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Applying the Thinking Process of the Theory of Constraints: An Exploratory Research Methodology to Evaluate the Lack of Use of Cut-to-Length Harvesting Systems in the Southeastern United States

Ian P. Conradie, W. Dale Greene, James F. Cox, and Glen E. Murphy

The authors are, respectively, Partner, Ingeser Consultores, Santiago, CHILE, email: iancon@mi.cl; Professor, Daniel B. Warnell School of Forest Resources, Center for Forest Business, The University of Georgia, Athens, GA 30602-2152 USA, greene@forestry.uga.edu; Professor Emeritus, Terry College of Business, The University of Georgia, Athens, GA 30602 USA, email: jcox@uga.edu; and Professor, College of Forestry, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331 USA, email: glen.murphy@oregonstate.edu.

ABSTRACT

Although this application of the Thinking Process of the Theory of Constraints has been applied to a forestry supply chain, the Thinking Process can be applied to analyze and solve most problems. Two Thinking Process tools, the Current Reality Tree and the Future Reality Tree, are described and illustrated. The Thinking Process methodology is action research and is especially valuable in exploratory research with small populations thereby making it useful when conventional statistical methods are not appropriate. The Current Reality Tree uses cause-and-effect logic to establish relationships between the symptoms and the core problem(s); the Future Reality Tree uses cause-and-effect logic to test potential solutions for sufficiency, and positive and negative consequences before implementation. The problem under study is why cut-to-length (CTL) harvesting systems (used to convert trees to logs) are rarely used in the southeastern United States, although CTL has many advantages over other systems in numerous parts of the world. First, 16 reasons why this problem exists were identified. Next, the Current Reality Tree was used to identify the core (primary) problem, and the Future Reality Tree was used to construct a possible solution. The complexity of CTL equipment was identified as the core problem.

Keywords: Harvesting, cut-to-length, southeastern United States, Theory of Constraints, Thinking Process, cause-and-effect, Current Reality Tree, Future Reality Tree

Introduction

Success in the product development and introduction phases of the product life cycle is critical to the long-term success of an organization. Rogers (1995) indicates that for every successful product introduction there are hundreds of failures. Therefore, one focus of this study is to describe and illustrate the use of a logic-based set of tools to address a situation where a product has failed to be adopted. In this study, Goldratt's Thinking Process of the Theory of Constraints was used to analyze the problem. According to Mabin and Balderstone (2000), the Theory of Constraints has been successfully applied to hundreds of different organizations across a wide range of problems. This study applied the Current Reality Tree (a problem identification methodology) and the Future Reality Tree (a problem solution methodology) to the failure to adopt an emerging technology.

The second focus of this study is on the lack of use of cut-to-length (CTL) harvesting systems in the southeastern United States. A CTL system consists of a harvester that fells trees and then processes them into logs at the stump and a forwarder that extracts the logs. In Sweden and Finland almost 100 percent of wood is harvested by CTL systems while in North America only 20 to 30 percent of logging is done this way (Gellerstedt and Dahlin 1999). Brink (2001) determined that the global trend is to replace feller-bunchers and skidders with harvesters and forwarders. Heidersdorf (1991) reported that the primary advantages of CTL harvesting systems are lower environmental impacts and higher fiber recovery. Greene et al. (2001) showed that CTL operations have yet to be widely adopted in the southeastern United States; in Georgia, for example, it accounts for less than 1 percent of logging.

Brink (2001) identified change drivers affecting timber harvesting during the last decade (1990–2000) and those expected during the next decade (2000–2010) in four regions of the United States, three regions of Canada, Sweden, Finland, Germany, New Zealand, Chile, and Australia. He found the most important change drivers to be technological and productivity improvements, environmental impacts, and social pressure. Out of 20 changes that are expected to take place in harvesting systems by 2010, an increase in CTL systems was ranked 12th (1st = most important change). It was ranked 16th in the southeastern United States, where it currently has little use.

From the literature we knew that the population and possibly the resulting sample size of organizations that had CTL equipment (past and present) in the southeastern United States would be small. Conventional statistical methods therefore have limited application. On the other hand, a decision often must be made given the limited information available. Thus, the objectives of this study were to:

1. Describe the research paradigm dilemma and illustrate a new methodology that can be used to analyze small populations (and possibly small sample sizes), establish the cause-and-effect relationships among problems, identify the few core problems, test the sufficiency of the causal relationships, and identify the consequences (positive and negative) of solutions to the core problem(s).

2. Apply the new methodology to identify the few core problems that cause numerous other problems (symptoms), which ultimately led to the low adoption of CTL, and identify and test actions that can be taken by different stakeholders in the supply chain to solve the core problems that can increase the adoption of CTL systems.

Literature Review

In this section, the conflict between qualitative and quantitative research paradigms is discussed first; second, an overview of the history and use of the Theory of Constraints in qualitative research is given; and lastly, an international and local perspective on CTL adoption is provided.

Methodology Paradigms: Qualitative versus Quantitative Research Paradigm Conflict

One purpose of business research is to provide a foundation on which to make decisions (Sekaran 2000). However, a requirement of effective decision-making is that information used for decision-making must be timely (Holbert 1976). To respond to this need, organizations have continually purchased bigger and faster computer and software systems. A second, equally important requirement to make effective decisions is that information used as the basis for decision-making must be generalizable (Sekaran 2000) to the population being studied. It is, therefore, necessary for organizational policies and procedures to apply to a large population to be effective. Other requirements to support effective decision-making are that information gathering must be cost effective and that the information meets the needs of the decision maker — it must provide information on the core problem, not on the symptoms. Organizational policies and procedures must apply to a large population to be effective. In order for a decision to be timely, the decision must be made using the limited information available, therefore suggesting a qualitative analysis of the available information. However, for the decision to be a generalization, it must be postponed until enough data are available therefore suggesting a thorough statistical (quantitative) analysis. Then the dilemma is making a decision based on qualitative or quantitative analysis.

This qualitative versus quantitative methodology paradigm debate is similar to the hard versus soft sciences operations research (OR) methodology paradigm debate over when and where to use the various OR tools. Several researchers recognized that the tools were quite complementary and developed different classification schemes identifying the benefits and uses of each methodology. Many authors (Jackson 1990; Mingers 2000, 2003; Mingers and Brocklesby 1997) discussed multi-methodological approaches to problem solving. More recently, Mabin et al. (in press) included the Theory of Constraints applications and Thinking Process methodologies (being used in this analysis) as part of a multi-methodology classification scheme. Davies et al. (2004) illustrated the complementary and systemic nature of the Thinking Process with causal loop diagramming. Causal loop diagramming is a tool of systems thinking and dynamics, an OR methodology. Both the Thinking Process and causal loop diagramming are viewed as cause-and-effect diagramming tools (as opposed to correlation modeling using statistical analysis). Causal loop diagramming maps system variables and their interactions, particularly the chain of interactions that form feedback loops in a system. Senge (1990) documented archetypes of problems and typical responses and their effects, including Fixes that Fail, Shifting the Burden, Tragedy of the Commons, etc., all of which are typically portrayed using cause-and-effect thinking in the form of causal loop diagrams.

Theory of Constraints

Much of the literature on the adoption of CTL harvesting systems is based on expert opinion (not scientific research) with authors listing the many reasons for the failure of CTL adoption in the southeastern United States. The problem faced in this study was the small population of suitable study subjects. It was, therefore, unavoidable that the type of research we had to do would be of a qualitative and exploratory nature (outside the normal paradigm of statistical models). One of the methodologies that met the criteria for this study was the Thinking Process of the Theory of Constraints.

Gillespie et al. (1999) see the Theory of Constraints as a management philosophy that defines a set of problem solving and management tools, which have had a significant effect on the operation of businesses throughout the world. The Theory of Constraints was originally developed in the early 1980s by Eli Goldratt (an Israeli physicist) and originally evolved from the Optimized Production Timetables scheduling system he developed and later explained in *The Goal* (Goldratt and Cox 1984). The problem -solving tools of the Theory of Constraints, better known as the Thinking Process, were first taught in 1992 and are explained in a novel written by Goldratt (1994). These tools can be used to solve most problems by building causal trees or diagrams. They use cause-and-effect logic to diagnose the core problem from its symptoms (or undesirable effects). It is, therefore, different from the normal approach of correlation and classification (Taylor et al. 2003).

Other tools of the Thinking Process are useful in building effective solutions and implementation plans, thus making it a complete process for problem solving. Early applications of the Thinking Process included diagnosing production-scheduling problems, failures in the product design and development process, problems of low profit, failed improvement programs, poor management information systems, unreliable vendors, proposed plant expansions, and poor performance measurements across functions. The Thinking Process can also be used to manage meetings, improve communications, and obtain buy-in.

Over time the focus of Theory of Constraints gradually moved from the production floor to include all aspects of business (Rahman 1998). According to Blackstone (2001), ten years ago the theory was primarily applied to production, but today it has been applied to a wide range of disciplines including: operations (drum-buffer-rope), finance and measures (throughput accounting), project management (critical chain project management), distribution and supply chains (replenishment), marketing (the unrefusable offer), sales, managing people, strategy, and tactics. According to Netherton (1996), Theory of Constraints has been adopted by industrial engineering departments in more than 50 universities. By 1998, 86 articles on Theory of Constraints were published in 21 refereed journals, with an additional 53 articles published in non-refereed journals (Rahman 1998).

Noreen et al. (1995) conducted an early study of companies that had implemented Theory of Constraints successfully. They identified the following weaknesses of the Thinking Process: “it is complex and difficult to master; it requires new ways of thinking; it uses unfamiliar terms; it relies on the quality of the information provided; and building the trees are time consuming”. They concluded that the power of the Thinking Process is most evident in cases where the problem is complex and solutions are not intuitively obvious.

In forestry related applications, Oberholzer et al. (2003) used the Thinking Process to identify a total of 176 problems that existed between logging contractors and forestry companies that hampered the functioning of logging contractors in South Africa. In the end, they identified that most of the problems were symptoms of seven core problems. Boyd and Cox (1997) described the use of the Thinking Process in analyzing the negative effects of incorrect measures in a mill. The Thinking Process has also been successfully used in manufacturing and service organizations, for-profit and not-for-profit organizations, military and civilian organizations, supply chains, project environments, and individual and group environments (Cox et al. 2003).

Technically, many of the previous Thinking Process applications can be viewed as action research. The purpose of action research is to solve business and management problems through the application of the scientific method. Action research and specifically the Thinking Process are concerned with management problems and are conducted in a company or local setting. In most instances, action research is not concerned with whether the results can be generalized to any other setting. The primary goal of action research is the solution of a given problem in a specific environment, not a contribution to science. However, Kwolek and Cox (1997) use the Current Reality Tree in action research to identify the core problems within and across a number of similar sized military maintenance depot environments. The core problems identified in one depot were similar and in most cases identical to the core problems found in other depots.

It is beyond the scope of this paper to teach all of the Thinking Process tools and their uses. Several texts (Cox et al. 2003; Scheinkopf 1999; Dettmer 1998) provide detailed procedures and examples illustrating the use of each tool.

A Perspective on Cut-to-Length Adoption

Many authors have written explicitly and implicitly about the adoption of CTL harvesting systems in different parts of the world. In the United Kingdom, the lack of skilled machine operators, distrust between the logging contractors and the forest enterprises, and maintenance issues hamper the profitability of CTL systems (Gellerstedt and Dahlin 1999). In Germany, the following problems are experienced when introducing mechanized CTL systems: difficulties regarding tree species, tree size, steep terrain as well as the lack of skilled operators and maintenance problems (Gellerstedt and Dahlin 1999). Murakami (2002) suggested that in order for Rigesa-MeadWestvaco (a company in Brazil) to adopt a CTL system the solid wood market will need to reassess the potential value gain for the end product that can be achieved by optimizing logs with CTL systems. Guimier (1999) emphasized the importance of skilled operators as a prerequisite for successful CTL operations in general and specifically in Canada.

According to Gellerstedt and Dahlin (1999), the lack of maintenance support, lack of skilled operators, the capital invested in other logging systems and at the mills, the culture of buying powerful machines, the low educational level and social status of forest workers, the low earning potential of forest workers, and the large number of small family contractors are reasons why CTL is not more widely used in North America. Harstela (1999) reported that lower productivity of CTL equipment and lower skilled operators contributed to lower adoption of CTL harvesting systems in North America. Tufts and Brinker (1993) state that CTL has not been used extensively in the United States because of the high initial cost, service and parts are not readily available, and operators must be trained on these machines. According to White (2003), notwithstanding the fact that less equipment is required with a CTL system, it is neither a simple system to operate nor is the initial investment in equipment low (it is in the region of US$ 1 million). He also believes that the right mix of trees, machines, and people are required for a successful CTL operation.

McCrary (2001) reported several reasons why CTL systems are rarely used in the southeastern United States. These reasons include: most loggers receive little or no monetary incentive for the intangible benefits provided by CTL, some forest companies who previously encouraged loggers to purchase CTL systems have since requested that they return to tree-length systems, CTL is sensitive to downtime as there are no backup machines to maintain production, and it is difficult to find competent operators. According to Holtzscher (1995), the adoption of CTL in the southeastern United States has been limited because of the complexity of the equipment, the high initial cost, lack of available finance, lack of service support, and resistance to change by local logging contractors. The high capital costs and the limited markets for CTL wood are seen as problems by Stokes and Watson (1996). Rummer (2001) states that although modern CTL systems have some good attributes, there are significant reservations about widespread adoption at this time. He reported that CTL wood is not compatible with the transport and mill systems currently in use, and that it does not fit in with the culture of the loggers in the southeastern United States.

From an international and local perspective, the major problems were the high capital investment, the lack of competent operators, the lack of maintenance support, the culture of the loggers, and the incompatibility of CTL systems with the systems already in place. Some authors also thought that the complexity of CTL systems could be a problem.

Methods

In this section, the reasons why the Thinking Process of the Theory of Constraints was used are first discussed. Then the selection of the study subjects and data gathering is explained. Finally, it is explained how the Thinking Process was used to analysis the data.

Other Methodologies versus the Thinking Process

Other cause-and-effect methodologies (e.g., fishbone diagrams and the five whys) and the Delphi-technique were considered for use in this study, but the Thinking Process was chosen for two reasons. First, this research is exploratory by nature as only a small population of qualified experts in this subject area (past and present users of the CTL technology) existed. Some authors have offered their opinions on the problem of CTL adoption but no scientific evidence has been provided to support their opinions. At this stage of inquiry we wanted to define the environment, the important elements, and the relationships based on a small number of data points. By using the Thinking Process we are able to strengthen evidence given in the survey by identifying the important variables and their relationships through logic. The Thinking Process is also not adversely affected by small sample sizes as long as the individuals represented in the sample have different perspectives of the environment and have identified the major problems why CTL is rarely used in the southeastern United States. The methodology is used to establish the existence of cause-and-effect relationships, not correlations.

The second reason the Thinking Process was chosen was because we wanted to take a systems perspective of the problem, not only identifying the surface problems (symptoms) and the core problem, but also identifying potential solutions across the system. The Thinking Process methodology supports this application effectively.

We did not view our study as a Diffusion of Innovation study as described by Rogers (1995). The main focus of our research was not to investigate the diffusion rate of the innovation of CTL in the southeastern United States, but why the CTL innovation failed in this region. Although the diffusion of innovations is a closely aligned school to our study, it is not appropriate to our research for a number of reasons. First, our research design does not follow the traditional research methodology paradigm of innovation disciplines where the vast majority of research studies use quantitative analysis (statistical analysis of surveys of innovation users). In contrast, our study is a qualitative study of a limited number of respondents. Second, our study does not fit the focus of traditional innovation research. Rogers classifies diffusion studies into eight different types and the focus of our study was not related to any of these. We were interested in why CTL has not been adopted in the southeastern United States.

Several other researchers have questioned the validity of Rogers' Diffusion of Innovation Theory as it ignores the influence of the supplier (Frambach 1993), and it does not describe the diffusion of innovation well when it is studied within and across organizations (Lundblad 2003). Since we were dealing with a forest supply chain, we could not ignore the other stakeholders in the supply chain (e.g., the suppliers of CTL equipment). Clarke (1999) is of the opinion that Diffusion of Innovation Theory is at its best as a descriptive tool, less strong in its explanatory power, and less useful still in predicting outcomes and providing guidance as to how to accelerate the rate of adoption. All of these issues were an integral part of our study, therefore, we could not use Rogers' Diffusion of Innovation Theory. This paper was not designed to invalidate the research on innovation, although it does raise some interesting questions concerning how to approach this research area.

The major problems with all the previously mentioned methodologies are their inability to explain causal relationships thus making them unsuitable for identifying and addressing core problems. They also do not allow for the solution to be tested for positive and negative consequences. In this application we are proposing a new methodology to address problems where small populations exist and the environment must be explored to identify the relationships that exist between them.

The Survey

According to Eisenhardt (1989), cases representing polar extremes of the phenomenon being studied are particularly suitable in exploratory research. Therefore this study included the two extremes of logging contractors in the survey conducted in late 2002: loggers in the southeastern United States who were using CTL systems and loggers in the southeastern United States who had previously used CTL but who were no longer using it (after trying it, it was rejected). We felt that only such loggers could provide us with valid responses for the research, as they had an intimate knowledge of and experience with CTL systems. They could provide a balanced view of the problem without making uninformed claims of why CTL is not the system of choice in the southeastern United States. Evidence suggested that all of these loggers are (or were) operating both CTL and non-CTL, which were sufficient to represent the viewpoints of non-CTL loggers without possibly introducing bias into the data.

Equipment manufacturers were also included in the survey. Evidence suggested that almost all of these manufacturers were selling both CTL and non-CTL equipment – therefore they also had insights into the viewpoints of non-CTL loggers. They had experience with facing the problems of CTL and non-CTL systems as part of their normal daily business. In addition, they knew loggers who abandoned their CTL systems. The equipment manufacturers would know better than anyone why they are unable to sell CTL equipment to both CTL and non-CTL loggers.

We regarded this as a purposive sample directed at the individuals with the most intimate knowledge of CTL equipment characteristics and capabilities. Data was collected from the study subjects through a mailed (posted or e-mailed) survey that included open-ended questions (a list of possibilities to choose from were not provided) on the perceived advantages and disadvantages of CTL, the perceived problems that limit the use of CTL systems in the southeastern United States, actions to eliminate the problems, and some other general questions (close and open-ended). Descriptive statistics was used to show the frequency of some survey responses.

The Thinking Process Analysis

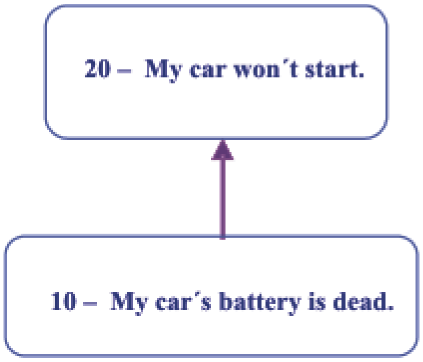
The primary methodology used to analyze the survey results was the Thinking Process of the Theory of Constraints. The Thinking Process consists of tools that use logic to construct cause-and-effect diagrams that are used to answer three questions:

1. What to Change?

Of all of the problems or symptoms faced by an organization (a forest supply chain in this case), what few core problems, if solved, cause significant improvement (an increase in the adoption of CTL systems)? In Theory of Constraints terminology, problems or symptoms are described as undesirable effects. This terminology is used to distinguish undesirable effects from the core problem that created them in the first place (Cox et al. 2003). The Current Reality Branch and Current Reality Tree were used to identify the causal relationships among undesirable effects and their relationship to the core problem(s). The Current Reality Branch is a logic-based tool (logic tree, diagram) for using cause-and-effect relationships to determine the causal linkages from actions or policies to their effects in the current situation. It provides the starting point for the Negative Branch Reservation and the Current Reality Tree. The Current Reality Tree is a logic-based tool that uses cause-and-effect relationships to determine root problems that cause the observed undesirable effects of the system.

In a logic tree, arrows link entities to show cause-and-effect relationships. A simple two-entity logic tree is shown in **Figure 1** (Blackstone 2001). Entity 10 states that my car's battery is dead. Entity 20 states that my car won't start. The arrow connecting entity 10 and entity 20 implies causality. The point of the arrow shows the effect while the base of the arrow shows the cause. Therefore, "(20) my car won't start" because "(10) the battery is dead", or expressed in another way, if "(10) my car's battery is dead" then "(20) my car won't start". The purpose of the Current Reality Tree is to find the core problem(s). In this simple example, the core problem of my car won't start is the dead battery. Once I understand the core problem I can take actions to correct it, but acting on a symptom (say, a symptom of the dead battery is the inability of the starter to turn) without understanding the core problem may be futile (e.g., replacing the starter if the battery is dead).

Figure 1. A simple logic tree.



Throughout this study, errors in the logic of the cause-and-effect diagrams were checked for by using the Categories of Legitimate Reservations (**Table 1**). The Categories of Legitimate Reservations are a set of rules, similar to grammatical rules, that is used to structure and scrutinize logical arguments (Cox et al. 2003). It consists of three levels containing seven categories and provides a precise methodology for pinpointing errors in logic. A legitimate reservation exists when the logic presented does not make sense.

Once the core problem analysis was completed, we checked that all of the problems described by several authors in the literature were represented in the Current Reality Tree, either as undesirable effects or some other logic entity explaining the existence of an undesirable effect. The data was triangulated from two different sources, the literature review and the survey, thereby ensuring that the problems the respondents identified were consistent with the ones identified in the literature, and that important reasons for the lack of CTL adoption by loggers in southeastern United States were not left out. A separate core problem analysis was performed for each of the individual respondents to ascertain if there was consistency among the individual root causes.

2. What to Change to?

Of all of the possible solutions to a core problem, what set of actions (called injections in Theory of Constraints terminology) create a win-win solution for all parties involved in the problem? Once the Current Reality Tree was completed, the Future Reality Branch and the Negative Branch Reservation process was used to identify, test, and construct a complete solution for the problem. The Future Reality Tree is a logic-based tool for constructing and testing potential solutions before implementation. The objectives are to develop, expand, and complete the solution as well as to identify and solve, or prevent new problems created by implementing the solution. The Future Reality Branch is similar to the Future Reality Tree except it is used to test and solve problems related to a specific action. The Negative Branch Reservation is an iterative process used to develop the causal logic from the current situation in the Current Reality Tree and a proposed action to the negative effects created by that action. Additional actions are proposed and tested to determine their effects until a satisfactory solution (desirable effect) is determined. The product of the Negative Branch Reservation is a Future Reality Branch (Cox et al. 2003). In **Figure 1**, we can solve the core problem of the dead battery by charging or replacing it. It would be futile to change the starter if the battery is dead (treating a symptom of the dead battery).

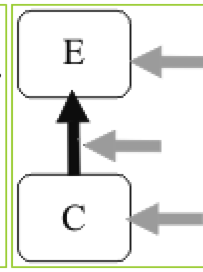
3. How to Cause the Change?

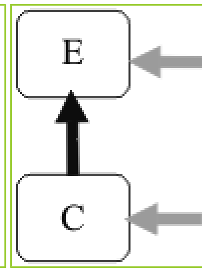
The development of an implementation plan that reduces resistance to change and creates ownership of the solution is critical to a successful implementation of any solution. The Prerequisite Tree and the Transition Tree are useful tools in identifying obstacles to implementation and developing the project plan. This was beyond the scope of this study.

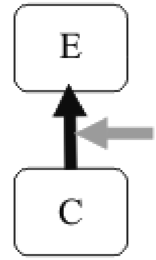
Conradie (2003) gives a detailed description of how the tools were used to determine the core problems and solutions described in this paper.

Table 1. The Categories of Legitimate Reservations (Cox et al. 2003; Scheinkopf 1999; Dettmer 1998; Noreen et al. 1995).

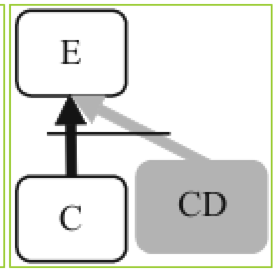
The black arrows show the original hypothesis and the grey arrows show the legitimate reservation.

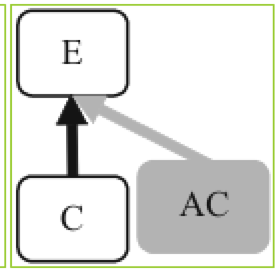
Level 1 Reservation **Clarity** is always the first reservation to use when the different entities, the causality between entities, or an area of the diagram is not fully understood; e.g., I do not understand the cause (C), or the effect (E), or C and E, or the causal relationship between C and E. An additional explanation is required. If the explanations are unsatisfactory we move to level 2.	

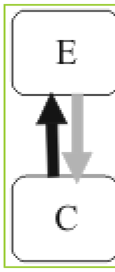
Level 2 Reservations The **entity existence reservation** challenges the existence of either the cause entity (C) or the effect entity (E) by explaining that C or E does not actually exist; e.g., I do not believe that C or E exists.	

The **causality existence reservation** challenges the causality arrow (the existence of causality between two entities). There is agreement that both entities (C and E) exist but there is disagreement about the link (the arrow) between the cause (C) and the effect (E); e.g., I do not believe that C is the cause of E. This reservation is normally eliminated by providing the missing logical entities and connections between the two entities.	
If the explanations are unsatisfactory we move to level 3.	

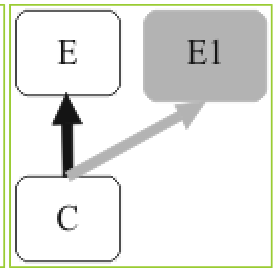
Level 3 Reservations
The **cause insufficiency reservation** is used to indicate that a cause (C) is insufficient by itself to cause the effect (E); another cause (CD) (called a core driver) must exist to cause the effect (E). In the diagram a "conceptual and" connector is used to satisfy this reservation (it is the line over the arrows from C and CD to E). Therefore, if C and CD then E.



The **additional cause reservation** is used to challenge that only the major stated cause (C) of the effect (E) has been identified. It poses the questions that there is at least an additional, non-trivial cause (AC) that adds to the size of the stated effect (E). Both C and AC independently contribute to E thereby magnifying the size of the effect with neither one being able to totally explain the size of the effect. A "magnitudinal and" connector is used to satisfy this reservation. This situation is indicated by two or more arrows entering a cause without a "conceptual and" connector. Therefore, if C then E, and if AC then E.	

The **house-on-fire** (cause-effect reversal) **reservation** indicates redundancy in the cause-and-effect relationship. The cause (C) is normally a rewording of the effect (E). Hence, the cause can be stated as the effect, and vice versa (the arrow could point either way). The cause (C) does not lead to the effect (E). This reservation usually occurs when we confuse why the entity exists with how we know the effect exists; e.g., if smoke billows from the house then the house is on fire is not valid logic as it explains how we might know the house is on fire but not the cause of the fire, which could be an electrical short circuit. Normally it is sufficient to ask "why" to determine the cause.	

The **predicted effect reservation** is generally the last reservation. It is used to show that the logic is flawed. Here another effect (E1) is used to show that the initially hypothesized cause (C) does not result in the initially observed effect (E). If E1 does not exist then C does not exist. Therefore, E is caused by something other than C. However, if C does result in E1, then this supports the original cause-and-effect relationship between C and E.



Results

In this section, the survey and some general observations from the study are discussed. Secondly, descriptive statistics on the advantages and disadvantages the respondents identified are provided. Then, the undesirable effects and the core problem using the Current Reality Tree are identified. Lastly, the actions to solve the problems using the Future Reality Tree are discussed.

Survey

The following study subjects were included in this study:

1. Nine CTL loggers who were using CTL (three each from Georgia and Louisiana, and one each from Arkansas, Alabama, and South Carolina);

2. Five ex-CTL loggers who used CTL but were no longer using it (two from Louisiana, and one each from Alabama, Georgia, and South Carolina); and

3. Four CTL equipment manufacturers that were active in the equipment market in the region at the time the study was conducted.

Eleven (61%) of the 18 questionnaires sent to participants were returned. Four (44%) of the CTL loggers returned their surveys (one each from Georgia, South Carolina, Louisiana, and Alabama). All of these respondents operated both CTL and other harvesting systems. The percentage of wood harvested by CTL loggers using CTL systems were 7 percent, 30 percent, and 8 percent, respectively (the fourth one did not provide a percentage, but operated both CTL and non-CTL systems). These loggers, therefore, were able to provide a balanced view of the lack of CTL adoption as they had intimate knowledge and experience of both systems. In our opinion, they also represented the viewpoint of loggers who were not using CTL. Three (60%) ex-CTL loggers returned their surveys (one each from Georgia, South Carolina, and Alabama). They cited economic reasons and the unavailability of suitable stands as reasons why the use of CTL was discontinued. All of the ex-CTL loggers also had experience with non-CTL systems, allowing them to give well-informed responses to the survey questions. Therefore, they were also able to present the viewpoint of non-CTL loggers. All of the surveys (100%) from equipment manufacturers were returned. One of the equipment manufacturers sold only CTL equipment while the other three were selling both CTL and other types of logging equipment in this region. We were satisfied that this sample gave a representative picture of the current reality, especially since the data from the survey was going to be triangulated to the literature.

One of the CTL loggers received a premium from 10 percent of the mills that he supplied with CTL logs. None of the ex-CTL loggers received any premium. Six of the seven CTL and ex-CTL loggers believed that value recovery is higher with CTL as compared to conventional tree-length systems. Only one in four equipment manufacturers believed that CTL was becoming a more acceptable system for the southeastern United States.

Advantages and Disadvantages

A total of 27 advantages of CTL were identified with 91 percent of the respondents (10 out of 11 respondents) perceiving better value recovery and the environmental friendliness of CTL as advantages. Other identified advantages included: CTL is not as sensitive to adverse weather, smaller and fewer or no landing areas are required to process the trees, the right product is sent to the right place thereby reducing handling and transport costs, CTL harvesting is more aesthetically pleasing, and the working environment is safer and more ergonomic for personnel. Conradie (2003) provides a detailed list of all of the advantages.

Respondents also identified 17 disadvantages of CTL with higher logging costs perceived by 73 percent (8 out of 11 respondents) as a disadvantage. The high initial cost of CTL equipment and the higher skills required by CTL operators were perceived by 64 percent (7 out of 11 respondents) and 55 percent (6 out of 11 respondents) to be disadvantages. Other disadvantages included: the productivity of CTL is lower compared to conventional systems, operators have a steep and long learning curve before they are competent, most mills have inventory and handling systems designed for tree-length, CTL technology is complex, higher skill levels are required for technical staff/owners, and parts and support from dealers is severely lacking. Conradie (2003) provides a detailed list of all of the disadvantages. This information was used to great effect during the construction of the Current Reality Branches, as it assisted in establishing some cause-and-effect linkages between problems.

What to Change . . . Symptoms versus Core Problems?

In the original survey, the stakeholders were asked to identify the constraints that limit the wider use of CTL harvesting systems. For the purpose of this study, these constraints are hereafter referred to as undesirable effects. The respondents identified 16 undesirable effects that limited the use of CTL systems (**Table 2**).

Table 2. Undesirable effects identified by the respondents, expressed as a percentage of the number of respondents in each stakeholder category and in total.

#[a]	Undesirable Effects	CTL *n*=4	Ex-CTL *n*=3	Manufact. *n*=4	Total *n*=11
1.	Limited markets for CTL wood exist.	25	33	100	55
2.	The initial investment in CTL equipment is high.	75	67	25	55
3.	The logging cost of CTL wood is high.	25	100	50	55
4.	It is difficult to find suitable stands for CTL equipment.	25	0	50	27
5.	It is difficult to find competent CTL operators.	25	0	50	27
6.	The culture of the loggers is geared toward conventional systems.	0	67	25	27
7.	Most loggers and new CTL operators go through a steep and long learning curve.	25	0	25	18
8.	There is a lack of secure logging contracts in the industry.	0	0	50	18
9.	There is a lack of technical readiness with most loggers regarding CTL.	0	0	50	18
10.	Operating and maintenance issues are complex on CTL equipment.	25	33	0	18
11.	Loggers do not understand the benefits of CTL equipment.	25	33	0	18
12.	Most landowners do not understand the benefits of CTL.	0	33	25	18
13.	The annual cut in the southeastern United States is decreasing.	0	0	25	9
14.	Most loggers operate conventional logging and transport systems.	0	0	25	9
15.	Mills do not pay extra for CTL wood.	25	0	0	9
16.	The technical and parts support from dealers is poor on CTL equipment.	25	0	0	9

[a] The numbers in this column are based on the descending response rate of the undesirable effects. All of the numbers, therefore, do not correspond to the numbers assigned as labels to undesirable effects used later in this paper.

The number of undesirable effects identified by each respondent varied from one (one respondent) to nine (one respondent) with a median value of four. Ten of the 11 respondents identified five or less undesirable effects. Most respondents had only a few problems with CTL systems. Limited markets for CTL wood, the high initial investment, and the high logging costs associated with CTL were each cited by 55 percent (6 out of 11) of respondents. Eight (73%) of the respondents identified the high logging costs or the high initial cost or both as undesirable effects. It is probable that once the core problem for the high logging costs and the high initial investment were identified, we would have identified the core problem for most of the respondents. The fact that some undesirable effects were identified by more than one respondent and by several authors in the literature strengthened their existence (triangulation of data).

After the initial analysis, the Thinking Process was used to establish the cause-and-effect relationships between all of the undesirable effects. In the process, the Current Reality Branches was constructed. A Current Reality Branch can be constructed from the top-down (effect-cause) by linking undesirable effects and depicting the probable causes between them. Once the construction is completed, it is read from the bottom-up. The following outline was used to construct the Current Reality Branches. **Figure 2** illustrates this process with two undesirable effects. Undesirable effects are labeled with a number following the abbreviation UDE as shorthand to identify them.

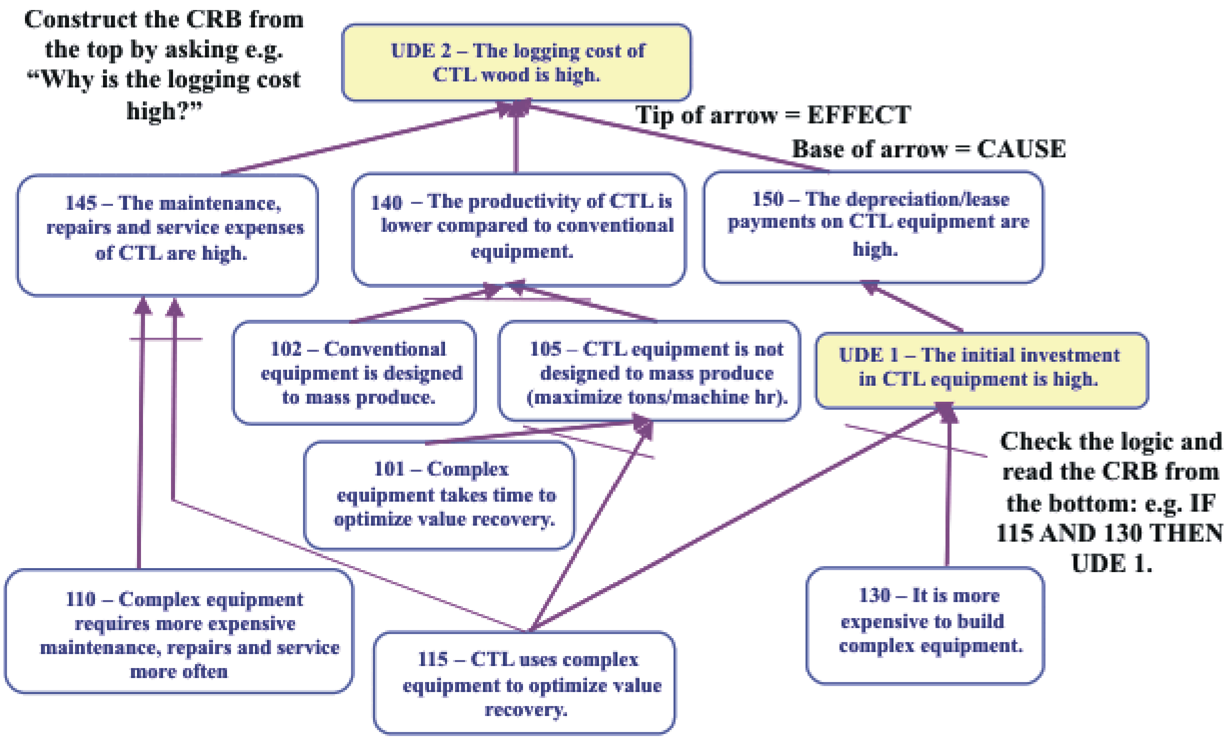
Step 1: Find any two undesirable effects that you feel have a causal connection.
We felt that "(UDE 1) the initial investment in CTL equipment is high" and "(UDE 2) the logging cost of CTL wood is high" had a causal connection.

Step 2: Determine which undesirable effect causes the other.
It was clear that "(UDE 1) the initial investment in CTL equipment is high" was causing "(UDE 2) the logging cost of CTL wood is high", although we intuitively knew that some logic was missing to say emphatically that UDE 1 was causing UDE 2. Therefore, we had to identify the missing cause-and-effect logic. The missing logic is identified by asking: Why is the logging cost of CTL wood high?

Step 3: Identify the cause-and-effect logic between the two UDEs and ultimately the core problem.
We used the causality existence reservation (**Table 1**) of the Categories of Legitimate Reservations to find the link between UDE 1 and UDE 2. We were sure that both undesirable effects existed although there was no direct link between the cause (UDE 2) and the observed effect (UDE 1). We knew from experience that "(UDE 2) the logging cost of CTL wood is high", because the depreciation/lease payments on CTL equipment are high. We placed this statement below UDE 2 in **Figure 2**, gave it an arbitrary entity number, entity 150, and connected it with an arrow to UDE 2. The tip of the arrow shows the effect while the base of the arrow is the cause. Therefore, the effect of the high depreciation/lease payments is the high logging costs.

Next, we needed to find out why "(150) the depreciation/lease payments on CTL equipment are high". Again, we had the knowledge that the cause of the high depreciation/lease payments on CTL equipment was "(UDE 1) the initial investment in CTL equipment is high". Hence, we connected UDE 1 with an arrow to entity 150. We have established that "(UDE 1) the initial investment in CTL equipment is high" causes "(150) the depreciation/lease payments on CTL equipment are high". According to White (2003), the initial investment is in the order of US$ 1 million.

Figure 2. Current Reality Branch for high logging costs (UDE 2) and high initial investment (UDE 1).



Although we established the cause-and-effect links between UDE 2 and UDE 1, we still needed to know why "(UDE 1) the initial investment in CTL equipment is high". Our knowledge of CTL told us that the initial investment in CTL equipment is high because "(115) CTL uses complex equipment to optimize value recovery". A large portion of the cost of a harvester can be attributed to the complex equipment consisting of the harvester head and the related optimizing computer system, which is required to ensure optimal value recovery. In most logging systems, there are trade-offs between productivity and the level of value recovery; the higher the productivity, the lower the level and accuracy of value recovery (all other things being equal). Some of the respondents in our survey and some authors in the literature agree that CTL equipment is complex (Holtzscher 1995; Gellerstedt and Dahlin 1999; White 2003).

Step 4: Check the logic in the Current Reality Branch using the Categories of Legitimate Reservations.

Once the cause-and-effect relationships were established, we needed to check if our cause-and-effect logic was correct by using the Categories of Legitimate Reservations (**Table 1**). Starting from the bottom (**Figure 2**), we checked if the following statement was true: **If** "(115) CTL uses complex equipment to optimize value recovery," **then** "(UDE 1) the initial investment in CTL equipment is high". We used the cause insufficiency reservation of the Categories of Legitimate Reservations (**Table 1**) to expose the fact that entity 115 by itself was insufficient to cause UDE 1, some other cause (core driver) was lacking. Thus in **Figure 2**, we added "(130) it is more expensive to build complex equipment" which we knew to be true for CTL equipment. Therefore, **if** "(115) CTL uses complex equipment to optimize value recovery" **and** "(entity 130) it is more expensive to build complex equipment," **then** the unavoidable effect is "(UDE 1) the initial investment in CTL equipment is high". The line across the arrows from entities 115 and 130 to UDE 1 indicates that both entities are needed to cause UDE 1 and it is read as an "and". In the Categories of Legitimate Reservations this "and" is referred to as a "conceptual and" connector. The "conceptual and" says that both causes must be present to create the effect, hence the effect is an interaction of the two causes by definition.

We used the same procedure to test the rest of the logic, for example: **If** "(UDE 1) the initial investment in CTL equipment is high," **then** the unavoidable effect is "(150) the depreciation/lease payments on CTL equipment are high". Next, we had to check if entity 150 by itself could explain the extent of "(UDE 2) the logging cost of CTL wood is high". We reached the conclusion that entity 150 was a major cause but there must be some additional causes of UDE 2. Through the additional cause reservation, we identified two more causes: "(140) the productivity of CTL is lower compared to conventional equipment", and "(145) the maintenance, repairs, and service expenses of CTL are high". They were added to **Figure 2**. Entity 145 existed because "(115) CTL uses complex equipment to optimize value recovery" and "(110) complex equipment requires more expensive maintenance, repairs, and service more often." A detailed explanation of how to read a Current Reality Branch (**Figure 2**) is provided in **Table 3**. A Current Reality Branch should always be read from the bottom to the top. The same method is used to read all logic tree used in this paper. The previously described procedure was used to construct all the Current Reality Branches for the undesirable effects.

The relative low productivity of CTL equipment compared to conventional equipment (entity 140) was partially caused by the combination of "(105) CTL equipment is not designed to mass produce (maximize tons/machine hour)" and "(102) conventional equipment is designed to mass produce". Next, we needed to find out what caused entity 105. It was caused by "(115) CTL uses complex equipment to optimize value recovery" and "(101) complex equipment takes time to optimize value recovery". Through the additional cause reservation we also identified the following additional four causes for (140) the productivity of CTL is lower compared to conventional equipment (**Figure 3**): "(240) the down time on CTL equipment is higher compared to conventional equipment"; the combination of "(350) many times loggers use less than competent CTL operators" and "(352) most conventional equipment operators are competent"; the combination of "(UDE10a) most new CTL operators go through a steep and long learning curve" and "(335) the learning curve is less steep and shorter for conventional systems"; and the combination of "(UDE10b) most new loggers go through a steep and long learning curve" and "(335) the learning curve is less steep and shorter for conventional systems". The Current Reality Branch depicted in **Figure 3** contains seven undesirable effects, all of which had a negative effect on productivity (entity 140) and all were caused by the complexity of the equipment (entity 115). **Figure 3** is an adapted and simplified version of the original Current Reality Branches constructed by Conradie (2003).

Table 3. How to read the Current Reality Branch in Figure 2.

1. Start at the bottom of the page with entity 115. **IF** (115) CTL u