,00	38,72	7,00	0,00	0,00	0,00	93,22
Sales (Ytl)	322,34	1.654,03	2.601,59	3.425,25	855,09	0,00	0,00	0,00	8.858,30
Operating Exp (Ytl)									1.050,00
Net Profit (Ytl)									7.808,30

The product mix was calculated (refer to Table 3.10) according to traditional cost accounting and the total net profit was 8.353,75 Ytl.

Table 3.10: Net Profit of Product Mix According to TCA CPRM

Traditional Cost Accounting (Ytl / 100kgs)									
	X1	X2	X3	X4	X5	X6	X7	X8	Total
Selling Price	390,00	395,00	400,00	405,00	490,00	350,00	355,00	360,00	
Variable Costs	297,90	297,70	303,64	316,54	367,84	272,77	272,57	290,74	
Contribution	92,10	97,30	96,36	88,46	122,16	77,23	82,43	69,26	
Constraint Min	8,70	10,80	14,10	17,60	23,40	8,70	10,80	14,10	
Added Value per constraint resource min	10,59	9,01	6,83	5,03	5,22	8,88	7,63	4,91	
Product Mix Order	1	2	5	7	6	3	4	8	
Units Produced	3,50	17,00	27,00	27,30	7,00	2,00	17,00	0,00	100,80
Sales (Ytl)	322,34	1.654,03	2.601,59	2.414,94	855,09	154,46	1.401,30	0,00	9.403,75
Operating Exp(Ytl)									1.050,00
Net Profit (Ytl)									8.353,75

The result can also be achieved by integer programming (Figure 3.5).

13:54:54		Thursday	October	04	2007			
Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)	
1	X1	3,5000	92,1000	322,3500	0	basic	43,9773	M
2	X2	17,0000	97,3000	1.654,1000	0	basic	54,5925	M
3	X3	27,0000	96,3600	2.601,7200	0	basic	71,2735	M
4	X4	27,4543	88,4600	2.428,6060	0	basic	85,9610	91,3590
5	X5	7,0000	122,1600	855,1200	0	basic	118,2837	M
6	X6	2,0000	77,2300	154,4600	0	basic	43,9773	M
7	X7	17,0000	82,4300	1.401,3100	0	basic	54,5925	M
8	X8	0	69,2600	0	-2,0135	at bound	-M	71,2735
Objective		Function	[Max.] -	9.417,6660				
Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS	
1	C1	801,2251	<=	1.440,0000	638,7749	0	801,2251	M
2	C2	1.278,8010	<=	1.440,0000	161,1988	0	1.278,8010	M
3	C3	1.025,8200	<=	1.440,0000	414,1800	0	1.025,8200	M
4	C4	844,1291	<=	1.440,0000	595,8708	0	844,1292	M
5	C5	1.032,6240	<=	1.440,0000	407,3760	0	1.032,6240	M
6	C6	868,2069	<=	1.440,0000	571,7931	0	868,2069	M
7	C7	1.120,5930	<=	1.440,0000	319,4074	0	1.120,5930	M
8	C8	1.269,5100	<=	1.440,0000	170,4906	0	1.269,5090	M
9	C9	1.440,0000	<=	1.440,0000	0	5,0549	959,5500	1.624,1720
10	C10	3,5000	<=	3,5000	0	48,1227	0	27,9707
11	C11	17,0000	<=	17,0000	0	42,7075	0	49,1406
12	C12	27,0000	<=	27,0000	0	25,0865	0	61,0745
13	C13	27,4543	<=	50,0000	22,5457	0	27,4543	M
14	C14	7,0000	<=	7,0000	0	3,8763	0	27,5321
15	C15	2,0000	<=	2,0000	0	33,2527	0	39,5980
16	C16	17,0000	<=	17,0000	0	27,8375	0	61,4861
17	C17	0	<=	17,0000	17,0000	0	0	M

Figure 3.5: Net Profit of Product Mix According to TCA

The product mix was calculated (refer to Table 3.11) using the theory of constraints and the total net profit was 9.002,40 Ytl.

Table 3.11: Net Profit of Product Mix According to TOC

	TOC (Ytl / 100kgs)								Total
	X1	X2	X3	X4	X5	X6	X7	X8	
Sales Price	390,00	395,00	400,00	405,00	490,00	350,00	355,00	360,00	
Material Costs	218,00	217,80	217,70	217,60	215,40	205,10	204,90	204,80	
Throughtput	172,00	177,20	182,30	187,40	274,60	144,90	150,10	155,20	
Constraint Minutes	8,70	10,80	14,10	17,60	23,40	8,70	10,80	14,10	
Throughput per constraint resource min	19,77	16,41	12,93	10,65	11,74	16,66	13,90	11,01	
Product Mix Order	1	3	5	8	6	2	4	7	
Units Produced	3,50	17,00	27,00	13,68	7,00	2,00	17,00	17,00	104,18
Sales (Ytl)	602,00	3.012,40	4.922,10	2.563,44	1.922,20	289,80	2.551,70	2.638,40	18.502,04
Operating Exp (Ytl)									9.500,00
Net Profit (Ytl)									9.002,04

The result can be achieved by integer programming (Figure 3.6).

20:45:29		Tuesday	October	02	2007			
	Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
1	X1	3,5000	172,0000	602,0000	0	basic	93,1646	M
2	X2	17,0000	177,2000	3,012,4000	0	basic	115,6526	M
3	X3	27,0000	182,3000	4,922,1000	0	basic	150,9909	M
4	X4	13,7571	187,4000	2,578,0880	0	basic	0	192,6241
5	X5	7,0000	274,6000	1,922,2000	0	basic	250,5806	M
6	X6	2,0000	144,9000	289,8000	0	basic	93,1646	M
7	X7	17,0000	150,1000	2,551,7000	0	basic	115,6526	M
8	X8	17,0000	155,2000	2,638,4000	0	basic	150,9909	M
	Objective	Function	(Max.) =	18,516,6900				
	Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
1	C1	804,5085	<=	1,440,0000	635,4915	0	804,5085	M
2	C2	1,282,9690	<=	1,440,0000	157,0314	0	1,282,9690	M
3	C3	1,029,9000	<=	1,440,0000	410,1000	0	1,029,9000	M
4	C4	703,0485	<=	1,440,0000	736,9514	0	703,0486	M
5	C5	860,0400	<=	1,440,0000	579,9600	0	860,0400	M
6	C6	896,6115	<=	1,440,0000	543,3885	0	896,6115	M
7	C7	1,157,2540	<=	1,440,0000	282,7457	0	1,157,2540	M
8	C8	1,244,8160	<=	1,440,0000	195,1843	0	1,244,8160	M
9	C9	1,440,0000	<=	1,440,0000	0	10,7086	1,199,2500	1,649,7750
10	C10	3,5000	<=	3,5000	0	78,8354	0	27,3380
11	C11	17,0000	<=	17,0000	0	61,5474	0	39,2917
12	C12	27,0000	<=	27,0000	0	31,3091	0	44,0745
13	C13	13,7571	<=	50,0000	36,2429	0	13,7571	M
14	C14	7,0000	<=	7,0000	0	24,0194	0	17,2885
15	C15	2,0000	<=	2,0000	0	51,7354	0	29,6724
16	C16	17,0000	<=	17,0000	0	34,4474	0	39,2917
17	C17	17,0000	<=	17,0000	0	4,2091	0	34,0745

Figure 3.6: Net Profit of Product Mix According to TOC

When sensitivity analysis of Right Hand Size of the results the model according to TOC was done, the capacity limit of the bobbin machine (resource I) being a constraint for the system was 1.649,775 minutes. In other words, the bobbin machine would be constraint until the extra capacity of bobbin machine was 14,57% above of the existing capacity of the machine $(1649,775-1440,000)/1440= 14,57\%$).

3.6 Discussions on the Results

To answer the question of “Is there any constraint in manufacturing system of the firm”, the analysis of source load was done and was seen that there were multiple constraint. The capacity usage rate of Bobbin machine is 144 %, the capacity usage rate of Ring Spinning machine is 127 %, Carding Machine is 122 % and Roving Machine is 108 % . As a result, this four resources are constraint resources due to the reason that they are behind of the demanded capacity.

It was seen that there was not any product mix determination in the firm while answering the question of “Does the firm determine the product mix decisions according to the tradional accounting system”. While discussing with the top

management of the firm, they informed that the main aim of the firm is to customer satisfaction and mostly for the sake of long-term profits they manufacture the products which are requested by customers even they have poor profitability. Such situation can be to manufacture poor profitable products with high profitable products due to the reason of the customers would like to receive their requirements from the same firm. For this reason, the firm does not determine optimum product mix and it manufactures without considering the poor profitability. But if there is, it would be the profitability to consider by top management. At this direction, the product mix model was determined by setting up the product mix model considering the unit contributions.

While answering the question of “Will the firm creates more profitable results by TOC comparing traditional cost accounting system”, the product mix determined by setting the model up with integer programming and analysing the algorithm of the solution by computer program considering total capacities. Afterwards, the product mix determined by setting the model up with traditional cost accounting system. Consequently, the results were compared with product mix which were determined by two models. Integer programming in WinQSB were used to analyse the models.

Net profit of the product mix achieved by TOC is 9.002,04 Ytl, net profit of the product mix achieved by traditional cost accounting system (Contribution Per Constraint Resource Ordering) is 8.353,75 and net profit of the product mix achieved by traditional cost accounting system (according to Contribution ordering) 7.808,30 Ytl.

Figure 3.7 shows us the Product Mix After Removing CCR at Resource I.

Table 3.12: Load Calculation After Removing CCR at Resource I

Products	Daily market potential (100 kgs)	Capacity per 100kgs for resources (minutes)								
		A	B	C	D	E	F	G	H	I
X1	3,50	28,70	45,85	36,75	36,05	44,10	30,10	38,85	22,05	25,90
X2	17,00	139,40	222,70	178,50	175,10	214,20	146,20	188,70	151,30	158,10
X3	27,00	221,40	353,70	283,50	278,10	340,20	232,20	299,70	313,20	326,70
X4	50,00	410,00	655,00	525,00	515,00	630,00	430,00	555,00	810,00	755,00
X5	7,00	57,40	91,70	73,50	72,10	88,20	60,20	77,70	174,30	140,70
X6	2,00	13,60	21,60	17,40	0,00	0,00	17,20	22,20	12,60	14,80
X7	17,00	115,60	183,60	147,90	0,00	0,00	146,20	188,70	151,30	158,10
X8	17,00	115,60	183,60	147,90	0,00	0,00	146,20	188,70	197,20	205,70
Total load(minutes)		1.101,70	1.757,75	1.410,45	1.076,35	1.316,70	1.208,30	1.559,55	1.831,95	1.785,00
Available capacity (min)		1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00	1.440,00
Overload (minutes)		-338,30	317,75	-29,55	-363,65	-123,30	-231,70	119,55	391,95	345,00
Capacity utilization (%)		76,5%	122,1%	97,9%	74,7%	91,4%	83,9%	108,3%	127,2%	124,0%

CCR2

10-03-2007 20:40:21	Decision Variable	Solution Value	Unit Cost or Profit C(j)	Total Contribution	Reduced Cost	Basis Status
1	X1	3,0000	172,0000	516,0000	0	basic
2	X2	17,0000	177,2000	3.012,4000	0	basic
3	X3	27,0000	182,3000	4.922,1000	0	basic
4	X4	26,0000	187,4000	4.872,4000	0	basic
5	X5	7,0000	274,6000	1.922,2000	0	basic
6	X6	2,0000	144,9000	289,8000	0	basic
7	X7	17,0000	150,1000	2.551,7000	0	basic
8	X8	17,0000	155,2000	2.638,4000	0	basic
	Objective Function	(Max.) =		20.725,0000		

Figure 3.7: Product Mix After Removing CCR at Resource I

The fifth step of the Five Focusing Steps is “Go back to step 1, but beware of system inertia”. If the system constraint is eliminated, then the system constraint is different source from that time, but the system is more profitable. We assume that the capacity of the bobbin machines (resource I) was increased 16,67 % by adding a new bobbin machine. It would be seen from the load calculation after removing CCR at I resource (Table 3.12), the new constraint became the resource H (Ring spinning machine). When the model solved by new capacities of the system in WinQSB, Total throughput of the system increased by 2.233,31Ytl from 18.516,69 Ytl to 20.750,00Ytl.

4. RESULTS

Optimum product mix decisions are very important in increasing profitability of the firms because the firms would like to produce the products which are making the maximum profit with existing capacities. Due to this reason, firms need to determine product mixes which provides the maximum profits. There are some kinds of new approaches like TOC, ABC etc. to the optimum product mix determination besides full costing and variable costing systems to remove their deficiencies. From the investigation results of the literature, it is clear that in determining the optimum product mix, TOC is much more profitable than traditional approaches

The purpose of the research is to provide and apply a model for product mix and the effect of the results to the profitability of the firm by using Theory of Constraint approach. In this frame, descriptive and exploratory case studies had been made in a ring spun cotton yarn manufacturing firm. As a result of detailed research, observation and discussions with top management in the frame of descriptive case study, manufacturing process had been observed and the data of the production cost had been provided.

Throughput accounting takes shape above of the five focusing steps of Theory of Constraints, identifying the system's constraint, deciding how to exploit the system's constraints, subordinating everything else to the step two, elevating the system's constraints, going back to step one.

Answer of the question "Is there any constraint in manufacturing system of the firm" is yes. Eight products had been investigated in the case study. There are some quantity of product demand different from these 8 products, sometimes but they were not considered in product mix analysis because of the uncertainty. The five combed products are processing in the 9 manufacturing processes. the three carded products are processing in the 7 manufacturing processes skipping the combing preparation and combing processes. While comparing the capacities needed to meet the demand and existing capacities of the machines, it had seen that the needed capacity is much more than the existing capacity. It means that there are constraint (bottleneck)

machines which limit the capacity. The analysis of source load was done and was seen that there were multiple constraint. The capacity usage rate of Bobbin machine is 144 %, the capacity usage rate of Ring Spinning machine is 127 %, Carding Machine is 122 % and Roving Machine is 108 % . As a result, this four resources are constraint resources due to the reason that they are behind of the demanded capacity.

Besides, it had been studied that whether the firm takes advantages of traditional cost accounting system while determination of the product mix decisions. It had seen that the main aim of the firm is customer satisfaction and mostly for the sake of long-term profits they manufacture the products which are requested by customers even they have poor profitability. For this reason, the firm does not determine optimum product mix and manufactures without considering the poor profitability. But if there is, it would be the profitability to consider by top management.

In case of determination of product mix, it had studied that how the product mix decision would be made according to throughput accounting and whether the results of throughput accounting was more profitable than the product mix decisions according to traditional cost accounting system or not with exploratory case study. Integer programming with WinQSB had been used in determination of the optimum product mix and the results of the TOC and TCA had been compared.

Consequently, it had been decided that the result of product mix profitability of TOC (9.002,04 Ytl) was superior than the result of product mix profitability of TCA (8.353,75 Ytl).

As a summary, in this research the traditional cost accounting system and the throughput accounting system of TOC were compared. For this reason, optimum product mixes determined and the results of the profitabilities compared. It was seen that the maximum profit was of throughput accounting system. To sum up, the firms which are in textile manufacturing business and have similar conditions, could be achieve more profitable solutions by throughput accounting of TOC.

5. CONCLUSION

The objective of this research was to utilize the TOC management principles to improve the performance of the manufacturing facility. TOC is a continuous improvement process wherein a manufacturing system is viewed as a chain, and the objective of the process is to continually strengthen the chain by identifying and strengthening the weakest link. The general principles of TOC can be applied to improve the performance of organizations. It is important to identify the flow of material, inventory and throughput at various organizations. The recognition of the nature of organization constraint is the first step towards continuous improvement due to the reason the system constraint is at the heart of TOC. Constraints are sometimes found to be policies and procedures rather than capacity or equipment. Although the drum-buffer-rope methodology was originated as a control technique for the shopfloor, it could be used to exploit the system constraint and subordinate the resources to it (Siha, 1999).

This research utilized the set of performance measures (throughput, inventory and operating expense) developed by Goldratt and provides support for the claim that these measures provide a direct link between the local production capabilities of the constraint and the organization's performance.

The only difference of the two approaches (TCA and TOC) was the assumptions upon which the product mix decisions were based and the measures of performance used in developing these decisions. All of the assumptions about the external conditions and how the market would respond remained constant both scenarios (Draman, R.H., 2002).

It can be seen from this research that the use of TOC based cost accounting for product mix decision making provides superior results when compared to traditional cost accounting. This research demonstrated that the strategic decisions based upon TOC based cost accounting produced significant improvements in financial performance when compared to decisions using TCA. The increase in daily profit

ranged from 8 to 15 percent. From this research one can speculate as to how constraint-based cost accounting might actually affect real world strategic decisions.

As a result, any improvements in planning and execution at the constraint can be directly translated into improved bottom line performance. Recognizing this direct cause and effect linkage between the constraint's improvement and improved organizational performance should provide some additional rigor to the strategic planning efforts.

Consequently, the firms which are in textile manufacturing business and have similar conditions, could be achieve more profitable solutions by throughput accounting of TOC.

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RESUME

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