

Theory of Constraints — What Is It?

Robert B. Austenfeld, Jr.

(Received on October 15, 1998)

1. Introduction

The purpose of this paper is to provide an overview of a powerful approach to improving systems called the Theory of Constraints (TOC). I first heard of this theory two years ago while attending a conference on quality management. At the next year's conference, I decided to take a one-day tutorial on TOC. Since that tutorial I've continued to learn more about this innovative approach to systems improvement and would now like to share what I've learned with anyone interested. This paper will be divided into the follow parts: some basic ideas, the five focusing steps and a simple example, the TOC thinking process including the eight categories of legitimate reservation and how to use the process, and finally some comments on "advanced" TOC. Before starting, however, let me provide some more background on TOC.

Theory of Constraints is almost synonymous with the name Eliyahu M. Goldratt and his now famous book, *The Goal*. Written in 1984 and since revised twice, *The Goal* has been referred to as both a management text and a novel; even a love story. The story's central character is Alex Rogo, the manager of a fairly large manufacturing plant that, tied to the traditional methods of cost accounting, just can't seem to get anything right. Although the plant's "efficiencies" are improving, its inventories are mounting, its people are overworked, its orders are late, and, as the story begins, Alex's boss has just given him three months to "turn things around" or the plant will be closed. In parallel with Alex's plant troubles and, in part due to them, are his marital difficulties. With little time to devote to his wife, Julie, whom he

really loves dearly, he forgets a promise to spend the weekend with her which is the straw that breaks the camel's back; Julie leaves him. From this point on the story is about Alex moving his plant back into the black and wooing his wife back. In both cases, the story has wonderful endings.

The story is mainly to explain, in a most readable form, TOC. Towards this end, the next most central character is Jonah, a former teacher of Alex. Alex just happens to run into Jonah after many years and, from their initial meeting, begins to realize that Jonah may have the answers he's looking for to turn the plant around. And indeed Jonah does; but, instead of giving them to Alex directly, Jonah employs the Socratic method forcing Alex (and the reader) to reflect at each important step to recovery on what should be done next. So the story is both a novel and a powerful management tutorial on TOC in that it forces the reader/student to think things through as the story progresses.

Since those early days of TOC, a number of consulting/training organizations have sprung up. One of the most famous is that of Goldratt's himself, the Avraham Y. Goldratt Institute (named after his father) in New Haven, CT. Another such organization is Goal Systems International (GSI). The person conducting the one-day tutorial I attended, Bill Dettmer, is from GSI. Typically, courses range from two to nine days or more. In fact, the Goldratt Institute even offers a 12 months program consisting of both classroom training and real world application periods.

Before delving into the details of TOC, let's set down a definition from the CIRAS¹⁾ home page (1998):

The Theory of Constraints (TOC) is an overall management philosophy that enables the managers of a system to get more of the goal that the system is designed to produce. If, for example, the goal of a business is to make money now and in the future, TOC will enable the managers of the company to do so. Although technically correct, this definitions leaves a lot to be desired in terms of

1) Iowa State University's Center for Industrial Research and Service (CIRAS).

really understanding TOC. It is towards that end this paper is presented.

2. Some Basic Ideas

The following are the fundamental ideas upon which TOC is built:

- Consider systems as chains.
- In every system (chain) there is at least one and usually only one significant constraint (or weakest link).
- To improve a system you must have a clear understanding of the system's goal.
- Concentrate on three measures: throughput (T), inventory (I), and operating expense (OE).
- Concentrate on global optimization.
- Constraints can be physical or policy.

Let us now look a little closer at each of these basic ideas.

Consider systems as chains. Turning this idea around we could think of a chain as a system. That is, think of each link as a component of something that, taken together, performs a function (or satisfies a goal) of some sort — say, transmission of a force from one end of the chain to the other. That something is called a system; it has taken inputs (a force at one end) and, by a process of “action and reaction,” has performed the function of transmitting that force to the other end where it becomes an output. The analogy can be applied to any system but perhaps is most easily visualized in terms of some simple manufacturing operation that involves taking some material and processing it through several steps into a finished product.

In every system (chain) there is at least one and usually only one significant constraint (or weakest link). Goldratt contends that just as with a chain there is a weakest link, in every system there will be at least one (usually only one) “weakest component.” This weakest component is the system's constraint. Using a simple example from Dettmer (1997), suppose we have a five step manufacturing system

Figure 1. A simple five step manufacturing process.

inputs →	Step A	Step B	Step C	Step D	Step E	outputs →
each step's capacity →	10 Units/Day	20 Units/Day	6 Units/Day	8 Units/Day	9 Units/Day	

composed of five processes (Figure 1). In this example the market demand is 15 units per day. It should be obvious that with a market demand of 15 units per day there is no way this system will meet demand. However, the question TOC asks is where is the constraint? Looking at each step, we can see that the most this system can produce is 6 units per day due to that being the most Step C can do. In TOC terms, Step C is the weakest link (or constraint) of this system.

To improve a system you must have a clear understanding of the system's goal. This may sound self-evident but, as the book *The Goal* demonstrates in this quote, the system's goal is probably often not well understood in a manager's mind; Alex Rogo the plant manager is talking to Jonah who is about to board an airplane:

"Wait a minute! What do you mean, I don't know what the goal is? I know what the goal is," I tell him.

By now we're at the door of the plane. Jonah turns to me. The stewardess inside the cabin is looking at us.

"Really? Then, tell me, what is the goal of your manufacturing organization?" he asks.

The goal is to produce products as efficiently as we can," I tell him.

"Wrong," says Jonah. "That's not it. What is the real goal?"

I stare at him blankly.

The stewardess leans through the door.

"Are either of you going to board this aircraft?"

Jonah says to her, "Just a second, please." Then he turns to me. "Come on Alex! Quickly! Tell me the real goal, if you know what it is." (Goldratt, 1992,

pp. 32–33)

Alex goes on to suggest power and, then, market share but, again, Jonah indicates that neither of those is the real goal and leaves Alex at the gate to figure it out.

Concentrate on three measures: throughput (T), inventory (I), and operating expense (OE). The “goal” discussion that Jonah starts at the airport gate later concludes with the answer that the goal of the organization is to make money. However, the TOC philosophy is in significant disagreement with traditional thinking on the best way to achieve this goal. Whereas conventional wisdom from the traditional cost accounting world says we should do everything we can to cut costs (operating expenses), TOC says we should instead concentrate on making money first! To provide the measure needed to see how well we are meeting this primary goal (making money) Goldratt has come up with the following definition (CIRAS home page, 1998):

- Throughput (T): The rate at which the system generates money through sales.
(Or, the money coming into the organization.)

Throughput is selling price minus materials. Another name for throughput is “contribution.”

To round out our picture of what is happening in a system when we make changes to it, Goldratt has come up with two more definitions (again, courtesy of CIRAS):

- Inventory (I): Everything the system has invested in that it intends to sell. (Or, all the money tied up inside the system.)
- Operating Expense (OE): All the money the system spends in order to convert I into T. (Or, all the money leaving the system.)

Inventory includes not only the “usual” inventory consisting of raw material, purchased parts, work-in-process (WIP), and finished goods, but also the “remaining value” of anything owned by the company to produce T such as buildings, machinery, computers, etc. Depreciation on these items is OE. OE includes all employee time whether we’re talking about direct or indirect labor, vacation time,

or sick time. As long as the employee is being paid the same amount regardless of T, it is OE. Also the usual things such as utilities and consumable supplies are part of OE.

All three measures are denominated in dollars as is the goal: *to make more money now and in the future*. This way it is easy to begin evaluating business decisions based on answering these three questions:

- Will it increase T? If so, how?
- Will it decrease I? If so, how?
- Will it decrease OE? If so, how? (Dettmer, 1997)

When considering these questions, one should also ask which of these three should be given priority? This is, indeed, the crux of TOC! The traditional approach to “improving the bottom line” is to cut costs (i.e., OE) first. Why? Because this is what managers can control. There is also the feeling that too much inventory is bad but, other than an across-the-board reduction in inventory, just how much is correct is not usually well understood. Last comes throughput; something the traditional manager believes is solely out of his or her control because it depends on things like market demand or how much capacity he or she has. TOC turns this paradigm upside down asserting that throughput should come first, inventory second, and cutting costs (i.e., OE) last. Why? Because logically the practical limits on decreasing I and OE are reached much sooner than the practical limit on T. In theory, there is no limit on T, while the theoretical limits on I and OE are zero. Here’s how Goldratt himself expresses it:

When we come to evaluate which avenue T, I or OE presents more opportunities for improving the long-run, the answer is obvious. In striving to decrease OE and I, the magnitude of improvement available is, by definition, limited since both of them cannot exist in the range of negative numbers. But this is not the case for T, this measurement, which we strive to increase is, inherently, unlimited. When it comes time to judging the performance of a specific period,

T and OE are on the same level of importance, nevertheless, when it come time to evaluating what we should do, in order to increase the ability of the company to make money on an on-going basis, T definitely takes a first and foremost position. (1990, p. 116)

Goldratt goes on to show that because of the impact of I on T (for example, due to increased carrying costs and depreciation), I should be given second priority with OE a close third.

In summary, TOC “accentuates the positive” by concentrating on the money coming into the company: throughput. This flies in the face of conventional wisdom that seeks to immediately cut costs when there is a downturn in operations. Dettmer (1997) give a good example of TOC thinking by mentioning how some defense contractors have sought to find new markets for their technology (increasing their T) versus simply going into a restructuring and layoff mode.

Concentrate on global optimization. It is all too common for businesses to fail to take a global perspective when trying to improve their operations. Perhaps Deming said it best as quoted in Walton (1986):

How to improve quality and productivity? “By everyone doing his best.” Five words and it is *wrong*. That is not the right answer. You have to know what to do. Doing your best won’t do it. We should be thankful that not everybody’s doing his best. Look at the chaos that there would be. Held down to this and that, bumping into each other, working at cross purposes. Not knowing what to do. Just doing his best. (p. 32)

Usually a company believes that it should concentrate on making each part of its system work at its best efficiency. However, what often happens is that by trying to optimize each part’s contribution to the organization, there is often suboptimization of whole system taking place. TOC, as already mentioned, looks for that part of the system that matter most in terms of throughput, namely the system constraint. Then, using the “five focusing steps” (to be discussed in Section 3), gives the most

attention to that part. In other words, TOC always thinks in terms of the company's goal and subordinates decisions about management of each of the system's parts to how each part's operation impacts that goal — a global perspective!

Constraints can be physical or policy. In the example given above in Figure 1 (repeated here), it is obvious the constraint is Step C which permits only 6 units

Figure 1. A simple five step manufacturing process.

inputs →	Step A	Step B	Step C	Step D	Step E	outputs →
each step's capacity →	10 Units/Day	20 Units/Day	6 Units/Day	8 Units/Day	9 Units/Day	

per day to be produced when in fact the market demand is 15 units per day. By invoking TOC, this company can break this constraint which would then move it to Step D and then to Steps E and A. Finally the constraint would no longer be a purely “physical” constraint since we would now be able to meet our market demand of 15. Now the question arises as to what do we do next. This now makes the constraint a “policy” constraint since management must decide if it is willing to take whatever steps are necessary to break the “market” constraint. Of course there are other types of policy constraints that could arise such as relationships with vendors or how the various functions within the company work together — for example, is there a constraint because we have not devoted enough resources to our production design function? In general, it is much harder to break policy constraints, but the payoff is usually much greater (Dettmer, 1997).

Having covered some of the basic ideas of TOC. Let us now turn to some of the tools that allow us to actually use this powerful management philosophy. If the constraint is physical, then Goldratt has developed his five focusing steps to deal with these. Should the constraint be a policy constraint, then Goldratt's logical thinking process is the answer. We'll consider the five focusing steps first.

3. The Five Focusing Steps

The five focusing steps are:

1. Identify the system constraint.
2. Decide how to exploit the constraint.
3. Subordinate everything else.
4. Elevate the constraint.
5. Go back to Step 1, but beware of “inertia.”

Step 1. Identify the system constraint. Where is the constraint and is it a physical or policy constraint? For a physical constraint, we will follow the other four focusing steps; a policy constraint, as mentioned, would call for the “logical thinking process.” To illustrate these five steps, let’s set up a simple example²⁾. Assume we have the following manufacturing layout to produce two products, Product P and Product Q, as shown in Figure 2. Summarizing Figure 2, Product P requires two kinds of raw material: RM-1 and RM-2; Product Q also requires two kinds: RM-2 and RM-3. Product P also requires Part A. The costs per unit of product for each kind of raw material and for Part A are shown under the cost/unit column. The time for each process that the raw materials must undergo, are also shown. Assembly time is 10 minutes for Product P and 5 minutes for Product Q. Finally, the total minutes required, for each process and assembly, to meet weekly demands for both products are shown along with the grand totals for both products combined. It turns out the minutes required of each process and assembly are: 2,000 minutes of Process A, 3,000 minutes of Process B, 1,750 minutes of Process C, and 1,250 minutes for assembly.

Now the question is can we meet our demand; i.e., is there anything *constraining*

2) This example is taken from the Goal Systems International (GSI) tutorial given at the American Society of Quality (ASQ) Quality Management Conference, February 25, 1998 (San Diego, CA).

Figure 2. A Simple Two Product Manufacturing Process (n/a = not applicable).

	raw materials & part	cost/unit	process time for each kind of raw material (minutes)			assembly time
			Process A	Process B	Process C	
Product P (weekly demand is 100 units)	RM-1	\$20.00	15	n/a	10	n/a
	RM-2	\$20.00	n/a	15	5	n/a
	Part A	\$5.00	n/a	n/a	n/a	n/a
Totals	n/a	\$45.00	15	15	15	10
Minutes reqd/wk to meet demand →			1,500	1,500	1,500	1,000
Product Q (weekly demand is 50 units)	RM-2	\$20.00	0	15	5	n/a
	RM-3	\$20.00	10	15	n/a	n/a
	Part A	not reqd	n/a	n/a	n/a	n/a
Totals	n/a	\$40.00	10	30	5	5
Minutes reqd/wk to meet demand →			500	1,500	250	250
Grand total minutes required/week to meet demand (both P and Q) →			2,000	3,000	1,750	1,250
Load (2400 minutes/week available)			0.83	1.25	0.73	0.52

our ability to meet demand. By calculating the minutes required of each step of our manufacturing system, we can then compare this information with the total minutes available. Assuming the usual 40 hour work week, we come up with 2,400 minutes/week available. The last item in Figure 2 shows how this available time compares with what's required: Process A is 83% loaded; Process B, 125%; Process C, 73%; and assembly only 52%. Obviously the constraint is Process B.

2. Decide how to exploit the constraint. Since we can't make all we want of both P and Q, the question arises which should we concentrate on? Recalling that we want to do everything possible to maximize throughput (T), let us determine the T for each product. To do that we will need some more information as shown in Figure 3. At first glance, it appears that we should make as much of Product Q as

Figure 3. Calculation of Throughput (T) for Products P and Q.

	unit selling price (A)	cost of raw materials and part (B) (see Fig. 2)	throughput (T) per unit (= A-B)
Product P	\$90.00	\$45.00	\$45.00
Product Q	\$100.00	\$40.00	\$60.00

possible because it has the higher T (\$60.00 v. \$45.00). However, we haven't taken our constraint into consideration. The question we really want to answer is which product gives us the most T for each precious minute of Process B, our constraint? To determine this we simply divide the T for a unit of each product by the minutes of constraint required to produce that unit. Referring to Figure 2, Product P requires 15 minutes of Process B time and Product Q 30 minutes. Dividing the T of Product P (\$45.00) by 15 yields a T per constraint minute of \$3.00. Similarly, dividing Product Q's T (\$60.00) by 30 yields a T per constraint minute of \$2.00. Therefore, if we want to exploit our constraint we should make as much of Product P as possible. As was pointed out during the tutorial, without this sort of analysis, conventional wisdom would have opted for producing as much of Product Q as possible because (1) product costs are lower (\$40.00 vs. \$45.00), (2) the selling price (and sales commission) is higher (\$100.00 vs. \$90.00), and, as mentioned, (3) the unit contribution (T) is higher (\$60.00 vs. \$45.00). Such thinking is suboptimizing³⁾, the opposite of TOC's overall system thinking paradigm.

That we've indeed improved our situation by making as much of Product P as possible can be confirmed by running a net profit calculations for two cases: (1) make as much of Product P as possible and (2) make as much of Product Q as possible. See Figure 4 for these calculations. As shown by Figure 4, the differences in T for these two cases yields a net profit difference of \$600.00 and the difference between making a profit or running in the red. Besides exploiting our constraint by

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- 3) Suboptimizing in the bad sense because sometimes you *want* to suboptimize some parts of your system to ensure the constraint is being properly serviced.

Figure 4. Weekly Net Profit for Two Cases: Making as Much of Product P as Possible and Making as Much of Product Q as Possible Given the Constraint of Process B (*these figures are for a one week period).

	product	constraint (Process B) time/unit	market demand*	amount of process B used*	number of units produced*	through- put (T)* (see Fig. 3)
1. Maximize amount of P	P	15 min	100	1500 min	100	\$4500.00
	Q	30 min	50	900 min	30	\$1800.00
Total throughput (T)		\$6300.00				
Operating expense (fixed)		\$6000.00				
Net profit		\$300.00				
2. Maximize amount of Q	P	15 min	100	900 min	60	\$2700.00
	Q	30 min	50	1500 min	50	\$3000.00
Total throughput (T)		\$5700.00				
Operating expense		\$6000.00				
Net profit		(\$300.00)				

using it to its maximum advantage (here, making as much of Product P as possible) we must now ensure that everything else is supporting the constraint or, at least, not hindering it.

3. Subordinate everything else. In our example, we could do other things to help get the most from our constraint such as changing our sales approach so we push Product P over Product Q or changing the reward system so that rewards are based on increases in total throughput versus individualized, local throughputs. A common consideration is to ensure that all the other processes and operations (non-constraints) that the constraint depends on are “tuned” to feed just the right amount of input to the constraint⁴⁾. For example, in our scenario (see Figure 2), we would want to be sure RM-2 and RM-3 are always available when needed and that Process A is feeding its output to Process B as needed. This doesn’t mean, however,

4) This technique in TOC talk is called “Drum-Buffer-Rope.”

that we want a lot of materials or work-in-process sitting in front of Process B waiting for processing since our TOC wisdom calls for keeping inventory (I) as low as possible. In other words, we get our system operating so it begin delivering just the right amount of input to the constraint all the time. This might mean suboptimizing some parts of the system but this is “good” suboptimizing since it contributes to a higher total throughput. Maybe a good analogy would be a sacrifice in baseball — the batter is thrown out at first but a runner advances and, sometimes, even scores; that is, the “throughput” is improved.

4. Elevate the constraint. If steps 2 and 3 haven’t broken the constraint, we are now ready to elevate it by considering significant investment to get even more out of the constraint. This could entail hiring more people and adding another shift or adding more equipment. In *The Goal*, the constraint was a machine called NCX-10. After identifying, exploiting, and subordinating, Alex Rogo’s people elevated the constraint by doing several things such as outsourcing some of the work and reactivating an older machine to handle some of the load.

5. Go back to Step 1, but beware of “inertia.” Once you’ve broken the constraint by exploitation, subordination, and elevation, identify the new constraint. As we saw in Figure 1, once we broke the constraint of Step C, it moved to Step D and then to Steps E and A until finally the market became the constraint. One question that arises is are we simply continuing to fine tune our manufacturing system so we have what’s known as a “balanced line;” that is, every step in the manufacturing process operating in perfect synchronization with every other step? As ideal as this sounds, it isn’t what we want because natural statistical variation among the dependent steps means that we’ll never achieve complete balance. In fact, due to that variation, our constraint will tend to move around which is exactly what we don’t want. TOC wisdom says to make a strategic choice on where you want your constraint and then you can manage it; a constraint that always moving around can’t be managed!

As far as the other part of this step, “beware of ‘inertia’,” we must never become complacent in thinking that just because we’ve broken a constraint there is nothing else we can do to improve throughput.

Now that we’ve examined the five focusing steps let’s look at how we handle the more difficult type of constraint; one involving a policy or, perhaps more often the case, one due to the “that’s the way we’ve always done it” syndrome. Now we must invoke Goldratt’s logical thinking process.

4. The Logical Thinking Process

Most problems companies face in trying to make significant improvements to their bottom line (i.e., throughput) involve situations much more complicated than the simple example we just considered. In fact, these problems often, as mentioned, involve going against some traditional way of doing things. This means you will probably be required to first fully think out the potential solution and then be able to present it and allow it to be scrutinized by others before it can be approved and implemented. Towards this end, Goldratt’s logical thinking process consists of two parts: five logical tools, each with a specific purpose, and, to test the logical soundness of these tools, eight categories of legitimate reservation. First we will consider the five logical tools (or trees) and, in Section 5, the categories of legitimate reservation. The five tools are:

- The Current Reality Tree (CRT)
- The Conflict Resolution Diagram (CRD)
- The Future Reality Tree (FRT)
- The Prerequisite Tree (PRT)
- The Transition Tree (TT)

To help us understand better where these five tools fit into the change process we look at the three basic questions Goldratt says a manager must answer: *what* to change, *what* to change *to*, and *how* to cause the change. As shown in Figure 5

(taken from Dettmer, 1997), we see that the Current Reality Tree (CRT) answer the first question (*what* to change?), the Conflict Resolution Diagram (CRD) and Future Reality Tree (FRT) answer the second question (*what* to change *to*?), and the Prerequisite Tree (PRT) and Transition Tree (TT) answer the third question (*how* to cause the change?). Figure 5 also sketches out the contents of each tool (tree/

Figure 5. The Relationship Between the Three Basic Questions and The Five Logical Tools (from Dettmer, 1997).

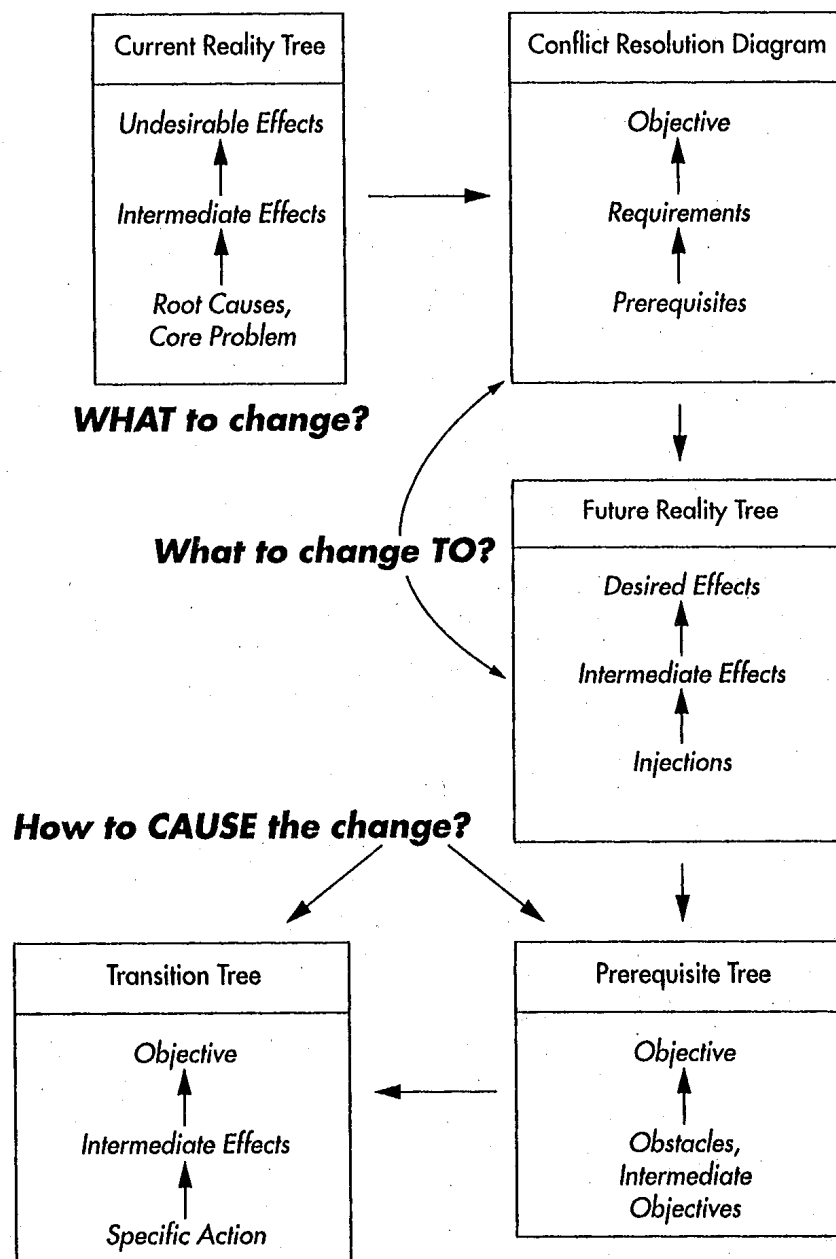
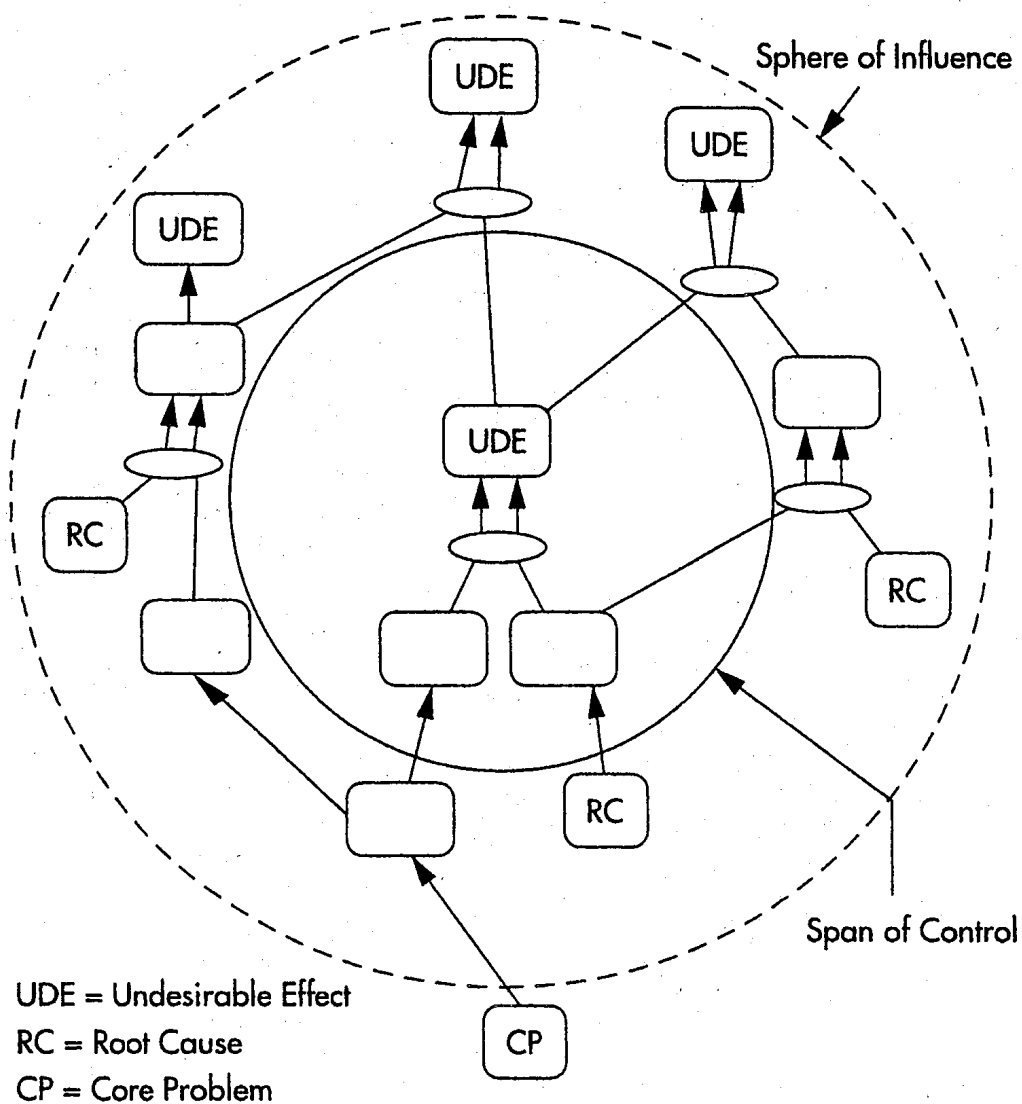


diagram). We will now take a closer look at each tool. As will soon become obvious, I've drawn heavily on Dettmer (1997) for this part of the paper.

The Current Reality Tree (CRT). Although Dettmer (1997) lists several purposes for the Current Reality Tree (CRT), its essential purpose is to start with some things that are wrong and work our way back through a series of causes and effects until we identify the root causes and core problem. Figure 6 is a generic example of a CRT. The "things wrong" are called UDEs or undesirable effects. A root cause is a cause without any arrows entering it and a core problem is defined as a root cause

Figure 6. A Generic Example of a Current Reality Tree (CRT) (from Dettmer, 1997).



accounting for 70 percent or more of the UDEs⁵⁾.

Several things are important to understand when developing a CRT. First, it is a cause and effect diagram; that is, working our way down from the top UDEs, we first identify all the causes for each UDE and connect these with arrows. The arrows represent the assumptions that are inherent in a cause and effect diagram; namely, the “if (the cause), then (the effect).” For example, “If I leave now, then I will get home on time.” When sufficiency requires two or more causes to produce the effect, an ellipse is used to show this cause sufficiency. This means that the CRT is a “sufficiency-based” tree⁶⁾; i.e., all (reasonable) causes must be shown. For example, we might modify our last example to say: “If I leave now *and* there is not too much traffic *and* my car doesn’t break down, then I will get home on time.” The number of causes you must provide depends a lot on for whom you are making the tree. If you tried to put down every possible cause, things could get out of hand.

Another thing that is important to understand is knowing your span of control and sphere of influence. As depicted in Figure 6, your span of control is usually much smaller than your sphere of influence. By circumscribing these two things on your CRT, you can quickly see just where you can take direct action to change things and where you will have to sell others on your logic. Dettmer (1997) suggests encompassing “as much as you dare in your sphere of influence, even if you’re not quite sure how you’ll go about doing the influencing” (p. 99). The question might arise as to what to do if the core problem falls outside your sphere of influence. In this case Dettmer recommends selecting “two or more root causes [within your sphere of influence], according to your subjective liking, that can account for a majority of the UDEs” (p. 99). As with all five logic tools, Dettmer provides detailed step-by-step

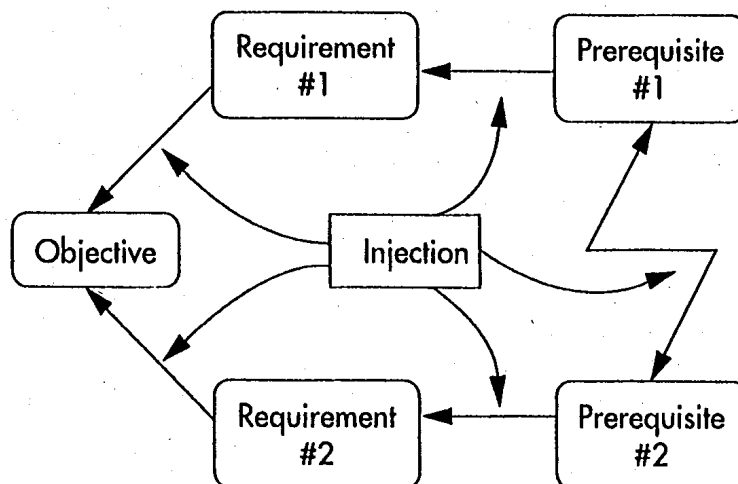
5) The core problem (CP) in Figure 6 happens to account for all of the UDEs but this is not necessarily always the case. However, it is usual for one root cause to account for the majority of the CRT’s UDEs.

6) As are the FRT and TT.

instructions on how to construct a CRT and an example. Also, for those seriously interested in learning how to construct a CRT, he has included an exercise.

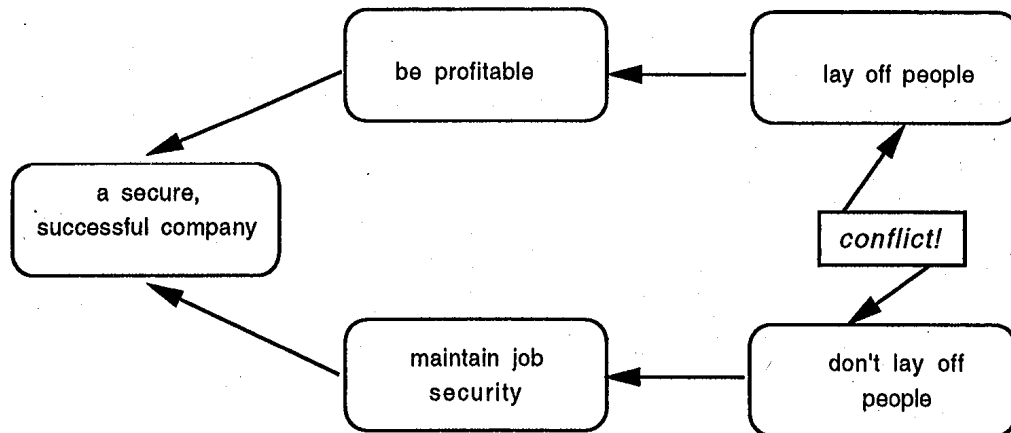
The Conflict Resolution Diagram (CRD). With the construction of the CRT, we've identified the core problem or, if you will constraint, that's keeping us from using more of our potential and increasing our throughput. In TOC terminology, we've identified *what* to change as shown in Figure 5. Now it is time to work on what to change *to*, and the first step is to develop a Conflict Resolution Diagram (CRD). Why does this come next? Because root causes or core problems usually exist because of some hidden conflict. The purpose of the CRD is to reveal that hidden conflict and resolve the conflict. Figure 7 is a generic example of a CRT. The objective is what both parties (or everyone) wants. The two requirements are necessary conditions to achieve the objective. The prerequisites are actions or conditions that must exist to achieve the requirements. It is at the level of the prerequisites that the conflict exists. To draw on an example from the Goal Systems International (GSI) tutorial⁷⁾ (see Figure 8), assume the objective is "a secure,

Figure 7. A Generic Example of a Conflict Resolution Diagram (CRD) (from Dettmer, 1997).



7) This example is taken from the Goal Systems International (GSI) tutorial given at the American Society of Quality (ASQ) Quality Management Conference, February 25, 1998 (San Diego, CA).

Figure 8. An Example of a Conflict Resolution Diagram (CRD) (from the GSI tutorial).



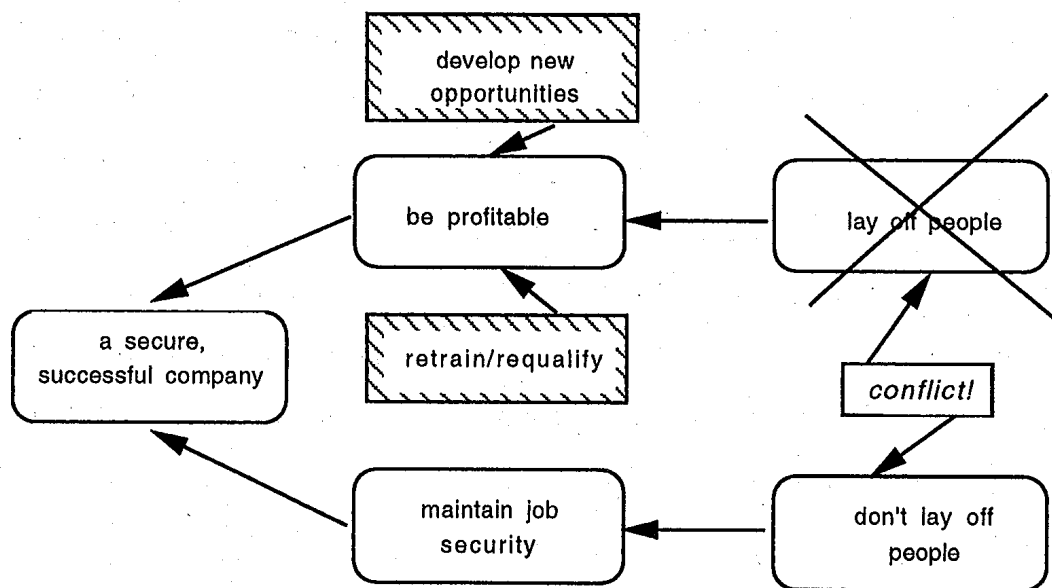
successful company.” Although there are many necessary requirements for this, let us suppose that two of them are “be profitable” and “maintain job security.” In our example, the respective prerequisites for these two requirements are “lay off people” (to be profitable) and “don’t lay off people” (to maintain job security); obviously a conflict. The first step in resolving this conflict is to identify all the assumptions associated with the CRD. As defined by Dettmer, an assumptions “is a statement about reality that is accepted as true or valid without question or demand for proof” (p. 131). So we begin looking at the assumptions that underlie such statements as “to have a secure, successful company” we must “be profitable” or we must “maintain job security.” Also we look at the assumptions that underlie “to be profitable” we must “lay off people” and “to maintain job security” we must “not lay off people.” Some assumptions we might come up with are:

- Laying off people is the only/best way to improve profitability.
- Laying off people never has any adverse downstream consequences on profitability.
- Retaining everybody is the only/best way to maintain job security.
- Everyone will always be needed right where they are. (GSI handout, p. 18).

It is obvious that these assumptions may well be invalid which brings us to the next

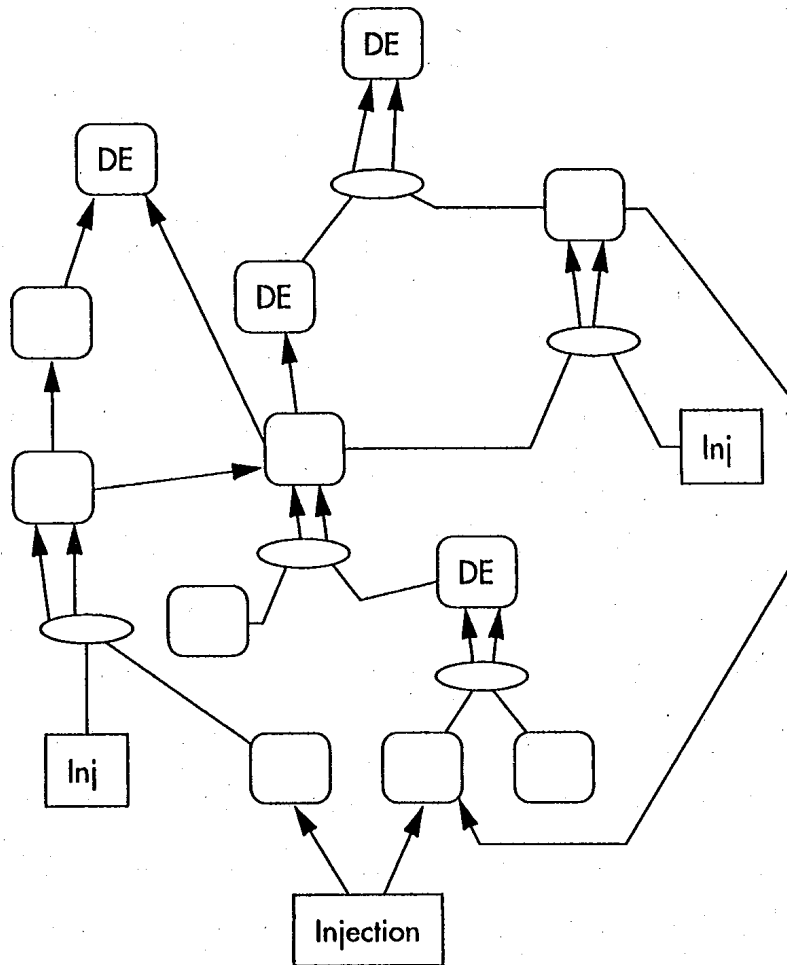
step: develop what are called “injections” to break the conflict. An injection is an action or condition that lets you achieve the requirement without the conflicting prerequisite. For example, in our current example, two injections were developed to show that you don’t need to “lay off people” to “be profitable.” These are shown in Figure 9. As can be seen, what we have done is *not to go for a compromise* but to eliminate the problem. Goldratt likes to call this the “Evaporating Cloud” method since we can think of the core problem as “a big black cloud” that, using the CRD, gets evaporated. See Dettmer (1997) for a complete description of and procedure for using the CRD. Goldratt (1990) also devotes a chapter to this method and provides a detailed example of its use.

Figure 9. An Example of a Conflict Resolution Diagram (CRD) Showing Injections (from the GSI tutorial).



The Future Reality Tree (FRT). Figure 10 shows a generic example of a Future Reality Tree (FRT). Its purpose is to show how some change you are contemplating, be it an action or a desired condition, will affect your reality. More specifically, the FRT will tell you if and how such a change will lead to desired effects (DEs). The injection at the bottom of Figure 10 is the change you want to test. Building the FRT begins with listing of all your DEs. If you’ve constructed a CRT,

Figure 10. A Generic Example of a Future Reality Tree (FRT) (from Dettmer, 1997).



its undesirable effects (UDEs) can be changed into their opposites to give you the DEs; e.g., change “we are losing customers” to “we are gaining customers.” Similarly, if you’ve already developed one or more conflict resolution diagrams (CRDs), these are likely sources for injections. The primary injection will be the one that attacks the core problem of the CRT. Once you have your list of DEs and have identified one or more injections, you place the DEs at the top of the diagram and the injections at the bottom. Then you fill in the gaps by building upward starting with the most important (primary) injection. As you move up from injection to DEs, you operate in the same way as you did building the CRT; i.e., creating intermediate effects as necessary and ensuring that there are sufficient causes for each effect/DE. Again the ellipse is used to indicate that all the arrows through it are necessary to

ensure sufficiency. As can be seen in Figure 10, other injections may be needed to obtain some necessary intermediate effect or DE. Again, a complete procedure for completing a FRT is given in Dettmer (1997).

Once the FRT is essentially complete, each DE should be looked at as a source for creating a positive reinforcing loop back down the FRT to strengthen the operation represented by it. Such a loop is shown on the right side of Figure 10. Another concern is the unintentional creation of "negative branches." Again, after the FRT is complete, Dettmer says you should start at the bottom and ask this question of each injection: "Besides this desired outcome, what else could result from this injection that I would not like?" (p. 210). If there is such a result, it should be developed showing how, through cause and effect, the UDE occurs. At the point where the branch actually turns negative, determine the assumptions that underlie that particular arrow. Then follow the same technique used to break a conflict with the CRD: formulate appropriate injections to invalidate faulty assumptions.

Dettmer makes a strong point of not worrying too much whether you have created a perfect CRT/CRD before developing your FRT:

If you don't precisely identify the core problem in the Current Reality Tree, it's not critical — you only need the Current Reality Tree to get you into the area of the core problem. If you don't identify all the assumptions that need to be broken in the CRD, don't worry. As long as you have a major invalid assumption to attack, you have enough to get started. The Future Reality Tree will catch any omissions from the CRD or inaccuracies in the Current Reality Tree through negative branches. As Goldratt has said, "It's better to be approximately correct than precisely incorrect." (p. 195)

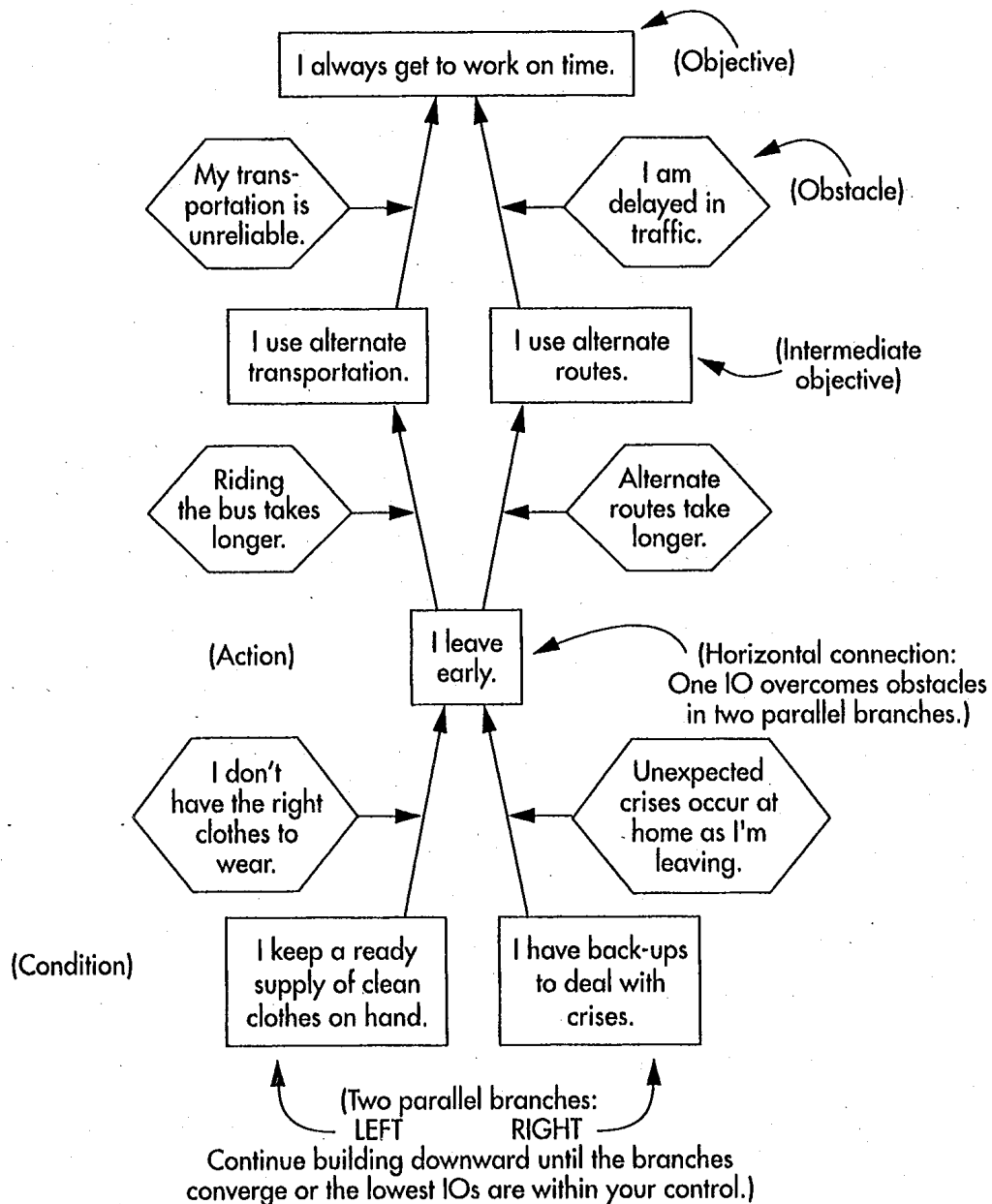
Accordingly, it is the FRT where we want to be as precise as possible.

The Prerequisite Tree (PRT). Referring back to Figure 5, we now know fairly well what we have to change *to*; all that remains is determining *how* to cause the change and the first step here is the Prerequisite Tree (PRT). Now we must look

more closely at the primary change (injection) we are planning to make and determine these three things: (1) what obstacles are likely to present themselves to achieving the change, (2) what actions need to be taken to overcome these obstacles, and (3) what is the logical sequence of these actions? Determining these things is the purpose of the PRT. Since the logically sequenced actions represent other objectives we must achieve, they are called intermediate objectives (IOs).

Figure 11 shows an example of a simple PRT taken from Dettmer. Here our

Figure 11. An Example of a Prerequisite Tree (PRT) (from Dettmer, 1997).



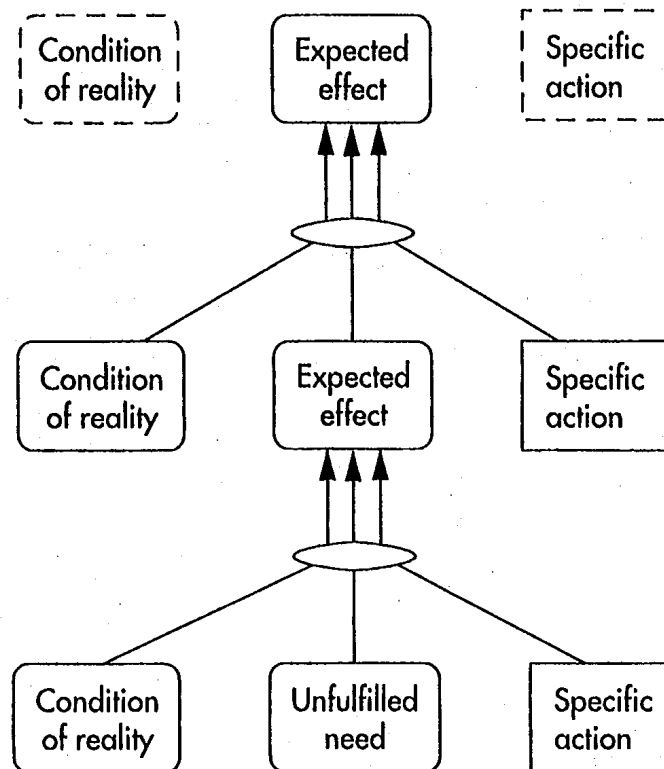
objective (the change we want to achieve) is "I always get to work on time." Having gone through all the steps in developing a PRT, Dettmer has come up with several obstacles such as "Unexpected crises occur at home as I'm leaving." For each possible obstacle, he has come up with an IO to overcome it such as "I have back-ups to deal with crises." Notice that:

- You could have two or more branches leading up to your objective.
- A single IO might be able to overcome more than one obstacle as is the case with the IO "I leave early" which overcomes obstacles "Alternate routes take longer" and "Riding the bus takes longer."
- The IOs are sequenced according to how they would most likely occur.

As the note at the bottom of Figure 11 states, you continue building your PRT downward until the branches converge or the lowest IOs are within your control. Also, Dettmer says that as you get closer to the bottom of your PRT, your IOs, which can be either actions or conditions, should be mostly actions. To convert conditions into actions you can use the CRD as what Dettmer calls a "creative engine." Now we are ready to go to final phase of our logical approach to change: the Transition Tree (TT).

The Transition Tree (TT). Whereas the Future Reality Tree (FRT) tells us if a proposed change will, indeed, lead to the effects we desire, the purpose of the Transition Tree (TT) is to tell us how to do something we've already decided to do by providing the step-by-step instructions in an appropriate time-sequence. The basic building block for a TT consists of: a condition of reality, an expected effect, an action, and the integration of these three into a new expected effect (see Figure 12). As with the FRT, you build the TT upward once you've established your objective. The first level, as shown in Figure 12, starts with an unfulfilled need instead of the effect. This first level represents what you believe to be the first action that needs to be taken. Subsequent scrutiny may prove this wrong and you might have to build *down* a bit more.

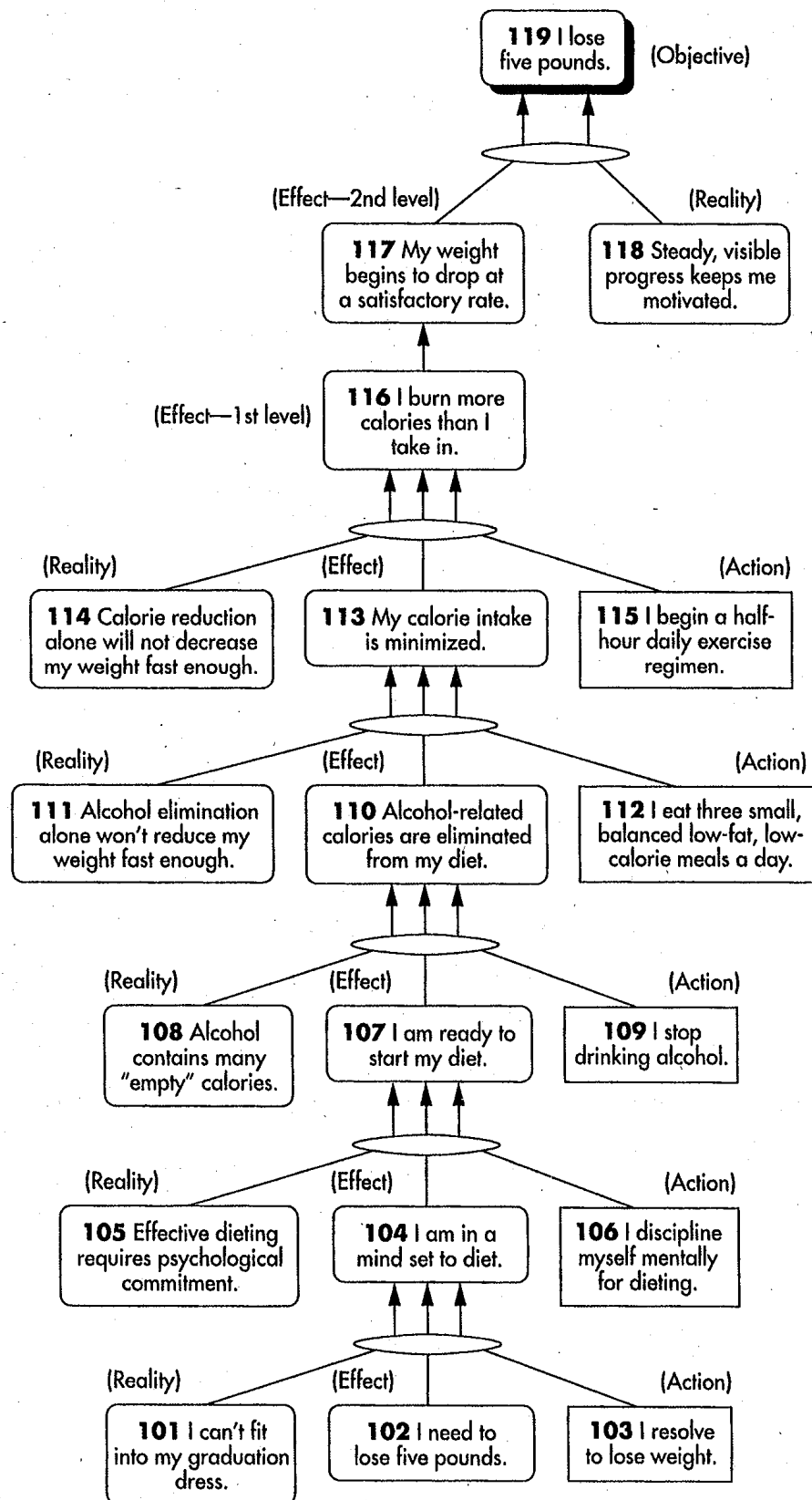
Figure 12. How a Transition Tree (TT) Is Built Up (from Dettmer, 1997).



As you proceed up the tree, you may not need a third element to go with your latest expected effect and new action. According to Dettmer (1997), “if the new action and last effect seem incomplete, decide whether you need a supporting statement about reality, or a statement of need to get you to the next level of effect” (p. 302). Similar to the Current Reality Tree (CRT) and Future Reality Tree (FRT), the TT is a sufficiency-based tree so we must be sure that each effect has sufficient causation from the combination of your carefully selected action and need (or condition of reality) with the last effect.

If you’ve constructed a Prerequisite Tree (PRT), it could form the basis for the TT in that its objective would be the TT’s objective and the intermediate objectives (IOs) become the expected effects for the TT. In fact, according to Dettmer, Goldratt originally thought of the TT as the culmination of the three prior trees (CRD, FRT, and PRT). However, aside from using the TT in conjunction with these other think-

Figure 13. An Example of a Simple Transition Tree (TT) (Jennifer's Transition Tee #2: "How to Lose Five Pounds in a Hurry") (from Dettmer, 1997).



ing tools, it can be a valuable tool by itself for organizing complex projects. Out of the TT can come such things as a step-by-step checklist of actions necessary or, even, the basis for a more detailed PERT⁸⁾ chart. Figure 13 shows an example of a simple TT (Jennifer's Transition Tree #2: "How to Lose Five Pounds in a Hurry").

Using this TT to illustrate the way a TT can be used for project implementation, the actions for "losing five pounds" would be:

- Resolve to lose weight.
- Discipline myself mentally for dieting.
- Stop drinking alcohol.
- Begin eating three small, balanced low-fat, low-calorie meals a day.
- Begin a half-hour daily exercise regimen.

With the completion of the TT we've also completed our "*how* to cause the change" phase of the three-phase change protocol: *what* to change, *what* to change *to*, and *how* to cause the change (Figure 5). As may have been apparent, each of these five thinking tools can be used with the others or by themselves. To understand better how they work together, I recommend the interested reader study Dettmer (1997).

One thing Dettmer continually emphasizes throughout his book is the need to scrutinize the trees to ensure they are logically sound. To do this in a systematic way, the TOC has eight categories of legitimate reservation. It is to these that we now turn.

5. The Eight Categories of Legitimate Reservation

Dettmer refers to these categories of legitimate reservation of the "logical glue"

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- 8) Program evaluation and review technique (PERT) is a method for controlling a complex program such as the development of a major weapons system — say a new fighter aircraft — or a major construction project. The PERT chart shows all the required program activities and their interrelationships.

that holds the trees together. Without requiring the trees to withstand the test of these eight categories, there is no way we can be sure they really do embody sound logic. The eight categories are:

- Clarity
- Entity existence
- Causality existence
- Cause insufficiency
- Additional cause
- Cause-effect reversal
- Predicted effect existence
- Tautology

We will now take a closer look at each category. See Appendix for a summary list of the tests Dettmer has devised to see if each legitimate reservation is met.

Clarity. Clarity simply means that the tree is clear to the person listening to its explanation; that is, the statements of cause and effect are meaningful and the connections between them make sense. This is a logical starting point since, without a basic understanding of what the person presenting the tree is saying, there can be no further real progress in getting it validated. I recall a bit of wisdom I once read on a cubical wall that seems relevant here: "The greatest problem with communications is the assumption that its been achieved." Unless we're sure we've "achieved communications," subsequent efforts are likely to fail. Please note that with this reservation we are concerned with the *meaning*, not the *content* of what's being discussed. That is, the listener may not agree with the *content* but, at this stage, we are only concerned that he/she understands the *meaning* of what's being said.

Entity existence. Dettmer defines an entity as "a complete idea expressed as a statement" (p. 36). To meet this reservation, the entity (usually a statement of a cause or an effect), must satisfy three things: completeness, structure, and validity. By completeness we mean the idea is fully expressed; usually using at least a sub-

ject and a verb, and sometimes an object. For example⁹⁾, “economic recession” is not a complete idea but “economic recession occurs” is.

As for structure, we look at two things: (1) do we have a compound entity and (2) is there an embedded “if-then” statement. A compound entity contains two or more ideas and we want to limit our entities to one idea; e.g., “the sky is falling and it hits Chicken Little on the head” is two ideas that need to be separated. An embedded “if-then” statement would be: “we park the car in the garage in order to avoid damage from the elements.” We need to separate this sort of statement into a true “if-then” representation showing, in this case, that *if* “we park the car in the garage” *then* “we avoid damage from the elements.”

Finally, to test for the validity of our entity, we check if the content of the entity is sound. For example, “the sky is falling” really doesn’t have any validity in reality whereas a statement like “most grass is green” does.

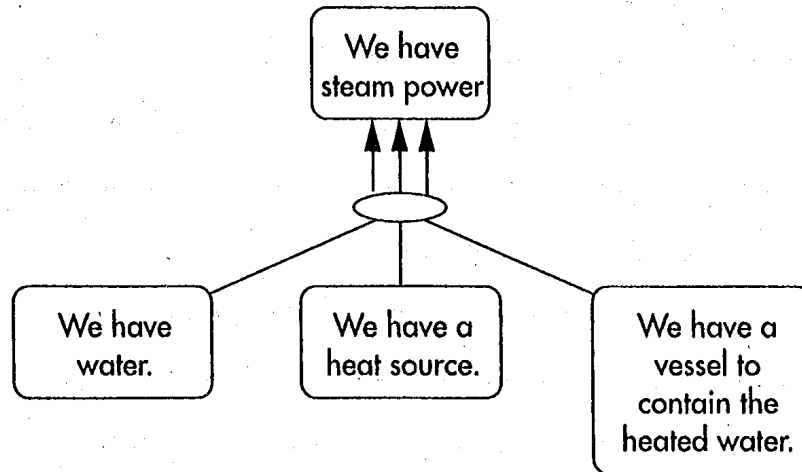
Causality existence. Now we are asking if the connection between the cause and effect is valid; that is, the arrows in our logic trees. Two questions must be answered: (1) does the cause really result in the effect? and (2) is the cause intangible? The first question can usually be answered by simply stating the cause and effect as an “if-then” statement using the exact words in the cause/effect entities; if the statement makes sense then you probably have a good “connection.” When the cause is intangible, that is, can’t be directly measured or observed, you need to find another effect that is attributable to the same cause. For example, if “I stop watering the lawn,” then “the grass dies” is an example of a tangible cause since you can observe that you’ve stopped watering the lawn. However, if “my boss is dissatisfied with me,” then “my performance appraisal is poor” is an example of an intangible cause because, unless he tells you, you can’t really “observe” your boss’ dissatisfaction. In this case another effect due to the same cause is required to verify the origi-

9) For the sake of “not reinventing the wheel,” I will take most, if not all, examples for this section from Dettmer (1997).

nal cause-effect relationship.

Cause insufficiency. Here we simply ask do we gave enough causes? For example, in Figure 14 we have three causes working together to give us the effect “we have steam power.”

Figure 14. Three Interdependent Causes Causing an Effect (from Dettmer, 1997).



These *interdependent* causes are all required for the effect; i.e., without any one of these causes, there would be “cause insufficiency” for the effect. To show this interdependency, an ellipse is used. Although in theory you could have an unlimited number of interdependent causes, Dettmer recommends trying to limit the number to three (or four at most).

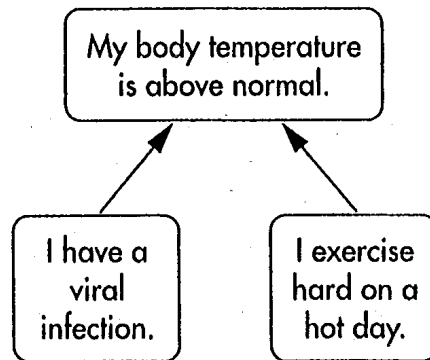
Related to the concept of cause insufficiency is the idea of “oxygen.” In the jargon of TOC, oxygen means a cause that has been omitted by the person presenting the logic tree because it is, to the presenter, intuitively obvious.¹⁰⁾ The presenter must realize that to someone else, say a person scrutinizing the tree, the “oxygen” may not be intuitively obvious and, indeed, may be considered significant to the

10) The idea of oxygen comes from the cause and effect example of the two causes, “we have a heat source” and “we have fuel” being considered sufficient to produce the effect “we have a fire.” Of course, oxygen is also necessary but might be considered so obvious that it isn’t necessary to write it down as a cause.

problem at hand.

Additional cause. With cause insufficiency we were checking to see if we needed more causes to join existing causes to create the effect. With additional cause we are checking to see if there are additional *independent* causes that could account for the effect. Figure 15 is an example of this. Here either “I have a viral infection” or “I exercise hard on a hot day” could be the cause of “my body temperature is above normal.” Each additional cause could actually be the combination, through an ellipse, of two or more interdependent causes.

Figure 15. An example of Additional Cause (from Dettmer, 1997).



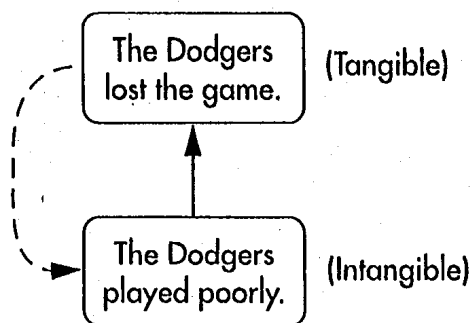
Cause-effect reversal. As the name of this category implies, we now are questioning whether the arrow is pointed the right way; i.e., does the indicated cause really cause the indicated effect? An example from Dettmer goes: “*If* standardized test scores are at or below the 50th percentile, *then* the academic qualifications of new students are poor.” A careful analysis of this statement will show that it wasn’t the test scores that caused the students to have poor academic qualifications; the test scores are only an *indicator* of these poor qualifications. So, in testing for this reservation, a scrutinizer would either simply be guided by a “gut feeling” that the arrow is going the wrong way or realize that what is passing for a cause is, in fact, only an indicator of the effect.

Predicted effect existence. This reservation is based on the fact that most causes result in more than one effect and we can use the prediction of one or more addi-

tional effects to either substantiate or refute a given cause-effect relationship. For example, the cause "car battery is dead" might be given for the effect "car doesn't start." A predicted effect for this cause would be "starter doesn't crank." If this predicted effect isn't there, that is, the starter *does* crank, then this would refute the first cause-effect relationship. This reservation is used to substantiate other reservations, such as causality existence. The predicted effect existence reservation can also be used to verify an intangible cause such as "customers don't like our products" for the effect "sales are down." If we predict another effect "customers return our product in great numbers" and it is shown to be true, we can say we have support for the intangible cause.

Tautology. Tautology, or circular logic, means the effect is given as the reason for the cause such as in the Dettmer's "baseball" example shown in Figure 16. The effect "the Dodgers lost the game" is given as the effect for the cause "the Dodgers played poorly." However, on closer examination one would have to conclude that the effect is really being given as a reason for the Dodgers playing poorly and we need one or more additional (predicted) effects to substantiate the intangible cause such as how many hits the Dodgers got, how many errors they made, etc. In fact, the Dodgers may have played very well and lost a close game.

Figure 16. An example of Tautology (from Dettmer, 1997).



6. Using the Logical Thinking Process

What TOC is all about is causing meaningful change and this is the purpose of the logical thinking process with its five tools (or trees). Summarizing the specific purpose of each tree:

We began with a Current Reality Tree, which told us what needed to be changed. Then we used a Conflict Resolution Diagram to begin the design of a new reality — what to change to. We used a Future Reality Tree to verify that the idea we created would, in fact, solve our problem without creating other new ones that we couldn't handle. Then we searched out obstacles to implementation and determined how to overcome them using a Prerequisite Tree. Finally, we constructed a step-by-step implementation plan [the Transition Tree] to guide us in causing the change to happen. (Dettmer, 1997, p. 308)

And, as we created each new tree, we scrutinized it using the eight categories of legitimate reservation.

It is also a good idea to get others to scrutinize our trees since we often “can't see the forest for the trees” (no pun intended), overlooking some obvious mistake. Furthermore, we don't usually deal with a change that involves only ourselves; we must also sell others on the idea. It is also good to involve others in the work leading up to the change so they have ownership. It is well known that without inducing this ownership, the chances for implementing any real and meaningful change are small. Dettmer devotes a whole chapter to discussing the use of the thinking process in groups. He lists these possible but not all inclusive applications:

- Small-group scrutiny
- Communicating disagreement (without incurring resentment)
- Building trees in teams
- Persuading others with your logic (getting “buy-in”)

With small-group scrutiny you are affording yourself the chance to get others'

opinions about what you've done by letting them scrutinize your tree(s). On the other hand, if you are one of the scrutinizers, you will, no doubt, disagree with some things the presenter has presented. The TOC thinking process includes a set of communication protocols that allow one to air reservations (see Section 5) in a nonthreatening and professional way. For example, for the clarity reservation, the scrutinizer would say: "Could you clarify for me the word (here the word is stated)?" and the presenter responds "The word (here the word is stated) means..." giving a synonym or short phrase. Dettmer has developed a complete set of such protocols to handle all eight categories of reservation. He has even included a way to use them with someone not familiar with the formal protocols. However, for an organization whose members are seriously working together for meaningful change, it would be appropriate for everyone involved to adhere to the formal protocols.

The application of building trees in teams has the advantage of "two (or more) heads being better than one," especially if you don't have the full expertise to develop a good tree. And, the "persuading others" application is a natural for the trees since they offer you a way to systematically present your idea for change and a forum for soliciting input from those you must persuade.

As mentioned, there are other ways the trees can be used; basically any time you need to either get someone else to review your thinking or when you are trying to sell your thinking to another.

7. How to Become a "Jonah" or Advanced TOC

If you've read *The Goal* (Goldratt, 1992) you know that the character Jonah was the person who was responsible for helping the plant manager, Alex Rogo, turn his operation around from a being forced to close (due to missing order dates, excessive inventory, and losses) to sharp increases in revenue and actually asking for more customers. All because the plant was able to begin thinking in terms of overall throughput versus local optima (called "efficiencies"). What is most interesting,

however, is Jonah never *tells* Alex (or his staff) what to do but, using the Socratic approach, forces them to think through the problems on their own. Recall the scene reproduced in Section 2 of this paper where Jonah, while getting on a plane, continues to prod Alex to name the goal of his organization. Alex is left to figure this out by himself. As another example, let's listen in as Jonah is discussing where the quality control (Q.C.) function should be relative to the bottleneck (the constraint in this case). "Bob" is Alex Rogo's production manger:

Jonah asks, "Did these parts come through a bottleneck?"

"Yeah, they did," says Bob.

"Do you realize what the rejection by Q.C. has done to you?" asks Jonah.

"It means we have to scrap about a hundred parts," says Bob.

"No, think again," says Jonah. "These are *bottleneck* [constraint] parts."

It dawns on me [Alex] what he's getting at.

"We lost the time on the bottleneck," I say.

Jonah whirls toward me.

"Exactly right!" he says. "And what does lost time on a bottleneck mean? It means you have lost throughput."

"But you're not saying we should ignore quality, are you?" asks Bob.

"Absolutely not. You can't make money for long without a quality product," says Jonah. "But I am suggesting you use quality control in a different way."

I ask, "You mean we should put Q.C. in front of the bottlenecks?"

Jonah raises a finger and says, "Very perceptive of you." (pp. 156–157)

Notice how Jonah never gives the answer directly but teases it out of his interlocutors so that they are really understanding things for themselves. This, of course, is why the Socratic method is such a powerful learning tool. Also, it is forcing Alex and his staff to take ownership of these ideas and, maybe most important, training them to become "Jonahs" themselves.

Towards this end, the Avraham Y. Goldratt Institute, established by Goldratt (and

named for his father), offers, among others, a "Jonah Course." This is the course description from the Institutes's home page (1998):

This 9 to 12-day program is for individuals and management teams who want to accelerate the improvement process in their area of responsibility or in a subject matter of primary interest to them. The combination of the participants intuition and common sense and the mastery of the Thinking Processes (TP) results in a detailed action plan to apply to your current environment and the skills to apply it to other subjects. (TOC Applications part of Avraham Y. Goldratt Institute home page)

The course will train participants to exploit their common sense and intuition and break away from the traditional ways of thinking. It does this by having them develop a real world implementation plan to solve some real problem. By the time the plan is "cussed and discussed" the basic cause and effect concepts of TOC are well indoctrinated into the participants' heads. After this intensive course, they are ready to go back to their organizations and be Jonahs themselves!

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THE EIGHT CATEGORIES OF LEGITIMATE RESERVATION

(Tests for the Validity of the Reservation)

(Dettmer, 1997)

Category	Tests for the Validity of the Reservation			Notes
1 Clarity	Is any additional verbal explanation required for the cause or effect, as written?	Is the connection between cause and effect convincing at “face value”?	Is this a “long arrow” (i.e., are intermediate steps missing)?	1
2 Entity Existence	Is it a complete sentence with at least a subject and verb (sometimes an object too)?	Is it properly structured: not a compound entity or embedded “if-then”?	It is valid; i.e., its content is sound; something the listener can reasonably accept?	
3 Causality Existence	Does the cause, in fact, result in the effect (i.e., does an “if-then” connection really exist)?	Does it make sense when read aloud exactly using “if-then”?	Is the cause intangible (not measurable)? If so, an additional predicted effect should be found.	
4 Cause Insufficiency	Can the cause result in the effect on its own, or must it exist in concert with one or more other causes?	Is an “and” gate (ellipse) required (when one or more additional interdependent causes are necessary)?	Is some cause omitted <i>really</i> “oxygen.”	2 & 3
5 Additional Cause	Is this the only major cause or are there other independent causes that might result in the effect?	If the cause in question is eliminated, are there other circumstances under which the effect might still be present?		4
<p>Notes:</p> <ol style="list-style-type: none"> Here we’re concerned only with the meaning, not the content, of the presenter’s statement. This is the most common deficiency. Each cause could be 100% responsible (need each or no effect) or proportionately responsible (without one, effect reduced but still there). The suggested additional causes must produce the effect in at least as much magnitude as the original cause(s). 				

APPENDIX — page 2 of 2

THE EIGHT CATEGORIES OF LEGITIMATE RESERVATION (continued)

(Tests for the Validity of the Reservation)

(Dettmer, 1997)

Category	Tests for the Validity of the Reservation			Notes
6 Cause-Effect Reversal	Is the arrow really drawn in the right direction? Might the depicted cause really be a perceived effect?	Could the effect statement be an abbreviated version of a more accurate statement?	Could it be the cause statement is really an indicator rather than a source?	
7 Predicted Effect Existence	Is the cause intangible? If so, are there one or more additional expected effects that must exist for the cause-effect relationship to be valid?			5 & 6
8 Tautology	Is it circular logic (i.e., is the effect offered as a rationale for the cause)?	Is an additional verifiable effect offered?		7
<p>Notes:</p> <p>5. Used in connection with categories 3, 4, 5, or 6 (doesn't stand alone).</p> <p>6. Consider the following characteristics of predicted effects when using them to either support or refute a cause-effect relationship: expectation, coexistence, and magnitude.</p> <p>7. Used in connection with another causality reservation, usually category 3.</p> <p>General comment: The CRT, FRT, and TT are <i>sufficiency</i> trees expressed in the "if-then" format and the CRD and PRT are <i>necessity</i> trees expressed in the "in order to ... we must ... because ..." format. The categories of legitimate reservation are primarily for the sufficiency trees but do have some applicability to the necessity trees.</p>				