Introduction to the Theory of Constraints
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Learning Objectives

Upon completion of this course, student will be able to:
- Discuss the origins of the Theory of Constraints
- Examine its philosophy and governing principles
- Describe its applications
- Walk through its Five Focusing Steps
- Study some examples, and review typical results
- Examine the relationship between the Theory of Constraints and Critical Chain Program Management

Introduction

Goal - Making Money

The Theory of Constraints (TOC) is a system improvement philosophy developed by Dr. Eliyahu M. Goldratt.

In order to understand the foundation of this theory, think of an organization or company in terms of its investments in equipment and inventory. Operating expenses are continually poured in to pay for people and equipment. As the people and equipment add value to the inventory, they generate throughput. In for-profit organizations, throughput refers to the money generated through sales. In nonprofit, service, and government organizations, throughput refers to better serving customers at less cost.

TOC explains that the three ways for a company to make money are as follows: reduce operating expenses by eliminating waste in the operation; reduce inventory to better utilize machines and equipment; and increase throughput in order to be more profitable or to better serve the customer.

Typical TOC Results

Since 1985, TOC has been delivering startling, tangible results to companies worldwide. An independent study of TOC implementations around the world found the following significant results were being achieved consistently:

- Revenue / Throughput / Productivity - UP 63 percent
- Revenue / Throughput / Profit – UP 76 percent
- Due Date Performance – UP 44 percent
- Inventory Levels – DOWN 49 percent
- Lead Times – DOWN 70 percent

Moreover, the study found these results usually occurred within a few months to a year.
Process Structure

Before we continue, let’s take a moment to review the structure of a process, as it relates to TOC.

There is no product or service without a process, and no process without a product or service. A process is any activity or group of activities that takes an input, adds value to it, and provides an output to an external or internal customer. These activities are independent elements, which are linked together and depend on each other to function properly. As shown here, a higher level process can be broken down into sub-processes, each with its own inputs and outputs.

In any process, there are steps that flow smoothly and others that don’t. Steps that act as constraints or bottlenecks in the process are typically caused by such things as limited resources, complexity, and variation.

Next, we will examine how this process structure fits in with the TOC philosophy.

TOC Philosophy

TOC is a system-based improvement philosophy. It asserts that the constraint determines the performance of the system. Managing from the constraint provides the focus and leverage to maximize system performance. Eliminating systemic constraints is the focus of TOC.
To visualize this basic TOC philosophy, think of the operations or steps in a Value Stream as links in a chain. A chain is only as strong as its weakest link. To improve the strength of the system, it is necessary to find the weakest link in the chain, and strengthen it.

Now, let’s look at a very simple example.

**How Does This Relate?**

Now let’s apply the TOC philosophy to a purchasing process. In this process, purchase requests can be entered at the rate of 12 per hour. Purchase orders can be prepared at the rate of seven per hour, and four per hour can be approved. The rate of vendor selection averages eight per hour, and orders can be placed at the rate of six per hour. The overall market demand is seven per hour.

The throughput of the process is determined by the system constraint. In other words, the weak link sets the pace for the entire operation. Select the weak link in this process by clicking on it.

**Application of Theory of Constraints**

Although TOC was originally introduced in manufacturing, its application is not limited to production. For example, business development and product development can benefit through shorter cycle times and increased throughput; it can help improve the supply chain, from supplier through customer; and it applies to all types of business management and service functions. In fact, TOC is a holistic approach that applies to all facets of a business.
Types of Constraints

Now that you understand the basic TOC philosophy, let’s dig a little deeper to see how it works.

There are two types of constraints that can occur in any organization or process flow: non-physical and physical.

Policies, rules, measurements, and training are examples of non-physical constraints. Organizations design and implement policies, measurements, and the like to help employees make better decisions and take appropriate actions. In reality, however, these non-physical constraints can inhibit a system’s ability to continue to improve. To keep up with changes to the business, an organization must constantly review its policies, rules, measurements, and training.

Physical constraints stem from limitations or inefficiencies with people, materials, equipment, and in some cases, geography. Because physical constraints are usually easy to see, organizations can use Lean and Six Sigma techniques to deal with them.

Non-physical constraints are much more difficult to deal with. For example, most people have trouble identifying and improving ineffective or inefficient policies. That’s because many policies cover several departments or organizations, and responsibility for changing policies often lies outside their domain.

TOC Body of Knowledge

TOC is about change. Applying the principles and tools of TOC answers questions about what to change; what to change to; and how to cause the change. These are basic questions to which every manager must seek answers.

In his book, The Goal, Dr. Goldratt describes a five-step improvement process that focuses on managing the physical constraints. These steps form the process by which many organizations have achieved dramatic improvements to their processes. They are called the Five Focusing Steps of TOC.

TOC also includes a set of six tools and techniques for a logic-based analysis. Known collectively as the TOC Thinking Process, they deal with the qualitative problems presented by constraints, especially policy
constraints. The TOC Thinking Process is applicable to any system, as long as the goal of the system can be determined.

We will provide a brief overview of the TOC Thinking Process later in this module. But first, let’s take a closer look at the Five Focusing Steps.

**5 Focusing Steps of TOC**

The Five Focusing Steps of TOC are used to concentrate improvement efforts on the parts of the process that are most capable of producing the most positive impact on the system. Before applying these steps, the TOC approach requires an organization to understand the system, its goals, and measurements.

The Five Focusing Steps are Identify; Exploit; Subordinate; Elevate; and Repeat.

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**Step 1: Identify**

The first of the Five Focusing Steps is to identify the current constraint. This is the single part of the process that limits the rate at which the goal is achieved.

Earlier, we used a simple chain analogy to introduce the basic concept of TOC, where the weakest link represented the constraint. Another way to visualize physical constraints is to think of water flowing
through a series of pipes. The larger the diameter of the pipe, the greater the flow rate. If a narrow section of pipe is inserted, the flow through this pipe will determine the flow of the entire system downstream.

In every system, there is one step that most constrains the output of the entire system. This one point is the current constraint, or bottleneck. The bottleneck rate becomes the maximum output rate of the entire process.

**Bottleneck**

The trick to the Identify step is to understand what a bottleneck looks like. On paper, a bottleneck is predicted for a given time period, or product mix, when the demand is greater than the supply. For example, if the equipment hours required to produce to a certain demand exceed the available hours, then a bottleneck will occur. Similarly, in any nonmanufacturing environment, if customer needs exceed the ability to deliver or perform, a bottleneck will occur.

Symptoms of a production bottleneck include high Work-In-Process inventory before the operation; high utilization at the operation; and a chronic state of both high Work-In-Process and high utilization.

Remember, bottlenecks can occur in service and nonprofit organizations, too. Here, symptoms include not achieving sales goals; not producing what customers want; and too slow or poor outside-in positioning and execution.

The Value Stream Map is a tool that can help identify and quantify bottlenecks.
Step 2: Exploit

The second of the Five Focusing Steps is Exploit. This step is sometimes called Optimize.

After the constraint has been identified, the next step is to optimize it without additional investment. The goal is to make quick improvements to the throughput of the constraint, using existing resources. In other words, “Make the most of what you have.”

Let’s look back at our earlier examples to see how this step might apply in both a production and a service environment. In our pipe example, the focus would be to make sure as much water as possible flows through the restricted area, without enlarging the pipe. In our purchasing process example, several Lean tools would be applied to reduce transportation, defects, and waiting time, without adding additional investment in people or equipment.

Step 3: Subordinate

The third of the Five Focusing Steps is Subordinate.

Once the constraint has been identified and exploited, the next step is to subordinate everything else to the decisions made in Steps One and Two. The organization must determine how to synchronize the rest of the chain to operate without the constraint. It must review all other activities in the process to ensure they align with, and truly support, the needs of the constraint. To do this, it looks for ways to offload from the constraint to the non-constraints. Only improvements to the constraint or bottleneck will improve system throughput.

To illustrate this step, let’s take another look at our pipe and purchasing process examples. In our pipe example, the Subordinate step must ensure that all other pipes are flowing as smoothly as possible to allow the narrow portion of the pipe to provide its maximum flow.

In the case of the purchasing process, the tools put in place to visually manage purchase orders must be maintained and carefully controlled; the priority system must be well documented and communicated to the organization in order to be followed; and backup approvers must know each other’s role.

Requests requiring approval must take top priority.
Drum-Buffer Rope

Drum Buffer Rope (DBR) is a planning and scheduling technique derived from TOC. It is commonly used during the Subordinate step. The fundamental assumption of DBR is that within any process there is one constraint (or a limited number of constraints) that controls the overall output of that process. This is referred to as the “drum” because it sets the beat, or pace, for all other resources.

A “buffer” is placed ahead of the constraint operation to ensure the constraint does not run out of work. The aim of DBR is to protect the weakest link in the system, and thereby the system as a whole, against process waste and variation. The intent is to maximize the overall system’s effectiveness.

The “rope” controls material release duration in order to keep the buffer at a certain level. It is a time-based mechanism, which pulls directly from stock or from previous operations to maintain the buffer.
Drum-Buffer Rope Production Control

TOC encourages every process to work as fast as possible – when there is work. In a manufacturing operation, the constraint is a drum that beats the cadence of the plant. A time buffer of material placed between the raw materials and the constraint protects it from starvation. A rope throttles the raw materials to maintain buffer inventory at minimum levels. DBR ensures that work completes at predictable flow times.

In the DBR process, every effort is made to increase the efficiency of the constraint, even to the detriment of other measures. The inventory level (the buffer) must ensure the constraint never runs out of work. The rope mechanism restricts all inventory not needed to protect the constraint, from entering the system. Each operation is directed to work as fast as possible (without compromising quality) when there is work, and to sit idle when there is none.
Step 4: Elevate

The fourth of the Five Focusing Steps is Elevate. The aim of this step is to increase the capacity of the constrained resource in order to bring constraint performance to a higher level. By increasing the flow of the current constraint, this step enables the system to generate even more throughput. Normally, actions are continued at this step until the current constraint has been “broken.” In some cases, capital investment may be required.

In our purchasing process example, Elevate might consist of providing an electronic means for purchase order approval that includes a tracking and notification system. In the case of our pipe example, the Elevate step would focus on increasing the diameter of the narrow portion of the pipe to increase the flow through the system.

Notice that the current constraint’s flow has increased, but there is now a new constraint that limits the overall flow. As you will see in the next step, improvement efforts don’t end when the flow of the current constraint is successfully increased.
Step 5: Repeat

The fifth of the Five Focusing Steps is Repeat.

The Five Focusing Steps are a continuous improvement cycle. Therefore, once a constraint is resolved, the next constraint should be addressed immediately. Going back to Step 1, the cycle starts again with the identification of the new constraint.

The Repeat step is a reminder to never become complacent. To ensure continuous improvement, an organization must aggressively improve the current constraint, and then immediately move on to the next constraint.

TOC Thinking Process

Now that you understand the Five Focusing Steps of TOC, let’s take a brief look at the TOC Thinking Process.

As you learned earlier in this module, there are six tools and techniques in the TOC Thinking Process. While these tools can be used in a standalone manner for a variety of situations, they come together to provide an integrated problem-solving methodology. It is one that answers questions regarding what an organization’s goals or standards are; what to change; what to change to; and how to cause the change to happen.
The Intermediate Objectives Map (or IO Map) is a graphic representation of a system’s goal, critical success factors (CSFs), and the necessary conditions (NCs) for achieving them. It is intended to fix, in time and space, a firm baseline or standard for what should be happening if the system is to succeed. These are not the things an organization would like to do, but rather the things it must do if the goal is to be achieved.

The Current Reality Tree (or CRT) is used to examine the cause and effect logic behind the current situation, and it determines why that situation is different from its preferred state. To do this, the CRT begins with undesirable effects. It then works backward to identify a few critical root causes, which originate all the undesirable effects. Eventually, these critical root causes will include the system constraint. The CRT answers the question of what needs to be changed.

The Conflict Resolution Diagram, or Evaporating Cloud, is designed to resolve hidden conflicts, which are usually the basis of chronic problems. It identifies an objective, requirements, and prerequisites, which are often in conflict with each other.

The Future Reality Tree (or FRT) is used to verify that a proposed action will produce the desired results. It is also used to help identify any unfavorable new consequences, or contemplated actions, and fix them before they become problems. The FRT, along with the CRT, answers the question of what to change to.

The Prerequisite Tree is used to help implement decisions once the course of action has been determined. It determines the sequence of activities needed for implementation; identifies implementation obstacles; and suggests the best ways to overcome those obstacles.

The Transition Tree is designed to provide step-by-step instructions for implementing a course of action. It is a detailed roadmap of the objective. The Transition Tree, along with the Prerequisite Tree, answers the question of what actions will cause the change.
Projects

Projects fail at an alarming rate. Many are canceled before completion, wasting time, money, and resources. Surviving projects often fail to deliver the full project scope, or they deliver late or over budget.

Successful projects meet the needs of all the stakeholders who have an interest in the project. Every project has a goal, which typically requires conditions of scope, cost, and schedule to be satisfied. The scope sets a minimum standard for the project results. The necessary cost and schedule conditions often set maximum values.

These conditions of scope, cost, and schedule are interdependent. For example, the longer a project takes, the more it costs. The more a project costs, the longer it takes. The longer a project takes, the more opportunities exist to impact the scope. And so on. Resources have an influence on all three necessary conditions.

Critical Chain Project Management

Critical Chain Project Management (CCPM) is a method of planning and managing projects. Like TOC, it was developed by Dr. Goldratt.

Traditional project management methods emphasize task order and rigid scheduling. CCPM, on the other hand, puts the main emphasis on the resources required to execute project tasks. It focuses on keeping the resources evenly loaded. At the same time, it requires them to be flexible in their start times and to quickly switch between tasks, and task chains, to keep the whole project on schedule. The Critical Chain is defined as the longest path through the project, considering both task logic and resource conflicts. Critical Chain tasks control the project duration and do not change for the life of the project. The Critical Chain schedule builds from the back to the front, rather than front to back. By working backwards through the tasks to build the project, it focuses on the final delivery date. In so doing, CCPM creates a schedule that minimizes resource conflicts. This scheduling method is based on two principles. The first is that multi-tasking on the critical path hinders productivity. The second is that unavailable resources can cause the project schedule to slip.
Lost Productivity

We have all seen the extraordinary things that can be accomplished, and the seemingly impossible challenges that can be met, when everyone is focused on the most urgent and important work. On the other hand, lack of clear goals, measurements, and communications can hinder creativity and productivity in very subtle ways. There are many ways in which project productivity can be lost; Parkinson’s Law and the Student Syndrome are two of the most critical.

Parkinson’s Law states that work expands to fill the available time and resources. It is a major component of lost productivity, and it is almost invisible. As an example, imagine you have a task due in two months. You know it won’t take two months, and your other tasks are not very well defined. Therefore, you start slowly and work on the tasks in small chunks. You fear that if you finish too early, then new tasks will be assigned to you with unrealistic time requirements. You may even finish the task early, but not declare it done for the same reason.

The Student Syndrome refers to a tendency for people to wait until the last possible moment before fully applying themselves to completing a task. For example, they may put in some effort in the beginning, but when more urgent issues arise, the activity stops. In short, they feel no sense of urgency until right before the deadline. Often, the unexpected occurs and Murphy’s Law strikes, causing additional delay and a missed deadline.
Critical Chain Methodology

Project task duration times are often estimated with wastes built in as a safety net. However, Parkinson's Law and the Student Syndrome work to offset the safety and slack time built in to tasks. As a result, the project becomes affected by uncertainty and delay, which are bound to occur in any project.

Critical Chain methodology offers the following three tactics to help overcome this uncertainty:

Fill the schedule with task durations that are too tight to allow or encourage delay and procrastination
Get rid of task due dates, and focus on protecting the promise date of the entire project
Protect project resources from interruptions that cause distractions

Critical Chain methodology requires that the schedule be built with only the time to do the work activity. That is, without any safety time built in. To accomplish this, we focus on the resources who do the work. There are only two kinds of resources: resources that perform critical tasks, and resources that perform noncritical tasks. Since the critical tasks determine how long the project will take, they become the focus of attention. We want to make sure that the critical chain resources are available when a preceding task is done, without relying on fixed due dates.

The task duration estimate is not a single number, but a range of possibilities starting with the minimum time to complete work, up to a safe estimate with 85 to 95 percent confidence. Between this is the aggressive estimate at 50 percent confidence, which has most of the safety time removed.
Creating Buffers

The difference between the 50 percent tasks duration and the 85 percent is the safety time which, as we have seen, is often built in to the task duration estimate. In Critical Chain, these safety times are removed from the tasks and placed in buffers; in this case a project buffer.

Buffer Management

The purpose of the project buffer is to protect the due date from variation that can occur in the critical chain. In more complex projects, there will be a feeding buffer at the end of each task, which protects the critical chain process from variation due to noncritical tasks. Whenever a new resource is required, a resource buffer is used to alert that new person to be available to work on the task.
Buffer Usage

If a task finishes early, the excess time is added to the buffer. If the task is late, time is taken away from the buffer. As tasks are completed, we know how much they have consumed or replenished the buffers. By watching the percentage of project buffer used, the team can get a sense of when to take action or not take action.

The buffers allow focus, simplify priorities, and provide early warning regarding the overall health of the project. Planning and action depends on how much buffer has been consumed or replenished by task performance, which tells us when to act to protect the critical chain and the project due date.

The Power of TOC

The Five Focusing Steps of TOC can be applied to every process, at every level in an organization. In fact, this is how TOC is most often implemented. However, the true power of TOC comes from applying many of the tools of Six Sigma and Lean. Here are some examples of what these tools can do:

1. Help organizations understand the interdependencies, between and across processes, that contribute to delivering a product or service. The Voice of the Customer (VOC) can be used for understanding the process.
2. Help organizations understand the impact that those interdependencies and normal variability have on their combined, overall performance. Six Sigma methodology can be applied, as needed, to help manage variation.

3. Appropriately buffer for interdependencies and normal variability so that that performance can be predictably and consistently high. Several Lean tools and control phase tools can be used for controlling the process.

**Where TOC is Needed Most**

In summary, TOC is a powerful thought process and tool set, which can have significant impact on all aspects of the business. It applies very well in strategic projects that are outside-in focused and highly cross functional. Many of the tools work well for complex business processes. These tools allow large projects to be subdivided into multiple sub-projects that need to be prioritized.

TOC also works well for avoiding sub-optimization. Recall that sub-optimization occurs when different sub-units each attempt to reach a solution that is optimal for that unit, but may not be optimal for the organization as a whole. TOC can be used to identify system interdependencies and manage the constraints against the goals of the organization. This gives organizations the ability to identify the right improvement projects on which to work.