Goldratt's "Theory of Constraints" Thinking Processes: A Systems Methodology linking Soft with Hard

Victoria Mabin
School of Business and Public Management
Victoria University of Wellington
PO Box 600
Wellington
Tel +64 4 463 5140
Fax +64 4 463 5253
Email vicky.mabin@vuw.ac.nz

Abstract

In its brief 20-year history, Goldratt's Theory of Constraints (TOC) methodology has evolved into a systems methodology that links elements of both soft and hard systems methods. The major component of TOC that underpins all the other parts of the methodology is the TOC Thinking Processes, a suite of logic trees that provide a roadmap for change. They guide the user through the decision making process of problem structuring, problem identification, solution building, identification of barriers to be overcome, and implementation of the solution. Tree-builders make recourse to a set of logic rules, which provide the analytical rigour usually associated with hard scientific approaches. This is combined with the ability to capture softer information and complexity provided by soft OR approaches. This paper briefly outlines the TOC methodology, and discusses the similarities and differences between TOC and other systems methods, particularly the Rational Model of decision-making.

Introduction:

Since its roots 20 years ago as a manufacturing scheduling method, the Theory of Constraints (TOC) methodology has now developed into a systems methodology that links elements of both soft and hard systems methods. The development of Theory of Constraints is credited in the main to Dr Eliyahu M. Goldratt, an Israeli physicist who has turned his attention to the business world, through a large number of books, seminars and other media (see for example, Goldratt and Cox, 1986/1992, Goldratt 1990a, 1990b, 1994, 1997). There are several works which provide reviews of TOC's history and development (McMullen, 1998), its major components (Cox and Spencer, 1998; Dettmer, 1997), applications (Noreen et al, 1995; Kendall, 1998), and published literature (Mabin and Balderstone, 1999). The major component of TOC that underpins all the other parts of the methodology is the TOC Thinking Processes. These are a suite of logic trees that provide a roadmap for change, by addressing the three basic questions of What to change, What to change to, and How to cause the change. They guide the user through the decision making process of problem structuring, problem identification, solution building, identification of barriers to be overcome, and implementation of the solution. The trees make recourse to a set of logic rules, called the Categories of Legitimate Reservation (CLR), which set out to check for and correct common flaws in our logic, and provide the analytical rigour usually associated with philosophy or hard scientific approaches. This is combined with the ability to capture softer information and complexity provided by soft OR approaches. The results of TOC have been dramatic. But more importantly for us as systems modelers is the new approach that TOC provides for capturing systems concepts and for utilising both hard and soft concepts in doing so. This paper briefly outlines the TOC methodology, and discusses the similarities and differences between TOC and other systems approaches, particularly the Rational Model of decision-making.

Overview of the TOC methodology:

The TOC has evolved over the past 20 years from a production scheduling technique to a systems methodology which is primarily concerned with managing change. Klein & DeBruine (1995) state that originally Goldratt set out to devise a systematic approach to identifying what was preventing a company from achieving its goal of making money for its owners. The approach was first used in a manufacturing environment and reported at an APICS conference in 1980. Hrisak (1995) advises that TOC is now used worldwide by companies of all sizes. He states that many managers who routinely use TOC believe they understand their businesses for the first time. From this understanding they gain a sense of control and of being able to act proactively. He says this is because TOC empowers managers by providing a consistent framework for diagnosing problems. The TOC methodology now encompasses a wide range of concepts, principles, solutions, tools and approaches, the description of which is beyond the scope of this paper. Interested readers can refer to Cox and Spencer (1998), or Balderstone (1999) for a complete overview.

For the present purposes we will concentrate on the systems aspects. TOC is perhaps not normally considered by systems modelers to be part of the systems literature, but it is a systems methodology in that it strives to ensure that any changes undertaken as part of an ongoing process of improvement will benefit the system as a whole, rather than just part of the system. At its most basic level, TOC provides managers with a set of tools that guide the user to find answers to the basic questions relating to change, namely:

- What to change?
- What to change to?
- How to cause the change?

Goldratt (1990b), Klein & DeBruine (1995) & Dettmer (1997) state that TOC views an organisation as a chain composed of many links, or networks of chains. Viewed as a constrained system, a chain's links all contribute to the goal and each link is strongly dependant on the other links. The chain, however, is only as strong as its weakest link. Goldratt's TOC states that the overall performance of an organisation is limited by its weakest link. He states that if an organisation wants to improve its performance, the first step must be to identify the system's weakest link, or constraint.

The Five Focusing Steps in the Process of On-going Improvement:

Goldratt (1990b, Goldratt and Cox 1992) introduced a method called the five focusing steps for addressing system problems on a continuous improvement basis. The steps are:

1. **Identify the constraint**: Identify the operation that is limiting the productivity of the system. This may be a physical or policy constraint
2. **Exploit the constraint**: achieve the best possible output from the constraint. Remove limitations that constrain the flow, and reduce non-productive time, so that the constraint is used in the most effective way possible
3. **Subordinate other activities to the constraint**: link the output of other operations to suit the constraint. Smooth work flow and avoid build up of work-in-process inventory. Avoid making the constraint wait for work
4. **Elevate the constraint**: In situations where the system constraint still does not have sufficient output invest in new equipment or increase staff numbers to increase output
5. **If anything has changed, go back to step one:** Assess to see if another operation or policy has become the system constraint. Goldratt (1990b) states that this step is consistent with a process of ongoing improvement.

Prior to the Five Focusing Steps, Goldratt (1986, 1990b) prescribes two extra steps, which Coman and Ronen (1994) include in the Focusing Steps, redefining them as a seven-step method. The two extra steps inserted at the start are:

1. Define the system's GOAL.
2. Determine proper, global and simple MEASURES of performance.

Scheinkopf (1999) describes these as prerequisite steps for any improvement process.

As can be seen from the above, one of the central tenets of TOC is that any system has constraints that prevent it from achieving its goal. The place to focus efforts is on making those constraints produce more, either by acting on the constraints directly, or on other operations interacting with them. The 5 Focusing Steps of TOC provide a simple but effective approach to continuous improvement in cases where the constraint is fairly clearly identifiable. However where the constraint is caused by policies or behaviours, or in other more complex and messy situations, the constraint may be harder to pinpoint, and what should be done to rectify it is not as clear-cut.

In such cases, the TOC Thinking Processes are more useful in deciding what to change, what to change to, and how to cause that change to occur. In much the same way as the 5 Focusing Steps focus on the constraint, the Thinking Processes focus on the factors that are currently preventing the system from achieving its goals. They do this by first identifying the symptoms within the system, which provide evidence that the system is not performing as well as desired. Working from there, the various TOC Thinking Process tools are then used to deduce what the causes of those symptoms are, what needs to be done to correct those causes, and how such corrective actions could be implemented. In this way, the TOC approach is to map the system from the point of view of the current problems, rather than try to model the whole system. This is a very subtle but major difference, allowing complex problems to be tackled without recourse to a full model of the system.

The Thinking Processes

The Thinking Processes comprise a suite of five logic diagrams (four trees and a "cloud") and a set of logic rules. The diagrams use two different types of logic. Three of the trees (Current and Future Reality Trees and the Transition Tree) use cause-and-effect logic. They are built up by constructing connections between observed effects and causes on the basis of "sufficient cause". Sufficiency can be of 3 types: "A is sufficient to cause C" or "If both A and B occur together, then they will be sufficient to cause C" or "A and B (separately) both contribute to C, and between them are sufficient to cause C". The Evaporating Cloud and the Prerequisite Tree both use necessary condition thinking: "In order to achieve A we must have B". The logic rules are called the Categories of Legitimate Reservation (see Dettmer, 1997, Noreen et al 1995), and have been proposed for use in validating Systems Dynamics models (Balderstone, 1999). The entire suite of Thinking Process tools is based on these constructs. Scheinkopf (1999) provides an excellent straightforward explanation of these building blocks, or see Goldratt (1994), Noreen et al (1995), or Dettmer (1997). A very brief overview of the main features of the logic diagrams is provided next. For a fuller description and examples, see Goldratt (1994), Noreen et al (1995), Dettmer (1997), or Kendall (1998).

Current Reality Trees (CRT)

Goldratt (1990b) calls an existing condition a reality. The tools he has designed are intended to be used to analyse and deal with a system condition, or reality, with which the TOC practitioner is unhappy. Dettmer (1997) defines a Current Reality Tree as a logical structure which has been designed to depict that state of reality as it currently exists in a given system. The CRT represents the most probable chain of cause and effect, given a specific, fixed set of circumstances. It is constructed from top-down: from observed undesirable effects, postulating likely causes for those effects, which are then tested via the CLR. One such test is to predict (and check for) other effects that would also arise if this cause did exist - hence the term Effect-Cause-Effect.

Dettmer (1997) states that the CRT is designed to achieve the following objectives:

- Provide the basis for understanding complex systems
- Identify undesirable effects (UDEs) exhibited by a system
- Relate UDEs through a logical chain of cause and effect to root causes
- Identify, where possible, a core problem that eventually produces 70% or more of the system's UDEs.
- Determine at what points the root causes and/or core problem lie beyond one's span of control or sphere of influence
- Isolate those few causative factors (constraints) that must be addressed in order to realise the maximum improvement of the system
- Identify the one simplest change to make that will have the greatest positive impact on the system. (P.64)

Dettmer describes the CRT as functional rather than organisational and as such is blind to internal and external system boundaries.

CRT's may also include positive feedback loops: generally there will be at least one feedback loop which constitutes a vicious cycle. The existence of a loop usually opens up more possibilities for the siting of remedial action: a change in or below a loop will have a significant effect.

Evaporating Clouds (EC)

Once TOC practitioners have identified what to change, the second step in the process deals with the search for a plausible solution to the root cause; that is, what to change to. This task is accomplished with the aid of the Evaporating Cloud (EC) and the

Future Reality Tree (FRT). Unlike the trees, the EC has a set format with 5 boxes. The practitioner identifies two opposing wants, that represent the conflict, the need that each want is trying to satisfy, and a common objective or goal that both needs are trying to fulfil. Then the practitioner surfaces the assumptions that underlie the connections between objectives and needs, needs and wants, and in the process, uncover the reasons for the conflict that exists in their reality and prevents them from achieving the desired objective. This direct conflict is often the same as that underlying the CRT. Goldratt (1990b) states that traditionally in resolving these conflicts, managers have sought compromise solutions. He says that his approach lends itself most often to resolving the conflict altogether without resorting to compromise. The EC is intended to achieve the following purposes:

- Confirm that the conflict exists
- Identify the conflict perpetuating a major problem
- Resolve conflict
- Avoid compromise
- Create solutions in which both sides win
- Create new 'breakthrough' solutions to problems
- Explain in depth why a problem exists
- Identify all assumptions underlying problems and conflicting relationships. (Dettmer, 1997, p.122)

Future Reality Trees (FRT)

Once a solution, called an injection, has been identified via the EC method practitioners assume for the next exercise that it has been achieved and start to build the Future Reality Tree (FRT). The tree is constructed and scrutinised to test the solution, once again using a effect-cause-effect method. The FRT identifies what to change as well as considering its impact on the future of the organisation. Scrutinising each step of the FRT as a group minimises the probability that participants may overlook significant negative branch effects or overlooked problems. This process is referred to as trimming negative branches. The resulting tree originates in one or more injections and ends in desirable effects which really reflect the opposite of the UDEs in the CRT. Klein & DeBruine (1995) state that the process of synthesising the total organisation fosters and nurtures communication, understanding and acceptance. This is because one of the components of the Thinking Processes is the set of logic rules that underpin the trees. Goldratt's Categories of Legitimate Reservation (CLR) provide guidelines for communicating any reservations about the validity of the elements and connections within the trees (see Dettmer, 1997; Balderstone, 1999).

The FRT serves the following purposes:

- Enables effectiveness testing of new ideas before committing resources to implementation
- Determines whether proposed system changes will produce the desired effects without creating negative side effects
- Reveals through negative branches, whether (and where) proposed changes will create new or collateral problems as they solve old problems, and what additional actions are necessary to prevent any such negative side effects from occurring
- Provides a means of making beneficial effects self-sustaining through deliberate incorporation of positive reinforcing loops
- Provides a means of assessing the impacts of localised decisions on the entire system

- Provides an effective tool for persuading decision makers to support a desired course of action
- Serves as an initial planning tool.

Prerequisite Trees (PRT)

Once practitioners have identified what to change to, the third step in TOC deals with implementing the solution. Goldratt (1990b) states that one of TOC's principles is that "ideas are not yet solutions." He feels it cannot be called a solution until implementation is complete and the system is working as intended. The PRT is intended to identify obstacles that prevent the injection from the EC being implemented.

The PRT uses a different logic from the previous trees, both of which use sufficiency logic (which basically asks "Is this enough?") to establish cause and effect relationships. The PRT uses necessity logic, as does the Evaporating Cloud. In the case of the PRT, it is to identify the critical elements, or obstacles, standing in the TOC practitioner's way of reaching the objective. Dettmer (1997) advises asking the following two questions to check whether a PRT is needed:

- Is the objective a complex condition? If so, a PRT may be needed to sequence the intermediate steps to achieve it.
- Do I already know exactly how to achieve it? If not, then a PRT will help map out the possible obstacles, the steps involved in overcoming them, and the appropriate sequence.

Dettmer (1997) states that the PRT is used to achieve the following objectives:

- To identify obstacles preventing achievement of a desired course of action, objective, or injection (solution idea arising from the Evaporating Cloud).
- To identify the remedies or conditions necessary to overcome or otherwise neutralise obstacles to a desired course of action, objective or injection.
- To identify the required sequence of actions needed to realise a desired course of action.
- To identify and depict unknown steps to a desired end when one does not know precisely how to achieve them.

Transition Trees

The last tool in the TOC thinking process is the Transition Tree, which Klein & DeBruine (1995) state allows practitioners to determine the actions necessary to implement the solution. Practitioners use the effect-cause-effect method to construct and scrutinise the details of the action plan, called the Transition Tree. As in construction of the FRT, each step is scrutinised using CLRs for negative branches.

Dettmer (1997) sees the FRT as a strategic tool in which major changes can be outlined. The implementation of these, however, will require complex interventions needing greater detail of actions to be taken, which is the intended use for the Transition Tree. As such he sees the Transition Tree as an operational or tactical tool.

Dettmer (1997) states that the purpose of a Transition Tree is to implement change. He says that the Transition Tree structure started off as a four-element tree, with a fifth element being added later. Dettmer feels that the use of the four or five element tree is situational. He states that the five-element tree is the preferred methodology

when constructing step by step procedures and there is a need to explain to others exactly why each step is required. Dettmer (1997) outlines the original four elements of the Transition Tree as:
1) A condition of existing reality,
2) an unfulfilled need,
3) a specific action to be taken, and,
4) an expected effect of the integration of the preceding three.
Each succeeding level of the Tree is built upon the previous level, with the expected effect taking the place of the unfulfilled need. These build progressively upward to an overall objective or desired effect.

The fifth element added to the Transition Tree is:
5) the rationale for a need at the next higher level of the tree.
This change was devised to better assist buy-in from those from whom the TOC practitioner requires assistance. People are often inclined to resist change without a good explanation for the background to it. Also, frequently the implementation of major change falls outside the span of control of the person designing the change initiative, so that it is important to obtain the commitment of those who have the required power to ensure implementation. The fifth element that Goldratt has added appears to address these issues.

Dettmer (1997) states that the Transition Tree has nine basic purposes, these are:
- Provide a step by step method for action implementation
- Enable effective navigation through a change process
- Detect deviation in progress toward a limited objective
- Adapt or redirect effort, should plans change
- Communicate the reasons for action to others
- Execute the injections developed in the EC or FRT
- Attain the intermediate objectives identified in a PRT
- Develop tactical action plans for conceptual or strategic plans
- Preclude undesirable effects from arising out of implementation. (P. 284)

Summary of the Thinking Processes:

The relationship of the tools with each other is shown in the appendix. This shows the 5 diagrams and the usual way they interconnect if used in sequence to solve a complex problem. The five stage Theory of Constraints thinking process begins with a Current Reality Tree, which diagnoses what, in the system, needs to be changed. The Evaporating Cloud is then used to gain an understanding conflict within the system environment or, as Goldratt prefers to call it, the reality that is causing the conflict. The Evaporating Cloud also provides ideas of what can be changed to break the conflict and resolve the core problem. The Future Reality Tree takes these ideas for change and ensures the new reality created would in fact resolve the unsatisfactory systems conditions and not cause new ones. The Prerequisite Tree determines obstacles to implementation and ways to overcome them and the Transition Tree is a means by which to create a step-by-step implementation plan. All of Goldratt's tools are designed to overcome resistance to change by creating a logical path which can be followed.

The five tools can be used individually or in concert depending on the complexity of the situation that is being faced. The process allows practitioners to logically and thoroughly prepare themselves to successfully develop and implement change solutions.

Many applications of the Thinking Processes have been published since their debut in Goldratt (1994): there have been many examples presented in the APICS Constraints Management Symposiums, and in books such as Noreen et al (1995), and Kendall (1998).

Linking Hard and Soft:

As can be seen from the above, TOC is a systems method inasmuch as a system of interest is being modeled. What distinguishes this approach from many other systems methods is that TOC does not attempt to model a complete system, but rather chooses to model only those aspects of the system which are considered pertinent to the adverse performance of the system.

The hard science presents itself in the form of the logical structures of the diagrams: viz, necessary condition logic, the sufficient cause logic, and the strict logic rules that are used to validate the cause and effect relationships of the logic trees. This is important to ensure that pertinent aspects of the problem are not omitted, and to allow correct deductions to be made. The softer science methods are apparent in the complexity of the problems being tackled, and the softer nature of the elements of the model, such as behaviours, policies, perceptions, and a plurality of views.

Links with other Systems approaches:

It is interesting to note the similarities and differences with the standard "Rational Model" adopted by problem solvers from various fields, including hard-systems approaches (Ackoff, 1978). In many respects the TOC method follows this apparently ideal approach, yet - in fundamental ways - it challenges it.

An excellent example is provided by The Goal (Goldratt 1986). The central character, Alex Rogo, is guided on the path to turning around his under-performing factory, by the enigmatic questions of an old physics teacher of his, called Jonah. Jonah deduces, by using effect-cause-effect thinking, that Alex doesn't really understand what is driving his business, in particular the damaging effect of local performance measures that Jonah sees in evidence. He asks Alex what the goal of his business is. Alex discovers that what he thought was obvious, is far from correct, so he sets out to define a clear and appropriate goal. Next he devises a set of performance measures that will serve the company at both global and local decision making levels by providing a clear indication of performance and also for helping decide which actions would be best. Alex devises and implements his solutions, in response to Jonah's enigmatic questions, with the help of the relevant members of his staff, and the plant is saved - for the time being! (The story resumes in the second novel, It's Not Luck, Goldratt 1994). One of Alex's key learning points is when he discovers that the system's performance is not predictable from the sum of its parts.

Now let us consider the Rational Model (Ackoff 1978, p13), summarised below:

1. Identify the problem
2. Define the objectives
3. Determine the criteria
4. Structure the Problem
5. Develop Alternatives
6. Evaluate Alternatives
7. Recommend Courses of Action
8. Implement Decisions
9. Repeat

The first step, defining the problem, is what is done first in The Goal: the problem is that the plant is not making enough money and is about to be closed. Alex then finds that he needs to define the goal or objective, then decide on how to measure performance relative to that goal. This is equivalent to defining criteria, yardsticks, and deciding on relative priorities between criteria. Thus the two methods are consistent in the first three steps. The next steps in the Five Focusing Steps are to identify the constraint that is limiting the system's performance, and exploit the constraint: to ensure it is working to give the maximum benefit to the system. Essentially here we consider the current use of the constraint, identify the reasons for the constraint and identify alternative actions and their impact on the constraint. (A number of specific and generic suggestions for action are contained in *The Goal* and in *The Race,* Goldratt and Fox, 1986). The rational model ends with implementation, though actual modeling approaches seldom give any guidelines on this step: in *The Goal*, this step is an integral part of the whole process. The final step of going back to the start in an iterative process is common to both methods in theory, at least.

So there are many similarities on the surface between the logical flow of events between the two approaches, and one could ask whether Goldratt had added anything new. However there are a number of significant differences. Goldratt's five focusing steps methods leads to a streamlined approach, by focusing on the key role played by the constraints. The Socratic method he uses, especially in his novels, promotes a self-help approach, which wins over people far more easily than the prescriptive approach inherent in the rational model. They are finding it out for themselves in a journey of discovery; no-one is telling them what to do! The solutions to the problems are generated by people within the organisation - not by outside experts. Here what matters is whether the actions will improve the output of the system, not on which is best. So this is perhaps more of a satisficing approach than a rational (optimising) approach. Goldratt demonstrates very clearly in his novels the dire consequences of not being clear about goals and of choosing inappropriate measures: the motivation for change is strong and clear. Finally, the process is one of on-going improvement, not a one-off solution.

The Thinking Processes seem to provide even more significant differences, while still adopting a seemingly rational process. Goldratt is starting from the assumption that we are usually far better at saying what's wrong, than what's right. Thus the first step in the process, building the Current Reality Tree, starts by listing the undesirable things about our reality, the symptoms, that are evidence of a system that is under-performing. The core problem, identified by the cause-and-effect reasoning in the

CRT, may be a lack of clear goals. Kendall (1998) states that the three pillars of success are policies, performance measures and training. Conversely these are the most common root causes of problems. These in turn are probably the results of unclear goals, or of multiple goals with unclear priorities between them. Or if our goal is clear and well-defined, then we can find ourselves being driven in two opposing directions, due to inappropriate local measures in different departments. This conflict is well captured and resolved using the Evaporating Cloud.

Once goals and performance measures have been agreed upon, it is necessary to identify options, and evaluate them, before planning implementation. The Evaporating Cloud helps us to identify possible actions by challenging the assumptions which underpin the conflict, and selecting the ideas that we think hold most promise. Next the Future Reality Tree predicts the impact of those ideas, if implemented, allowing an assessment of their effectiveness. The FRT also provides a first step in testing implementation issues. Finally the Prerequisite and Transition Trees are used to explore further implementation issues. The process theoretically is repeated if necessary, though this is rather less likely with the TP's than with the Five Focusing Steps method, because the TP's are such an exhaustive (and exhausting) process!

The changes arising from the use of the TP's tend to be more tailored than those arising from Five Focusing Steps, as the TP's encourage practitioners to develop their own solutions to difficult problems, and provide the necessary tools to do so. For example the Evaporating Cloud is excellent for generating new ideas for solving old problems, particularly behaviours or policies that are preventing a solution. The tools facilitate teamwork, both in the way they are used, and through the provision of the CLR. They encourage a systems view, particularly by understanding that seemingly disparate problems are often the result of the impacts and inter-relationships of some common root causes, which if dealt with, will lead to a marked improvement in the system's performance.

Conclusions:

Despite its origins as a manufacturing methodology, Goldratt's Theory of Constraints (TOC) methodology can now be regarded as a systems methodology that links elements of both soft and hard systems methods. The TOC Thinking Processes, which underpin the entire methodology, have been outlined. These comprise a suite of logic trees that provide a roadmap for change, guiding the user through the decision making process of problem structuring, problem identification, solution building, identification of barriers to be overcome, and implementation of the solution. A set of logic rules, called the Categories of Legitimate Reservation, provide the analytical rigour usually associated with hard scientific approaches. This is combined with the ability to capture softer information and complexity provided by soft OR approaches. The similarities and differences between TOC and other systems methods, are discussed. In particular, the TOC method is seen to focus on the problems currently being experienced, the most likely cause-and-effect relationships leading to these, and the best course of action to remove them, rather than aiming to model the entire system. The TOC methods also have much in common with the steps laid down in the Rational Model of decision-making. However, there are marked differences in the underlying assumptions, and methods used in the intervention process.

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THE TOC TP TOOLS ROADMAP