CUT-TO-LENGTH HARVESTING SYSTEMS IN THE SOUTHEASTERN USA:

VALUE RECOVERY AND ADOPTION BY POTENTIAL USERS

by

IAN PATRICK CONRADIE

(Under the Direction of Dr. W. Dale Greene)

ABSTRACT

Cut-to-length (CTL) is not the harvesting system of choice in the southeastern USA although it is perceived to be more environmentally friendly and to have the ability to recover more value from stems. This study found that the value recoveries at three sites were respectively 92.6%, 89.7%, and 93.8% when the optimal recoverable value, as calculated by optimization software, was compared to the actual value recovered by the harvesters. The differences were mainly caused by the tendency of the harvesters to cut fewer but longer logs than the optimal solution, measuring error, and the downgrading of some out-of-specification logs to lower-value products. The primary reason why CTL has not been adopted by loggers as the system of choice in the southeastern USA appears to be the complexity of the equipment used to achieve this high level of value recovery.

INDEX WORDS: Forestry, harvesting, cut-to-length, harvester, value recovery, optimization, AVIS, Theory of Constraints

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DEDICATION

To Paula and Kieran

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CHAPTER 1. INTRODUCTION AND OBJECTIVES

The trend to mechanize forest harvesting operations is increasing worldwide and is primarily driven by productivity, technological and cost improvements, and related issues (e.g. enhanced worker safety, overcoming labor shortages and high labor rate increases) (Murphy 2003, Brink 2001). Mechanization has also led to the design of specialized harvesting equipment and systems such as:

- Tree-length and chipping systems that are highly productive in volume terms but place less emphasis on recovering the highest value from the stem inside the forest; and
- Cut-to-length (CTL) systems that are less productive but emphasize high value recovery from the stem inside the forest.

The CTL system has become more complex compared to other systems thereby placing further burdens on its productivity (in terms of volume produced per time unit). According to Murphy (2003), a few decades ago, many in the forest industry could not have imagined the level of sophistication available in the forest today. This is particularly true for the equipment used in a CTL harvesting system. Such a system consists of a harvester, which fells and processes trees, and a forwarder, which extracts the processed stems to a landing. To fell a tree the harvester operator grips the tree with the harvester head, cuts it with a saw, and then directs the stem to fall. A pair of rollers feed the stem through delimbing knives until a pre-programmed length is reached, at which point it is crosscut. The pre-programmed log length is determined by an onboard measuring system and a computer that has been programmed with target log specifications and a price list for each log grade. The measuring system and computer thus optimize the value recovered from the stem by ensuring that the highest value logs are produced. The system can also be programmed to limit the number of logs in a specific grade if the demand for such logs is limited (Ponsse 2002b). The operator has the ability to override the system to cull unusable wood if such wood doesn't comply with the applicable log specifications. After the first log on the stem has been crosscut, the process is automatically repeated until the top diameter is reached. The processed logs are then picked up by the forwarder and carried to the landing (White 1995).

As previously described, the maximum value will only be recovered if the most valuable products, as compared to the lower value products, are maximized. Value recovery therefore plays an integral part in determining the profitability of harvesting, as profit is dependent on the volume produced, the unit value of the products, and the unit production costs [PROFIT = VOLUME x (VALUE – COST)]. The emphasis is normally on the volume produced and the production cost components, although research in New Zealand on value recovery in manual log-making operations has shown that it is easier to add $1 to unit product value than to reduce unit cost by $1 (Twaddle and Goulding 1989). The value recovery component is particularly important in a CTL system as it was designed to optimize value recovery, which increases its initial and operating costs.

The value component of using a harvester in a CTL operation will therefore be addressed with the objectives to:

- Determine the difference between the optimal recoverable value as calculated by optimization software and the actual value recovered by each harvester;
- Determine the difference between the optimal recoverable value calculated by optimization software and the actual value recovered by each harvester per product as this will identify which products are over or under recovered; and
- Determine the reasons for under and over recovery of products.

CTL equipment, which was designed to optimize value recovery, should make a positive contribution to profit, as it has been shown in New Zealand that profit can be increased through better value recovery. This might help to maintain the competitive position of the southeastern USA in the global forest products market. Although CTL also has other advantages over conventional tree-length systems (fellerbuncher /grapple skidder) it is rarely used by loggers in the southeastern USA (Greene and others 2001). This trend is contrary to Scandinavian countries where almost 90 percent of wood is harvested by CTL systems (Chiorescu and Gronlund 2001). As an expansion of the value recovery part of the study, the following additional objectives will be addressed:

- Determine the perceived advantages and disadvantages of CTL;
- Determine the perceived reasons why CTL is rarely used in the southeastern USA; and
- Determine the actions needed by the different stakeholders in the value chain if the use of CTL was to be increased in the southeastern USA.

CHAPTER 2. LITERATURE REVIEW

2.1 VALUE RECOVERY

Although the focus of this study is on value recovery with a harvester in CTL operations, the value recovered in manual log-making operations will first be addressed in the literature review as it is a natural starting point from which to lead into mechanized systems. In a summary of 48 reported studies and confidential reports on manual log-making operations conducted in South Africa, New Zealand, Canada, and the USA Murphy (2003) found that the average value loss was over 10% with a maximum of 33%.

Geerts and Twaddle (1984) described a method to assess the log value loss caused by manual log-making on a skidsite in New Zealand by using a computer program (AVIS – Assessment of Value by Individual Stems). They calculated a value loss of 26% when the actual value recovered was compared to the optimal value as determined by AVIS. The study also documented that AVIS was a valuable research tool for quantifying value losses and identifying where and why these losses occur.

The field procedure to determine the optimal and achieved stem value in manual log-making operations using AVIS was later described by Murphy and Twaddle (1986). They also showed that combining AVIS with statistical quality control techniques could provide an acceptable basis for a good recovery control program in which AVIS could be used to help train log-makers in value-recovery techniques, define optimum performance, analyze performance in economic terms, and help to identify sources of value loss. The statistical quality control techniques could be used to monitor performance on a regular basis, provide frequent and timely feedback, and document performance. In another study, Twaddle and Goulding (1989) described what the log-making process involves, how AVIS can be used in determining the value loss, and what were the main causes of value loss.

In a study conducted in New Zealand with three manual log manufacturers working in the same *Pinus radiata* stand, Murphy and Olsen (1988) found that value losses varied between 24% and 33% when the optimal value were compared to the actual value recovered. The main cause of the value loss was the down-grading of high-value products to lower value products. Yet another New Zealand study by Cossens and Murphy (1988) found that value loss ranged from 4% to 10% of the optimal when 19 log-makers optimized the same 31 stems on a landing.

Garland and others (1989) tested the use of computer-aided bucking on old-growth and second-growth Douglas fir stems to determine the various log mixes and therefore the ultimate value recovery. They found that the computer solution shifted a large portion of low-value logs to high-value logs, thereby increasing the recovered value by 14.2% and 11.9% respectively.

As the focus of this study is on mechanized harvesting systems in general, and on CTL in particular, the rest of the literature review will address such systems. According to Murphy (2003), mechanized value recovery studies reported in literature and carried out in Scandinavia, USA, and New Zealand, along with confidential audits of such operations undertaken by him in Australia and New Zealand, indicated that the value loss ranged from 1 to 68% with an average of 20% (Figure 2.1).

Olsen and others (1991) found that the total value recovered was increased by 7.5% when bucking decisions on a Hahn harvester were aided by the BUCK computer program, whereas Boston and Murphy (in press) reported the value loss in two CTL log-making operations in the southeastern USA to be 6% and 42%. Gingras (1992) determined the merchantable fiber recovery of six harvesting systems (Table 2.1) but unfortunately did not attempt to calculate the dollar value of the fiber recovered. The study helped to show that with proper planning and operator awareness timber harvesting can be conducted with minimal fiber waste and good yield from predicted cruise estimates. Certain systems, such as the CTL system with a harvester and a forwarder, showed the potential to recover additional volume over the initial cruise estimates.

Favreau (1997) expanded on the previous study by comparing the fiber loss of full-tree and CTL harvesting systems during summer and winter. For the full-tree system, the total volume left behind in the forest was estimated at 36.2 m^3/ha in summer and 24.8 m^3/ha in winter; of these amounts, only 8.2 m^3/ha of green wood of merchantable dimensions was left behind in summer versus 3.5 m^3/ha in winter. Fiber loss for the full-tree system at the sawmill (at the debarking-slashing center) was 4.3% of the weight loaded onto the center's infeed platform in summer, versus 10.7% in winter. With the CTL system, a volume of 16.5 m^3/ha was left behind in the forest in summer and 17.0 m^3/ha in winter; of these amounts, only 5.0 m^3/ha of green wood of merchantable dimensions was left behind in summer versus 4.0 m^3/ha in winter.

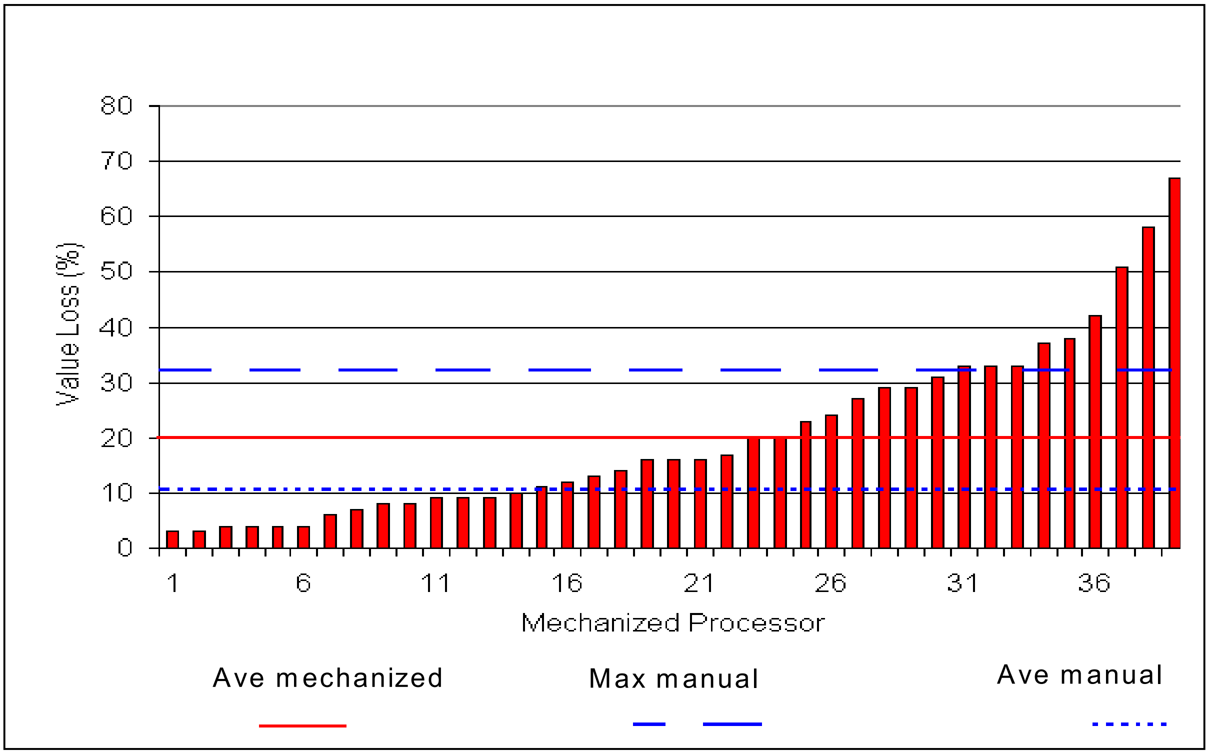


Figure 2.1. Value loss in manual and mechanized log-making (Murphy 2003).

Table 2.1. Fiber recovery of six harvesting systems (Gingras 1992).

System used	Fiber recovery index (%) *	Fiber yield index (%) **
Manual felling + cable skidder + stroke delimber	96	99
Manual felling + cable skidder + manual delimbing	104 ± 7	98 ± 14
Feller-buncher + grapple skidder + stroke delimber	97	91 ± 19
Feller-buncher + processor + forwarder	91	87 ± 16
Feller-buncher + grapple skidder + flail delimber-debarker-chipper	99	107 ± 13
Harvester + forwarder	99	113 ± 21

$$\text{* Fiber recovery index (\%)} = \frac{\text{Volume recovered } (m^3/ha) \times 100}{\text{Volume recovered } (m^3/ha) + \text{merchantable slash } (m^3/ha)}$$

$$\text{** Fiber yield index (\%)} = \frac{\text{Merchantable volume recovered } (m^3/ha) \times 100}{\text{Merchantable volume from cruise } (m^3/ha)}$$

Note: Fiber yield and recovery indices cannot be compared directly since recovery was measured in different forms (tree-length, random length and chips) at different locations (roadside and mill).

The study thus demonstrated that the CTL system provided a better yield in terms of the recovery of green merchantable wood with less seasonal variation.

Plamondon and Page (1997) compared the lumber yield from CTL and full-tree harvesting systems. A harvester and forwarder were used in the CTL system, whereas a feller-buncher, cable skidder, and stroke delimber were used in the full-tree system. The harvested wood from both systems was milled separately at the same sawmill with the following results:

- The lumber yields from the two systems were similar, though slightly in favor of the CTL system;
- Losses after drying were nearly identical; and
- The operational context may not have been perfectly typical, especially in the case of the full-tree system. Other studies would be necessary to confirm the wider applicability of the results.

Chiorescu and Grondlund (2001) reported the results of a simulation test using the Virtual SawMill software and the Swedish Stem Bank database, which contains detailed information about *Pinus sylvestris L*. The bucking, sawing, crosscutting, and board grading procedures were simulated for the different end-user requirements and a statistical model was built. The purpose of the model was to investigate the theoretical sensitivity of the final product to such parameters as external sawlog features, harvester measurement accuracy (for length and diameter), saw pattern optimization, and the log position in the saw line. Special emphasis was placed on evaluating the role of the harvester within this “puzzle”. The results showed that small improvements in the harvester’s measuring performance could lead to considerable improvements in the wood transformation chain. The bucking performance of the harvester therefore, plays a crucial role in the value recovery process.

Plamondon (1999) investigated the accuracy of six single-grip harvesters in eastern Canada and found considerable variability in length measurement errors with much of the variability attributed to the operator's ability to manage and use the measurement systems correctly. More pronounced branchiness and stem defects also adversely affected the results. He further concluded that all the harvester heads would be capable of producing logs for which 90% of the lengths would be within a 10 cm range. Anderson and Dyson (2001) also examined the measuring accuracy of common harvesters and processors operating in British Columbia and Alberta, Canada. The results showed large variation in the length and diameter performance of the machines, which was partly attributed to differences in the emphasis placed on measuring accuracy at the harvesting site. Other factors included variation in tree characteristics, lack of properly calibrated measuring systems, and incorrect target lengths programmed into the measuring system's computer. The length accuracy of manufactured logs is particularly important as it can have a significant impact on subsequent sawmill operations. Logs that are too short typically reduce both lumber recovery and mill productivity. Logs that are too long reduce mill productivity as more time is used by the breakdown saw to process these logs and more fiber is lost to chips.

2.2 CUT-TO-LENGTH IN THE SOUTHEASTERN USA

During the first half of the 20th century harvesting in the USA consisted of a labor intensive, shortwood system. The end of World War II signaled the advent of rapid mechanization with two breakthroughs, the chainsaw and the diesel truck, changing the face of harvesting in this region. The introduction of the wheeled skidder in the 1960's started the shift to tree-length (TL) harvesting systems, as it was now physically possible to handle such lengths. In the late 1960's feller-bunchers with shear heads were introduced to mechanize the felling function and in the 1970's grapple skidders were widely adopted, which increased productivity significantly. Circular saw heads also started to replace shear heads in the late 1980's, which further improved productivity and reduced butt damaged caused by shear heads. All these technological changes therefore had a great impact on the economic feasibility of TL operations (Brink 2001). The stage was therefore set for TL systems in North America. There has however been a move towards CTL systems in eastern Canada since the mid 1980's (Guimier 1999). Even though TL systems are still dominant in North America today, with only 20 to 30% of logging being done by CTL (Gellerstedt and Dahlin 1999), the trend over the past ten years has been more towards CTL, primarily because of the lower environmental impacts and higher fiber recovery of such equipment (Heidersdorf 1991). This trend has however not been present in the southeastern USA, as a survey conducted in Georgia during 1997, established that 88% of respondents used a feller-buncher/grapple skidder combination, chipping systems accounted for seven percent, while manual felling/cable skidding and mechanical felling/cable skidding each represented just over two percent (Greene and others 2001). It can therefore be concluded that CTL accounts for no more than 1%.

There was a drastic increase in the percentage of wood harvested by CTL equipment in Sweden for the period 1987 to 1992; the percentage in clearfellings increased from 55 to 80%, and from 37 to 64% in thinnings (Frohm 1993). According to

Chiorescu and Gronlund (2001) the CTL harvesting system today accounts for almost 90% of wood harvested in Scandinavian counties.

Brink (2001), in a study conducted in eight countries and fourteen regions around the world [USA (Pacific Northwest, Inland West Coast, Lake States, South, New England and the Appalachian Region), Canada (West Coast, Central and East Coast), Sweden, Finland, Germany, New Zealand, Chile and Australia], found that the most important change drivers (in order of importance) in harvesting over the last decade were technological and productivity improvements, environmental impacts, and social pressure. It is interesting to notice that Finland and Sweden, where CTL is the system of choice, didn't rank social pressure as important while it was important for the southern USA. The same three factors were also perceived by the participants in the study as being the most important change drivers for the next decade. The respondents also indicated that out of 20 changes that are expected to take place in harvesting systems by 2010, an increase in CTL systems was ranked 12th. Australia and Canada generally ranked it higher, while countries where the system is already well established ranked it low. It was ranked 16th for the southern USA, which indicates that CTL is not expected to replace TL in the near future, at least not without some dramatic event taking place.

Brink (2001) also determined that the global market share for harvesters increased from 49% in 1992 to 54% in 2001, whereas the increase for forwarders was from 19% to 35%. Based on these increases in market share he forecasted that harvesters and forwarders could have a 72% market share by 2010. He did however caution that the magnitude of the increase is uncertain but that the trend is to replace feller-bunchers/ skidders with harvesters/forwarders.

Therefore, despite the forecasts made, the lower impacts of CTL on the environment, the importance of lower environmental impacts, and the advantages of CTL systems as listed below, it has not been adopted as the system of choice in the southeastern USA. According Tufts (1997) and White (1995) the advantages of CTL include the following:

- less damage to residual trees in thinnings;
- the ability to merchandise products in the woods;
- recovery of higher-valued products;
- a smaller, more efficient workforce;
- greater operator safety and comfort;
- reduced road construction and maintenance;
- fewer landings (more land kept in production);
- reduced erosion;
- reduced scarification and replanting in natural forests;
- no accumulation of debris on the landing; and
- better aesthetics.

According to McCrary (2001) possible reasons why CTL is rarely used in southeastern USA includes:

- Most loggers receive little or no monetary incentive for the intangible benefits provided by such a system;
- Some forest companies, who previously encouraged loggers to purchase CTL systems, are requesting them to return to TL systems;
- It is difficult to find suitable operators for CTL equipment; and

- The system is sensitive to downtime as there are no backup machines to maintain production.

Despite the perceived advantages of CTL, it continues to be rarely used in the southeastern USA. One technique that can be used to investigate why this is the case is the Thinking Process (TP) as developed by Goldratt (1994) in his Theory of Constraints (TOC). The TP is a set of tools, which use cause-and-effect diagrams. The first question in the TP is: "<u>What to change?</u>", i.e. identify the core problem. The Current Reality Tree of the TP is used to answer this question. Once the core problem has been identified, the next question becomes "<u>What to change to?</u>" The TOC tool to solve this question is the Future Reality Tree, which is a logic-based tool for constructing and testing potential solutions before implementation. The next question is "<u>How to change?</u>" The Prerequisite Tree, which is a logic-based tool for determining the obstacles that block implementation of a solution, and the Transition Tree, which is a logic-based tool for identifying and sequencing actions in accomplishing an objective, are used to answer the last question (Rahman 1998, Cox and others 2001). The scope of this study excludes the last phase. Experts believe that it is the TP of TOC that will ultimately have the most lasting impact on business (Rahman 1998).

The Theory of Constraints was originally developed in the mid 1980's by Eli Goldratt (an Israeli physicist) and originally evolved from the Optimized Production Timetables (OPT) system he developed. The concept of OPT was illustrated in a novel, *The Goal* (Goldratt and Cox 1984), in which the theory was gradually unraveled through an everyday production situation. (More than one million copies of *The Goal* have been sold.) The concepts identified in the book were further developed as results from actual implementations became known. A second book, *The Race* (Goldratt and Fox 1986), was therefore written to overcome difficulties encountered in the implementation of the concepts. This book represented a logistical system for the flow of material, called drum-buffer-rope. By 1997, the overall concept became known as the Theory of Constraints (TOC), which Goldratt viewed as an overall theory for running an organization (Goldratt 1988). Gillespie and others (1999) saw TOC 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. Gradually the focus of the concept moved from the production floor to include all aspects of business (Rahman 1998). According to Blackstone (2001), ten years ago the theory was only applied to production but today it has been applied to a wide range of disciplines including: operations, finance and measures, project management, distribution and supply chains, marketing, sales, managing people, strategy, and tactics.

According to Netherton (1996) TOC has been adopted by over 500 organizations in 11 countries. Some Fortune 500 companies who have implemented TOC include: 3M, GM, Delta Airlines, Texas Instruments, Harris Corporation, Proctor and Gamble, Avery Dennison, National Semiconductor, Intel, Bethlehem Steel, Rockwell International and Weyerhaeuser (Cox and others 2001). Up to 1998, 86 articles on TOC were published in 21 refereed journals, with a further 53 published in non-refereed ones (Rahman 1998). There are numerous examples where the use of TP and TOC had positive results:

- Sheila Taormina, at the age of 27, won a gold medal in swimming at the 1996 Olympics in an Olympic and American record time (Cox and others 2001);

- Kent Moore Cabinets, a maker of custom cabinets in Texas, reduced the lead time to two days versus an industry average of four weeks. They also held employment at 160 while increasing sales from $6 million to $10 million (Gardiner and others 1994);
- Proctor and Gamble, who pioneered the application of TOC in distribution, reported a TOC impact of $600 million through inventory reduction and eliminated capital improvements by better scheduling of existing facilities (Gardiner and others 1994);
- Ashridge Management College, an executive education provider in London, doubled their surplus (and the tutors' annual bonus pool) within the first year (Gardiner and others 1994);
- The Trane Company, an air conditioning plant in (Macon) Georgia, tripled output within eight months (Spencer 1994, Gardiner and others 1994);
- Ford Motors Electronics Division reduced inventory by $100 million and the average lead time from 6.5 to 2.1 days (Gardiner and others 1994);
- Virginia Semiconductor reported a 90% reduction in work-in-progress, a 27% reduction in power consumption, an 82% reduction in cycle time and a 26% increase in on-time delivery (Cheng 2002 and Miller 2000);
- Profitability increased 20% at a manufacturer of golf clubs (Kroll 1998);
- Expozay, a New Zealand Company, reduced work-in-progress from 35,000 to 4,000 units in four weeks, thereby decreasing lead time from six weeks to four days, which in turn led to increased orders (Netherton 1996);
- A sawmill in New Zealand decreased log stocks by 90% and employee numbers by 20% (FIEA 2002); and

- Zycon, a microprocessor board manufacturer, increased their sales more than 150% without increasing their inventory (Cox and others 2001).

Managers are always looking for ways to improve performance and have, for many decades, used procedures and methods developed by industrial engineers and others to improve their performance. This is evident if one looks at the continuous improvement programs, such as Total Quality Management (TQM), Just-in-time (JIT), Six Sigma, Lean Management (an application of TOC), and TOC, which are implemented by businesses worldwide. In order for any manager to continuously improve it is imperative that he identifies the right problems, especially core problems, and come up with innovative solutions. Goldratt's structured, novel approach provides managers with the tools to find core problems and solutions. It is therefore an appropriate tool to evaluate the reasons why CTL is rarely used by loggers in the southeastern USA.

CHAPTER 3. METHODS

3.1 VALUE RECOVERY

The first part of this chapter describes the methods that were used to evaluate the optimal and actual value recovered with harvesters at three different sites in the southeastern USA.

3.1.1 The optimization software

AVIS software (NZFRI 1995) was used to determine the optimal and actual value recovered (the actual value recovered is referred to as the skid solution in AVIS). The software was developed by the New Zealand Forest Research Institute and consists of six different programs.

PCAVIS is the main program that calculates the volumes and values for both the optimal and skid solutions. These values are then used to determine the differences in the value recovered for each stem. All this information is stored in a separate report file, which is summarized by other utility programs (SUMPIE and PCSUMM) to create more useful information (Figure 3.1).

MAKELOG is the program that creates the log type file in which log specifications and log values for all log grades are contained. However, before the log type file can be created the rules for cutting log types must first be defined.

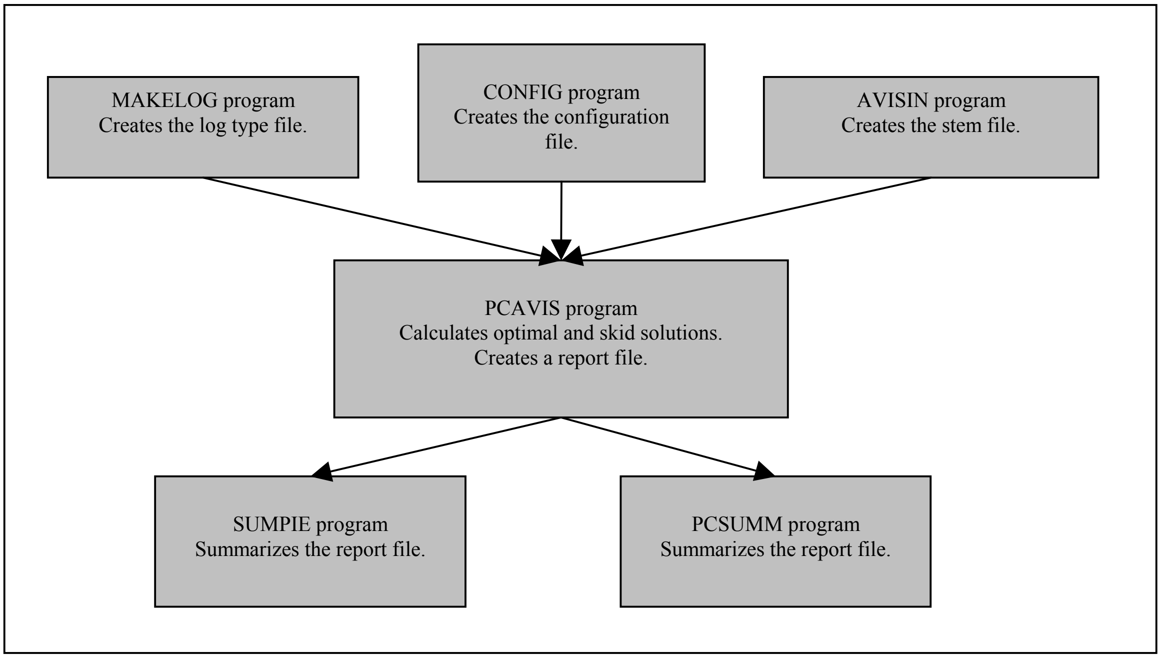


Figure 3.1. Structure of the AVIS system (NZFRI 1995).

These rules include defining the physical dimensions, the quality and sweep characteristics, as well as the values for each log type. The physical dimensions (lengths in meters and diameters in centimeters) of a log type are defined by:

- The minimum and maximum lengths;
- A step length between minimum and maximum lengths. If the allowable lengths for a certain log type are 3.8, 5.0, or 6.2 meters then the step length is 1.2 meters. However, if any length between the minimum and maximum is allowed, or the minimum and maximum lengths are equal, then the step length in terms of AVIS is defined as 0.10 meters;
- The minimum and maximum small end diameter (SED); and
- The maximum large end diameter (LED).

A set of quality codes is also required for each log type. This code is a single alphabetic character that relates to a certain quality feature or set of quality features, which could include: number and size of branches, crooks, dog legs, catfaces, and butt flare. In AVIS sweep for different log types can be assigned different numerical codes with the convention that 9 indicates a highly swept zone and 1 a slightly swept zone. The same convention was followed to create the log type file as it cannot be created without entering such a code for each log type. However, these sweep codes were not used any further in the study, as sweep was included in the set of quality features previously described when the stem file was created. Although AVIS allows the option to specify a minimum length of certain qualities for a specific log type it was not used in this study.

Each log type must also be assigned two values per unit of volume. The first value, usually the sale price of the logs, is used when calculating log values for display in the solution. The second value is a relative value, which reflects the relative difference in production priority not indicated by the difference in price between log types. It could therefore be used to reflect current demand for a log type. The optimal solution is determined by using this relative value. However, in this study the same stumpage prices were used for both the first and the second value.

In addition to the previously mentioned data, each log type requires a unique identity code and a name. The ID code is either a one or two-character code that is used when entering the skid solution to identify the log type being specified.

CONFIG is the program that is used to create the configuration file in which stand parameters, several coefficients and tolerance factors as well as value reduction factors for dealing with out-of-specification logs are contained. The two coefficients for the Peterson height function are calculated from the diameter breast height (DBH) and height data collected (NZFRI 1995). This function is used to estimate total tree height, which is in turn used to calculate under-bark diameters. The average stump height (in meters) at each site is also required, as this is important in improving the accuracy of estimating volume calculations.

The maximum log volume (in cubic meters) is a parameter that is used to impose a limit on the maximum log volume that can be produced. The maximum step between over bark diameter measurements is the maximum allowable distance (in meters) between over bark diameter measurements. The recommended maximum distance is somewhere between six and ten meters, as this provides enough measurements to obtain a reasonable degree of accuracy in calculating log volumes but doesn't overburden the log measurer with too many measurements. As log specifications for diameter measures are under bark in many parts of the world, a set of seven regression coefficients are required to calculate under bark diameters from the over bark diameters measured infield. However, in this study, the diameters specified in the log specifications at site A were over bark. At sites B and C the diameters in the log specifications were under bark, but were interpreted as being over bark. As the mills did not downgrade or reject logs complying with this interpretation, the diameter specifications at sites B and C were therefore also regarded as over bark. Hence, the seven regression coefficients were calculated to ensure that over and under bark diameters were the same.

When entering a skid solution into the stem file using AVISIN a log is identified as being of a certain log type by both an ID code and a length. When an out-of-specification length is entered, AVIS must have some length tolerance otherwise it will alert the user to every out-of-length-specification log entered. This parameter, the skid solution length tolerance, refers to the maximum length (in meters) a log may be out of specification and still be recognized as a certain log type.

In AVIS the value of out-of-specification logs in the skid solutions can be reduced by certain factors if these factors are entered into the configuration file. It therefore needs the SED tolerance and length tolerance (trim allowance) as well as the corresponding value reduction factors before such reductions are made. Value reduction factors for quality, sweep and multiple out-of-specification logs must also be entered. However, in this study, only the trim allowance value was entered. All the value reduction factors were set at zero as we didn’t want AVIS to reduce the values automatically.

AVISIN is a data entry program that creates a stem file in which both stem data and skid solutions are stored. The “Define Stem” option in this program allows over bark diameters (in centimeters), qualities and sweep along a stem to be entered. The first diameter to be entered is the LED at the butt. Thereafter cumulative lengths, as measured in meters from the butt, and diameters are entered in pairs (up to a maximum of twelve pairs). The number of meters between diameter measurements may not exceed the number as defined in the configuration file. After the diameter/length pairs have been entered, quality features along the stem are entered. The quality features are defined by a series of alphabetic codes as described in the log type file. The length that must be entered is the cumulative length (in meters) to where the quality changes. The "Enter Skid" option allows a skid solution (the actual way a stem has been cut) to be entered as a pair of data consisting of a log type ID and a log length.

SUMPIE is a companion program that uses the report file produced by PCAVIS (in which both optimal and skid solutions are stored) to create a summary that contains total stem lengths, volumes, values and value losses for individual stems.

PCSUMM is a companion program that uses the report file produced by PCAVIS to summarize information by log grades. Data on individual logs (i.e. length, volume, value, small end diameter) are selected from the report file and sorted into log types specified in the log type file for both optimum and skid solutions. For the skid solutions a table of defects is also provided.

3.1.2 <u>Selection of study participants</u>

The number of loggers to choose from was limited due to the fact that very few loggers operate CTL systems in the southeastern USA. It was however specified that at least three loggers, complying with the following requirements, would be included in the study:

- The on-board computer had to be used in the optimization process;
- More than one product had to be optimized; and
- *Pinus spp.* had to be harvested.

Five logging crews were identified that met these requirements. The three that were finally included in the study were selected on the basis of availability during the summer of 2002 when the infield measurements were taken. The selected loggers required that they would not be identified by name or the exact location of the logging site revealed, as sensitive information regarding stumpage prices were used in the value recovery analysis. They are therefore only identified as logger A, B and C. At all three sites *Pinus spp.* (predominantly loblolly pine) were harvested from natural pine stands and the method of payment for the wood was per unit harvested. The first site, which was located in central Georgia, was clearfelled, while the other two, which were situated in central Alabama, were thinned. The sites were all in the Piedmont physiographic region. The level of experience of the harvester operators varied between the sites:

- At site A, the operator had used the Ponsse harvester and forwarder for the past two years, with 85% of his time spent on the forwarder. He also had another five years of experience on other forestry equipment (i.e. fellerbuncher, loader and skidder).
- At site B, the operator had used the Ponsse harvester for six months and spent one year on a grapple skidder before moving to the harvester. As a student he spent his summer vacations working with other forestry equipment.

- At site C, the operator had used the Ponsse harvester for one year. He also had previous experience with a Valmet harvester, which he used for 18 months during 1995/96.

All three loggers used Ponsse Ergo harvesters with H73 harvester heads and the Ponsee Opti optimization system. The system predicts the taper of each stem from the diameters recorded on the lower butt-end of the stem, then creates a mathematical model of the stem, and finally divides the stem into the optimum number of logs before making the optimization cuts. The mathematical model of each stem is created on the basis of the previous stems. In this way Opti independently teaches itself the taper of the stems in a stand of trees (Ponsse, 2002a).

3.1.2 Infield data collection

The infield data that were collected during this phase were used to create the stem file, as well as to calculate the average stump height and the Peterson height coefficients for the configuration file. All diameters were measured with a manual caliper to the nearest 0.1-inch, and all length and height measurements were taken with a loggers tape to the nearest 0.1-foot. All the information gathered was recorded on a field form.

At site A 61 trees were selected for inclusion in the study, whereas 60 trees were included at sites B and C. At site A, the trees were selected and marked with an identification number by the researcher, whereas at site B and C the harvester operator selected the trees. This change in procedure was necessitated to expedite the data collection process, as well as to interfere less with production. At site A the DBH was taken on the standing trees at a height of 4.5’ (1.2 meters) from the ground line and on the uphill side if on a slope. Once the DBHs were taken, the marked trees were felled by the harvester. At sites B and C the harvester operator selected the trees and felled them immediately. After a felled tree was marked on the butt-end with an identification number, the tree number and stump height were recorded. A tape was then attached to the large end (butt) of the stem and the following recorded:

- LED of the butt (over bark);
- DBH (over bark). The distance from the butt where the DBH had to be taken was determined by deducting the recorded stump height from 4.5';
- Diameters (over bark) at intervals along the stem. Both the diameters and the corresponding lengths from the butt were recorded. The intervals between the diameters were not to exceed 19.7' (6 meters);
- All quality features with their corresponding beginning and the ending lengths from the butt; and
- The tree height, excluding the stump.

Once the previous data were recorded, the harvester operator optimized the felled trees while the researcher recorded, from within the cab, the log types being manufactured as well as their corresponding SEDs and lengths. These SED diameters and lengths were not used as input into the stem file. Once the felled trees were optimized, the researcher measured and recorded the SED (over bark) of each of the optimized logs per tree. Where it was impossible to take the SED measurement (e.g. the log was in such a position that the caliper could not get in between the logs), the LED of the next log was taken, and used as the SED. The length of each log was also recorded and used as input into the stem file. All the measurements (in imperial units) were entered into an Excel spreadsheet, which converted the imperial units to metric units as AVIS was developed for metric units.

3.1.3 Collection of log specifications and stumpage prices

As described earlier log specifications and prices for all the different products are required to run the optimization. This information was therefore obtained from the harvester operator and the appropriate manager in charge of the operation (Table 3.1). The number of products manufactured at each was different: three at site A (sawlogs, chip'n saw logs, and pulpwood), four at site B (plylogs, sawlogs, scragg logs, and pulpwood), and only two products (sawlogs and pulpwood) at site C.

3.1.4. Peterson height and under bark diameter regression coefficients

The two coefficients for the Peterson height function are required to estimate the total tree height, which in turn is used to calculate the under bark diameters. The Peterson height function is of the form (NZFRI 1995):

$$H = 1.4 + (hb_1 + hb_2/DBH)^{-2.5}$$

Where,

H = estimated tree height in meters

DBH = diameter at breast height over bark (OB) in centimeters

hb_1 = coefficient

hb_2 = coefficient

Table 3.1a. Log specifications and stumpage prices at site A.

Log specifications	Sawlogs		Chip'n saw logs		Pulp logs	
Min length	12.5'	3.8m	12.5'	3.8m	12'	3.6m
Max length	20.5'	6.2m	16.5'	5.0m	16'	4.9m
Step length	4'	1.2m	4'	1.2m	0.1"	0.1cm
Min SED	8"	20.3cm	6"	15.2cm	2"	5.1cm
Max SED	28"	71.1cm	12"	30.5cm	28"	71.1cm
Max LED	28"	71.1cm	12"	30.5cm	28"	71.1cm
Trim allowance	3"	7.6cm	3"	7.6cm	3"	7.6cm
Knots	No whorl or ring knots		No whorl or ring knots		No limit	
Sweep	Max=3" in any 16.5' No sweep in >1 direction		Max=3" in any 16.5' No sweep in >1 direction		No sweep that will not convey	
Crooks	No crooks		No crooks		See sweep	
Dog legs	No dog legs		No dog legs		See sweep	
Catfaces	No continuous defect >=4"		No continuous defect >=4"		No limit	
Butt flare	Not excessive butt flare		Not excessive butt flare		No limit	
Stumpage prices	$30.75/ton		$12.75/ton		$2.10/ton	
Quality	A		A		B	

Table 3.1b. Log specifications and stumpage prices at site B.

Specifications	Plylogs		Sawlogs		Scragg logs		Pulp logs	
Min length	17.6'	5.4m	16.6'	5.1m	10.6'	3.2m	10'	3.0m
Max length	17.6'	5.4m	16.6'	5.1m	12.6'	3.8m	20'	6.1m
Step length	0'	0m	0'	0m	2'	0.6cm	0.1"	0.1cm
Min SED	9"	22.9cm	8"	20.3m	6"	15.2cm	2"	5.1cm
Max SED	29"	73.7cm	29"	73.7cm	29"	73.7cm	29"	73.7cm
Max LED	29"	73.7cm	29"	73.7cm	29"	73.7cm	29"	73.7cm
Trim allowance	3"	7.6cm	3"	7.6cm	3"	7.6cm	3"	7.6cm
Knots	No ring knots		No excessive ring knots		No limit		No limit	
Sweep	No excessive sweep		No excessive sweep		No limit		No limit	
Crooks	No crooks		No crooks		No limit		No limit	
Catfaces	No catfaces		NA		No limit		No limit	
Stumpage prices	$35.00/ton		$20.00/ton		$10.00/ton		$2.50/ton	
Quality	C		D		E		E	

Table 3.1c. Log specifications and stumpage prices at site C.

Log specifications	Sawlogs		Pulp logs	
Minimum length	12.5'	3.8m	14'	4.3m
Maximum length	16.6'	5.1m	20'	6.1m
Step length	4'	1.3m	2'	0.6m
Minimum SED	7.5"	19.1cm	3"	7.6cm
Maximum SED	29"	73.7cm	29"	73.7cm
Maximum LED	29"	73.7cm	29"	73.7cm
Trim allowance	3"	7.6cm	3"	7.6cm
Knots	No excessive ring knots		No limit	
Sweep	No excessive sweep		No limit	
Crooks	No crooks		No limit	
Catfaces	No catfaces		No limit	
Stumpage prices	$20.00/ton		$2.50/ton	
Quality	F		G	

The values for hb_1 and hb_2 were estimated from the DBH and total tree height data using non-linear regression. The DBH, total height (excluding the stump), and stump height data were collected infield. Any tree on which any of the aforementioned measurements could not be taken, was excluded from the calculation of the Peterson height coefficients. The total tree height was calculated by adding the measured tree height to the stump height. The average stump heights were also required as input for the configuration files and were calculated to be 9.3, 9.4, and 13.0 centimeters respectively for sites A, B and C. The calculated hb_1 coefficients varied between 0.24123 and 0.279377, whereas for hb_2 the coefficients varied between 0.573613 and 1.419293 (Table 3.2).

A set of seven regression coefficients are also required to calculate under bark diameters from the over bark diameters measure infield. However, in this study, all diameters specified in the log specifications were regarded as over bark. These regression coefficients were therefore calculated to ensure that over and under bark diameters were the same. The equation for the regression coefficients is in the form (Gordon 1983):

$$ln(B/D) = b_0 + b_1(1-h/H)^{b2} + b_3\,(h/H)^{b4H} + b_5\,DBH + b_6\,H/DBH$$

Where,

D = diameter over bark (dob) in centimeters

d = diameter inside bark (dib) in centimeters

B = D – d, double bark thickness in centimeters

H = total height in meters

DBH = diameter at breast height over bark in centimeters

h = height above the ground in meters

b_0 to b_6 = coefficients

Table 3.2. Peterson height coefficients and other appropriate statistics.

	Site A	Site B	Site C
Estimation of hb_1	0.24123	0.279377	0.250405
Estimation of hb_2	1.288657	0.573613	1.419293
Number of observations	57	60	52
Approximate std error for hb_1	0.00589	0.00526	0.00472
Approximate std error for hb_2	0.1803	0.1249	0.0998
Approximate p-value for hb_1	<0.0001	<0.0001	<0.0001
Approximate p-value for hb_1	<0.0001	<0.0001	<0.0001
Adjusted R-squared	0.528	0.2692	0.8287

To ensure that the over and under bark diameters were the same (B=0), the seven coefficients were manipulated so that $B/D \approx 0$. Coefficients b_1, b_2, b_3, b_4, b_5 and b_6 were set to approximate zero (0.000001). Therefore,

$B/D \approx 0$ or (0.000001)
$\ln(0.000001) = b_0$
$b_0 = -13.82$

3.1.5 Conversion of stumpage price from \$/ton to \$/cubic meter (m^3)

Although the stumpage prices obtained from the loggers were in \$/ton, AVIS requires the value of all products to be expressed in \$/m^3. A factor was thus required to make the appropriate conversion. In order to calculate a conversion factor the volume and green weight of the trees had to be estimated, based on the DBH and total heights taken during the infield data collection phase. The green weight (in lbs) of stem wood and bark to a 4" d.o.b top for southern pine in the Piedmont was predicted using a program developed by Souter (2003), which incorporates weight tables from Clark and Saucier (1990). The same program and the appropriate volume tables from Clark and Saucier (1990) were also used to predict the inside bark volume (in ft^3) of the total tree (wood only) for southern pine in the Piedmont. He then used another equation (Souter 1999) to calculate the volume for both wood and bark. The OB density for each stem was then calculated using the equation:

OB density in ton/m^3 = (OB weight in lbs/OB volume in ft^3)/2000/0.0283 as

1 ton = 2000 lbs and 1 ft^3 = 0.0283 m^3

As all three sites were in the Piedmont, all the trees on these sites were combined to calculate the conversion factors in Table 3.3. As one ton was approximately equivalent to one m^3 the stumpage prices were not adjusted.

3.1.6 Creation of the configuration, log type and stem files

The final step before the optimization program could be run was to create the configuration, log type, and stem files. The configuration file was created with the CONFIG program in AVIS using the values in Table 3.4, whereas the log type files were created by the MAKELOG program using the information in Table 3.5-3.7. Specifications for waste logs (portion of stem that is unmerchantable) were also required. The last file required, the stem file, was created with the AVISIN program (Table 3.8).

3.1.7. Running the optimization

Once all the required files were created, the optimization was run using the PCAVIS program. PCAVIS reads the specified configuration, log type, and stem files after which it creates a report containing the optimal and skid solutions for all trees at a specific site (Table 3.9).

3.1.8 Analyzing the data

AVIS has some ability to summarize and analyze the results. SUMPIE is a companion program that creates a summary that contains total lengths, volumes, optimal and skid values, and value losses for each individual stem. PCSUMM, another companion program, provides a similar report but summarizes the information by log type. For the skid solutions a table of defects is also provided.

Table 3.3. Factors to convert stumpage prices from \$/ton to \$/m^3.

Over bark density	lbs/ft^3	ton/ft^3	ton/m^3
Average	57.32	0.0287	1.0126
Minimum	47.87	0.0239	0.8457
Maximum	59.33	0.0297	1.0482
Median	58.03	0.0290	1.0252
Standard deviation	2.25	0.001123	0.039666

Table 3.4. Configuration file data for all sites.

	Site A	Site B	Site C
Peterson height coefficient (hb_1 and hb_2)			
• hb_1	0.2413	0.2794	0.250405
• hb_2	1.288657	0.57361	1.419293
Average stump height, cm	9	9	13
Maximum log volume, m^3	1	1	1
Max step between OB diameter measurements, m	6	6	6
Under bark diameter regression coefficients			
• b_0	-13.82	-13.82	-13.82
• b_1, b_2, b_3, b_4, b_5, b_6	0.000001	0.000001	0.000001
Skid length tolerance, m	1	1	1
Allowable diameter error, cm	0	0	0
Diameter value reduction proportion	0	0	0
Allowable length error (trim allowance), m	0.01	0.01	0.01
Diameter value reduction proportion	0	0	0
Out-of-specification value reduction proportions for quality, sweep and multiple errors.	0, 0, 0	0, 0, 0	0, 0, 0

Table 3.5. Log type file data for site A.

Log type name	Sawlogs	Chip'n saw	Pulp	Waste
Log type ID	S	C	P	W
Minimum log length (to one decimal), m	3.8	3.8	3.6	0.1
Maximum log length (to one decimal), m	6.2	5.0	4.9	25
Step length (to one decimal), m	1.2	1.2	0.1	0.1
Minimum SED (as an integer), cm	20	15	5	1
Maximum SED (as an integer), cm	71	30	71	99
Maximum LED (as an integer), cm	71	30	71	99
Sale price, \$/m^3	30.75	12.75	2.10	0
Relative value, \$/m^3	30.75	12.75	2.10	0
Sweep code	1	1	8	9
*Quality code	A	A	AB	AB

* Refer to Table 3.1 for an explanation of the quality codes.

Table 3.6. Log type file data for site B.

Log type name	Plylogs	Sawlogs	Scragg	Pulp	Waste
Log type ID	Y	S	C	P	W
Min log length (to one decimal), m	5.4	5.1	3.2	3.0	0.1
Max log length (to one decimal), m	5.4	5.1	3.8	6.1	25
Step length (to one decimal), m	0.1	0.1	0.6	0.1	0.1
Minimum SED (as an integer), cm	23	20	15	5	1
Maximum SED (as an integer), cm	74	74	74	74	99
Maximum LED (as an integer), cm	74	74	74	74	99
Sale price, $/m^3$	35.00	20.00	10.00	2.50	0
Relative value, $/m^3$	35.00	20.00	10.00	2.50	0
Sweep code	1	1	8	8	9
*Quality code	C	CD	CDE	CDE	CDE

* Refer to Table 3.1 for an explanation of the quality codes.

Table 3.7. Log type file data for site C.

Log type name	Sawlogs	Pulp	Waste
Log type ID	S	P	W
Minimum log length (to one decimal), m	3.8	4.3	0.1
Maximum log length (to one decimal), m	5.1	6.1	25
Step length (to one decimal), m	1.3	0.6	0.1
Minimum SED (as an integer), cm	19	8	1
Maximum SED (as an integer), cm	74	74	99
Maximum LED (as an integer), cm	74	74	99
Sale price, $/m^3$	20.00	2.50	0
Relative value, $/m^3$	20.00	2.50	0
Sweep code	1	8	9
*Quality code	F	FG	FG

* Refer to Table 3.1 for an explanation of the quality codes.

Table 3.8. Explanation of the data in the stem file.

```
======================================================
Stem_no: 2   *1Data_set  11   2   0
  *2 0.0   1.2   3.0   5.1  10.2  12.2  15.2  18.3  20.3  21.3  21.6
  *2 38.1  29.2  26.2  23.6  21.8  19.1  16.5  14.0  10.2   7.6   4.3
  *3  A     B
  *3 18.3  21.6

  *4 Cut    5
  *5  S     S     C     P     W
  *5 5.10  5.10  5.10  5.00  1.30
======================================================
```

*[1] The first number in the Data_set field means that there were eleven diameter and length pairs for stem no. 2. The second number means that two quality codes were entered and the third number means that no sweep codes were used.
*[2] These are the diameters (top number in centimeters) with the corresponding cumulative lengths (bottom number in meters) from the butt.
*[3] These are the cumulative lengths (bottom number in meters) from the butt where a change in quality (top letter) occurs.
*[4] This means that five cuts were made when the stem was optimized by the harvester.
*[5] These are the log types (e.g. S = sawlog) with the corresponding log lengths (in meters) which were actually cut.

Table 3.9. Optimal and skid solutions as created by PCAVIS.

```
                            Stem filename: siteA.STM
                        Configuration filename: siteA.CNF
                          Log type filename: siteA.TYP

Stem number:  1
Optimal solution:
 CUT  SED   LEN  CUM.LEN  No  LOG TYPE   VOLUME   VALUE$
   1  269   6.2     6.2    1  saw         0.47     14.57
   2  254   3.8    10.0    1  saw         0.21      6.45
   3  209   3.8    13.8    1  saw         0.16      5.02
   4  151   3.8    17.6    2  cns         0.10      1.34
  RE   38   3.7    21.3    4  waste       0.03      0.00
                              TOTAL       0.97     27.38
Skid solution:
 CUT  SED   LEN  CUM.LEN  No  LOG TYPE   VOLUME   VALUE$
   1  267   6.40    6.4    1  saw         0.48     14.91
   2  224   6.30   12.7    1  saw         0.32      9.86
   3  179   3.80   16.5    2  cns         0.12      1.56
   4   66   4.30   20.8    3  pulp        0.05      0.11
  RE   38   0.50   21.3    4  waste       0.00      0.00
                              TOTAL       0.97     26.44
                                                 DIFFERENCE $0.93
                                                  VALUE LOSS   3%
```

From these tables all the out-of-specification logs were identified and their values reduced accordingly so as to reflect their true value. The actual value recovered and the accompanied value losses were then recalculated by AVIS.

The non-parametric Kolmogorov-Smirnoff (KS) test was used to test for differences between the optimal value loss percentage (0% in all cases) and the actual value loss percentage at each site before adjustments for out-of-specification logs were made. The null hypothesis is that the optimal and actual solutions are distributed identically; thus the test is sensitive to differences in location, dispersion, and skewness (Sokal and Rohlf 1995).

3.2 CUT-TO-LENGTH SURVEY

The second part of this chapter describes the methods used to evaluate the advantages and disadvantages of CTL, the constraints that limit the wider use of CTL, and the actions that can be taken to remove the constraints.

3.2.1 Identification and selection of the survey participants

To achieve the objectives of the study and to ensure that an overall picture from the different stakeholders was obtained the following categories of stakeholders were included in the study:

- CTL loggers (loggers who are currently using CTL);
- Ex-CTL loggers (loggers who once used CTL, and who are not using it now); and
- CTL equipment manufacturers.

Before any participants could be selected, CTL users in the southeastern USA first had to be identified. Four CTL equipment manufacturers who have CTL systems operating in the southeastern USA were included in the survey and they also assisted in identifying loggers they thought were currently using CTL equipment in this region. According to these records there were supposedly fourteen users of CTL, with a total of 25 harvesters (Table 3.10). On further inquiry I found that two of them no longer used CTL (were now ex-CTL loggers), another two could not be reached with the information supplied, one had only one instead of two harvesters, and one indicated that he never used CTL. A total of nine users, with 17 harvesters, were therefore included in this category.

Ex-CTL loggers were identified through knowledgeable people within the industry. A total of three were identified in this way. With the two loggers previously identified, a total of five loggers were therefore included in this category. Two were from LA, and one each from AL, GA and SC.

3.2.2 **Data collection**

Before any data collection took place the required approval to include human subjects in the study was obtained from the Institutional Review Board of The University of Georgia. Data collection took the form of a mailed (posted or e-mailed) survey with different questionnaires sent to different stakeholders for completion (Appendix 1). Four of the questions in the survey were the same for all the stakeholders:

- What, in your opinion, are the advantages of CTL?
- What, in your opinion, are the disadvantages of CTL?

Table 3.10. Initially identified CTL loggers.

User #	# crews	State	Comments
1	4	LA	Currently using CTL
2	2	LA	Currently using CTL
3	2	LA	Currently using CTL (only had one harvester, not two)
4	2	LA	Doesn't use CTL any more
5	2	LA	Doesn't use CTL any more
Sub-total	12	LA	
6	1	GA	Currently using CTL
7	1	GA	Currently using CTL
8	1	GA	Currently using CTL
Sub-total	3	GA	
9	4	AL	Currently using CTL
10	1	AL	No contact
Sub-total	5	AL	
11	2	AR	Currently using CTL
12	1	SC	Currently using CTL
13	1	OK	Doesn't use CTL
14	1	TX	No contact
Sub-total	5	others	
TOTAL	25	ALL	

- What, in your opinion, are the constraints that limit the wider use of CTL?
- What, in your opinion, needs to be done to remove the constraints?

The purpose of these questions was to gather as many as possible responses from the participants. The previously mentioned questions were included in the questionnaires, as they would lead the participants to first identify the advantages and disadvantages of CTL. From there they would be able to identify the constraints and the actions that can be taken to remove the constraints. As the Theory of Constraints (TOC) was used to analyze these data, and constraints have a different meaning in TOC, constraints are hereafter referred to as undesirable effects (UDEs). UDEs in this study are therefore problems that limit the wider acceptance of CTL. In accordance with TOC nomenclature, actions to remove UDEs will also hereafter be referred to as injections.

3.2.3 Analyzing the data

The advantages, disadvantages, UDEs, and injections were first analyzed in terms of the frequency of the responses provided. A ranking was thereafter assigned, based on the number of responses. As it was expected that the identified UDEs would be inter-related, the cause-effect-cause method was considered appropriate to analyze the causal relationships between the UDE's. According to Goldratt and Fox (1988) the process of speculating a cause for a given effect and then predicting another effect stemming from the same cause is usually referred to as cause-effect-cause. They postulated that every verified, predicted effect sheds more light on the cause, which often leads to a cause itself being regarded as an effect. In this way a whole cause-effect-cause tree can be built that will help to identify the root cause (core problem) why CTL is hardly used in the southeastern USA. It is important that the core problem be identified, so that a root treatment can be applied, rather than just treating the symptoms. A core problem is defined as one that causes at least 70% of the symptoms to exist and which can be directly or indirectly attacked (Cox and others 2001).

As described in Chapter 2, the Current Reality Tree (CRT) of the Thinking Process (TP) can be used to identify the core problem. The thinking process is based on causal logic, not correlation relationships. Sufficiency logic is therefore used in the process (sufficiency logic implies that a cause is sufficient for the effect to exist). It therefore indicates that if something exists (the cause) then something else (the effect) exists or will exist (Goldratt and Fox 1988). The CRT is constructed by establishing the causal relationships between the UDEs. These relationships can be established by asking, for example: “It is difficult to find competent CTL operators” because?….. The answer: “There is a lack of CTL training facilities in the southeastern USA”. Once a causal relationship was established, it can be verified in the following manner (using the previous example again): If “There is a lack of CTL training facilities in the southeastern USA” then “It is difficult to find competent CTL operators”. In the survey the participants were also asked to identify possible actions that would eliminate the UDEs. These injections were applied at the appropriate place on the CRT to eliminate either the core problem or a specific UDE. A future reality tree (FRT) is thus created, which shows the future reality after the UDEs were eliminated. For a comprehensive description on the construction of CRTs and FRTs refer to Cox and others (2001) or Blackstone (2001).

CHAPTER 4. RESULTS

4.1 VALUE RECOVERY

In the first part of this chapter the results from the value recovery study are analyzed with the ultimate objective to determine the difference between the optimal and actual value recovered, what products were over or under recovered, and the reasons for such over or under recovery.

4.1.1 DBHs and heights at all sites

The average DBH of the trees that were included in the study was highest (31.4 cm) at site A, which was clearcut. At site B and C, which were thinned, the average DBHs were respectively 25.0 cm and 22.1 cm. Heights averaged respectively 24.6, 21.1, and 18.2 m at sites A, B, and C (Table 4.1). The number of trees selected at site A was highest in the 27, 29, and 39 cm DBH classes with eight trees in each of these classes, whereas seven trees were each in the 31 and 33 cm DBH classes. At site B, ten trees from each of the 21 and 29 cm DBH classes were selected and felled by the harvester operator. Another nine were in the 27 cm DBH class. At Site C, which had the lowest DBH, most trees (ten) came from the 17 cm DBH class, with another eight from the 25 cm class (Table 4.2).

Table 4.1. Tree statistics for all sites.

Measure and statistics	Site A	Site B	Site C
DBH (cm)			
Minimum	13.5	12.7	10.4
Maximum	47.8	40.1	47.8
Average	31.4	25.0	22.1
Median	30.7	25.4	21.1
Standard deviation	6.7	5.9	8.1
Height (m)			
Minimum	15.3	15.0	11.1
Maximum	29.7	25.0	23.6
Average	24.6	21.1	18.2
Median	24.4	21.1	18.8
Standard deviation	2.8	1.9	3.6

Table 4.2. DBH class distribution at all sites.

Midpoint of DBH class (cm)	Site A	Site B	Site C
9			1
11			4
13	1	1	4
15		3	5
17		3	10
19	1	4	4
21	3	10	2
23	2	5	3
25	5	4	8
27	8	9	3
29	8	10	4
31	7	6	3
33	7	2	2
35	3		2
37	3	1	2
39	8	1	
41	3	1	
43			
45			
47	2		1

4.1.2 Value recovery at site A

At site A 61 trees were optimized into three products (sawlogs, chip'n saw logs, and pulp logs) with a total recoverable volume of 60.3 m^3. The minimum and maximum stem volumes were respectively 0.12 and 2.85 m^3, with the average at 1.02 m^3.

4.1.2.1 Value recovery for sawlogs

In the optimal solution 173 sawlogs with a total volume of 48.8 m^3 and a value of $1512.92 were manufactured, whereas in the actual solution (before adjusting for out-of-specification logs) 117 sawlogs with a total volume of 45.1 m^3 and a value of $1396.07 were made (Appendix 2). Therefore, the volume recovery was 7.6% (3.7 m^3) less, the value recovery was 7.7% ($116.85) less, and the number of sawlogs was 32.4% (56 logs) less than the optimal solution (Appendix 2). The under recovery of value, volume, and number of sawlogs was caused by the actual solution favoring longer sawlogs over shorter ones. The average length of sawlogs in the optimal solution was 4.35 m and the equivalent length in the actual solution was 5.58 m (Table 4.3). In the optimal solution 122 (70.5%) sawlogs were less than 5 m while in the actual solution only 15 (12.8%) sawlogs were less than 5 m (Table 4.4). By cutting more, shorter sawlogs the optimal solution produced a greater cumulative length of sawlogs, 752.6 m in the optimal solution versus 652.9 m in the actual solution (Appendix 2).

The average SED was larger in the actual solution than in the optimal solution, 26.3 cm versus 25.7 cm (Table 4.3). The specification for the minimum SED was 20 cm, while the length specifications were 3.8, 5.0, or 6.2 m. In the optimal solution the average volume was 0.28 m^3 while it was 0.38 m^3 in the actual solution (Table 4.3).

Table 4.3. Sawlog statistics at site A.

	Minimum	Maximum	Mean	Std. deviation
Optimal solution				
SED, (cm)	20.0	43.1	25.7	5.1
Length, (m)	3.80	6.20	4.35	0.92
Volume, (m^3)	0.13	0.88	0.28	0.14
Actual solution				
SED, (cm)	20.1	43.7	26.3	5.1
Length, (m)	3.80	6.40	5.58	0.86
Volume, (m^3)	0.14	0.75	0.38	0.15

Table 4.4. Frequency distribution for sawlog lengths at site A.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.8	122	70.5	122	70.5	4	3.4	4	3.4
3.9			122	70.5	11	9.4	15	12.8
5.0	22	12.7	144	83.2	5	4.3	20	17.1
5.1			144	83.2	34	29.1	54	46.2
5.2			144	83.2	1	0.9	55	47.0
6.2	29	16.7	173	100.0	1	0.9	56	47.9
6.3			173	100.0	59	50.4	115	98.3
6.4			173	100.0	2	1.7	117	100.0
Total	173	100.0			117	100.0		

In the actual solution two sawlogs were out-of-specification in terms of quality and another three were too long by 10 cm. The values of these logs were therefore reduced to reflect their true value. The two logs that were out-of-specification in terms of quality were downgraded to pulp logs, and the lengths of the three logs that were too long were reduced by 10 cm. The volume, number of plylogs, and cumulative lengths were therefore reduced accordingly, which increased the under recoveries (Appendix 2 and Figure 4.1). The actual value of the sawlogs was also reduced by $29.65, thereby increasing the total value loss of sawlogs to $146.50. This presents an increase in the value loss of sawlogs from 7.7% to 9.7% (Appendix 2 and Figure 4.1).

4.1.2.2 <u>Value recovery for chip'n saw logs</u>

In the optimal solution, AVIS manufactured 50 CNS logs with a total volume of 5.5 m^3 and a value of $71.91, whereas in the actual solution (before adjusting for out-of-specification logs) 53 CNS logs with a total volume of 7.8 m^3 and a value of $101.00 were made (Appendix 2). The volume recovery was 41.8% (2.3 m^3) more, the value recovery was 40.5% ($29.09) more, and the number of logs was 6% (3 logs) more than in the optimal solution (Appendix 2). CNS logs were therefore over recovered in terms of value, volume, and number of logs.

The optimal solution produced CNS logs with an average SED of 16.4 cm, a length of 4.18 m, and a volume of 0.11 m^3 while the corresponding numbers in the actual solution were 17.5 cm, 4.75 m, and 0.15 m^3 (Table 4.5). The specification for the minimum SED was 15 cm and the length specifications were 3.8 or 5 m.

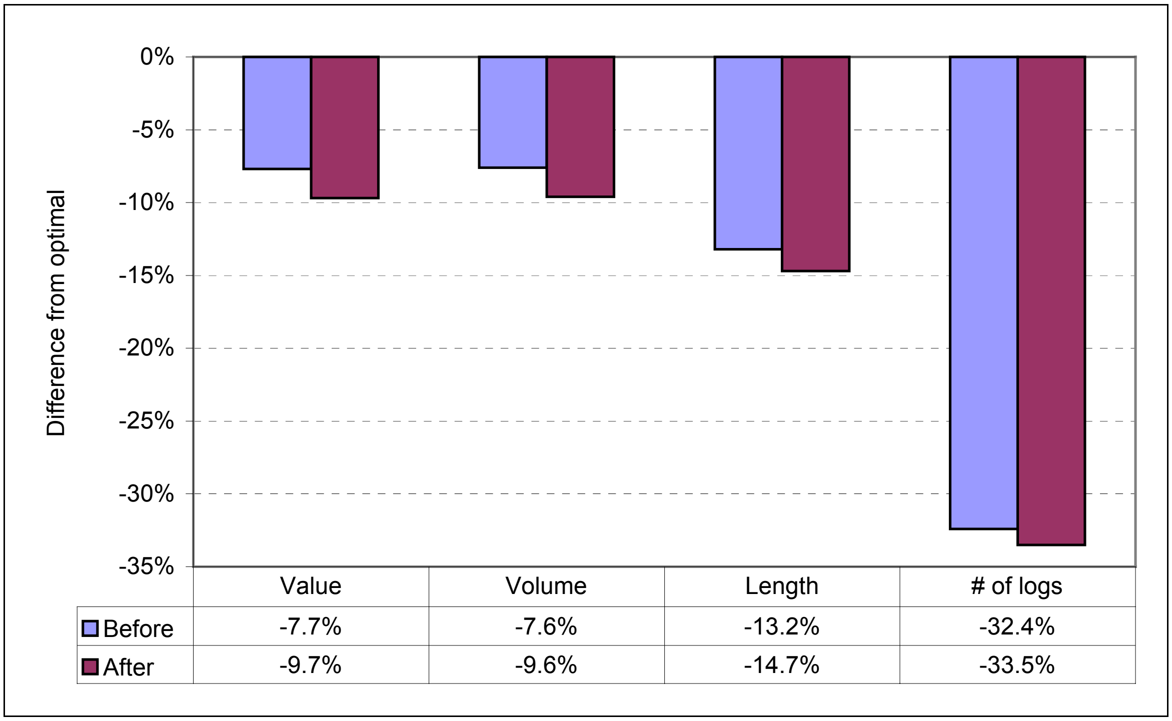


Figure 4.1. Under recovery of value, volume, length, and number of sawlogs at site A before and after adjustments for out-of-specification logs.

Table 4.5. CNS log statistics at site A.

	Minimum	Maximum	Mean	Std. deviation
Optimal solution				
SED, (cm)	15.1	19.6	16.4	12.0
Length, (m)	3.80	5.00	4.18	0.57
Volume, (m^3)	0.07	0.15	0.11	0.02
Actual solution				
SED, (cm)	15.2	21.0	17.5	14.0
Length, (m)	3.80	5.10	4.75	0.56
Volume, (m^3)	0.08	0.21	0.15	0.03

In the actual solution 14 CNS logs (26.4%) were a nominal 3.8 m and 39 logs (73.6%) a nominal 5 m, although in the optimal solution 34 logs (68%) were 3.8 m and 16 logs CNS (32%) were 5 m (Table 4.6). The actual solution therefore preferred to cut the longer 5-meter CNS logs before the shorter 3.8-meter ones, which reduced the actual recovery of CNS logs. However, the value loss caused by the preference for longer CNS logs was more than made up for by the value of sawlog material that was actually cut into CNS logs. The total length of the CNS logs in the optimal solution was 209 m, whereas the total length in the actual solution was 251.8 m, a difference of 42.8 m or 20.5% (Appendix 2).

Three CNS logs in the actual solution were out-of-specification in terms of quality and had to be downgraded to pulp logs. The volume, number of logs, and cumulative lengths were therefore reduced accordingly, which decreased these over recoveries. The value over recovery for CNS logs was reduced by $5.96 to $23.13, which represented a decrease in the over recovery from 40.5% to 32.2% (Appendix 2 and Figure 4.2).

4.1.2.3 <u>Value recovery for pulp logs</u>

In the optimal solution, AVIS manufactured 66 pulp logs with a total volume of 6.1 m^3 and a value of $12.06, whereas in the actual solution (before adjusting for out-of-specification logs) 71 pulp logs with a total volume of 7.5 m^3 and a value of $14.96 were made (Appendix 2). Therefore, the actual volume recovery was 23.0% (1.4 m^3) more, the value recovery was 24.0% ($2.90) more, and the number of pulp logs was 7.6% (5 logs) more than the optimal (Appendix 2).

Table 4.6. Frequency distribution for CNS log lengths at site A.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.8	34	68.0	34	68.0	11	20.8	11	20.8
3.9			34	68.0	3	5.7	14	26.4
4.9			34	68.0	1	1.9	15	28.3
5.0	16	32.0	50	100.0	3	5.7	18	34.0
5.1			50	100.0	35	66.0	53	100.0
Total	50	100.0			53	100.0		

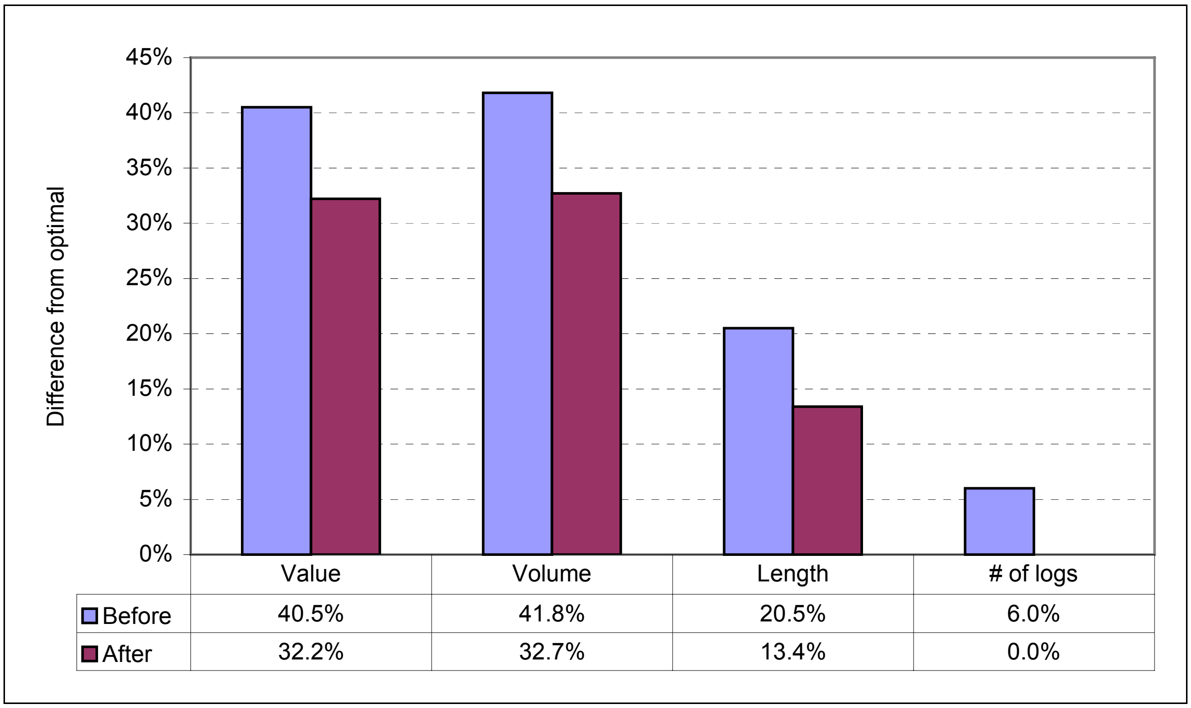


Figure 4.2. Over recovery of value, volume, length, and number of CNS logs at site A before and after adjustments for out-of-specification logs.

The optimal solution produced pulp logs with an average SED of 10.8 cm, a length of 4.4 m, and a volume of 0.09 m^3 while the corresponding numbers in the actual solution were 12.1 cm, 4.67 m, and 0.11m^3 (Table 4.7). The specification for the minimum SED was 5 cm, while the length specifications could be anything between 3.6 and 4.9 m.

In the optimal solution 66 pulp logs (100%) were less than 5 m, while in the actual solution only 31 pulp logs (43.7%) were less than 5m (Table 4.8). As before, the actual solution favored to cut longer pulp logs thereby reducing the value of the pulp logs actually cut. However, this value loss was more than made up for by the value from potential CNS material that was cut to pulp logs. The total length of pulp logs in the optimal solution was 292.4 m, whereas the total length in the actual solution was 331.6 m, a difference of 39.2 m or 13.4% (Appendix 2).

A total of 26 pulp logs in the actual solution were out-of-specification with 25 being too long, and one having a too small a SED. Two of these logs were downgraded to waste and the lengths of the others were reduced so as not to exceed the maximum allowable length. The volume, number of logs, and cumulative lengths were therefore reduced accordingly.

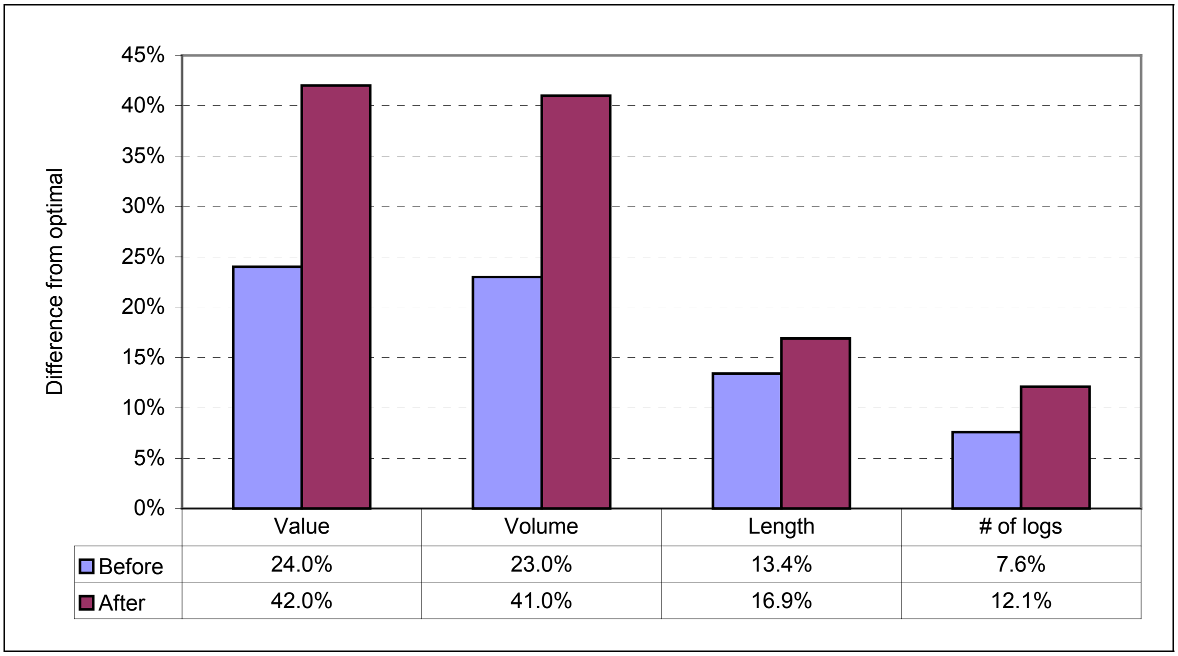
As some out-of-specification sawlogs and CNS logs were also downgraded to pulp logs, the over recovery of total volume, value, number of logs, and cumulative length increased (Appendix 2 and Figure 4.3). This resulted in an increase of the value of pulp logs by $2.16 to $17.12, which represented an increase in the over recovery from 24.0% to 42.0% (Appendix 2 and Figure 4.3).

Table 4.7. Pulp log statistics at site A.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	5.0	40.6	10.8	7.0
Length, (m)	3.60	4.90	4.43	0.54
Volume, (m^3)	0.01	0.54	0.09	0.10
Actual solution				
SED, (cm)	3.8	40.4	12.1	6.1
Length, (m)	3.40	5.90	4.67	0.62
Volume, (m^3)	0.02	0.58	0.11	0.09

Table 4.8. Frequency distribution for pulp log lengths at site A.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.4					1	1.4	1	1.4
3.5					5	7.0	6	8.5
3.6	16	24.2	16	24.2			6	8.5
3.7			16	24.2			6	8.5
3.8			16	24.2	5	7.0	11	15.5
3.9	2	3.0	18	27.3	4	5.6	15	21.1
4.0	1	1.5	19	28.8	3	4.2	18	25.4
4.1			19	28.8	2	2.8	20	28.2
4.2	3	4.5	22	33.3	1	1.4	21	29.6
4.3	2	3.0	24	36.4	1	1.4	22	31.0
4.4	4	6.1	28	42.4	1	1.4	23	32.4
4.5	1	1.5	29	43.9	1	1.4	24	33.8
4.6	3	4.5	32	48.5	2	2.8	26	36.6
4.7	1	1.5	33	50.0			26	36.6
4.8	2	3.0	35	53.0	4	5.6	30	42.3
4.9	31	47.0	66	100.0	1	1.4	31	43.7
5.0					16	22.5	47	66.2
5.1					14	19.7	61	85.9
5.2					5	7.0	66	93.0
5.3					1	1.4	67	94.4
5.4					2	2.8	69	97.2
5.5					1	1.4	70	98.6
5.9					1	1.4	71	100.0
	66	100.0			71	100.0		



	Value	Volume	Length	# of logs
Before	24.0%	23.0%	13.4%	7.6%
After	42.0%	41.0%	16.9%	12.1%

Figure 4.3. Over recovery of value, volume, length, and number of pulp logs at site A before and after adjustments for out-of-specification logs.

4.1.2.4 <u>Value recovery for waste logs</u>

In the optimal solution, AVIS manufactured 58 waste logs with a total volume of 2.2 m^3, whereas in the actual solution (before adjusting for out-of-specification logs) 55 waste logs with the same volume were made (Appendix 2). The total length of waste logs in the optimal solution was 76.3 m, whereas the total length in the actual solution was 94.1 m, a difference of 17.8 m or 23.3% (Appendix 2).

The optimal solution produced waste logs with an average SED of 13.8 cm, a length of 1.31 m, and a log volume of 0.04 m^3 (Table 4.9). In the actual solution the average SED and length were respectively 12.4 cm and 1.71 m with a log volume of 0.04 m^3 (Table 4.9). The recovery of volume, length, and number of waste logs were increased after some out-of-specification logs were downgraded to waste and after certain portions of out-of-specification logs were downgraded to waste (Appendix 2 and Figure 4.4).

4.1.2.5 <u>Summary of value recovery for all products at site A</u>

Eleven of the 61 stems (18%) were cut so that no value loss (0%) occurred. On another one stem the value loss was limited to 1%. The value loss for individual stems ranged from 0 to 42% (Appendix 3). The optimal solution (excluding waste logs) manufactured 289 logs with a total volume of 60.4 m^3 and a value of $1596.89, whereas in the actual solution (excluding waste logs and before adjusting for out-of-specification logs) 241 logs with a total volume of 60.4 m^3 and a value of $1512.03 were made (Appendix 2). The total value loss was therefore $84.86 (5.3%) or 94.7% of the optimal value was recovered (Appendix 2).

Table 4.9. Waste log statistics at site A.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	3.6	53.3	13.8	12.6
Length, (m)	0.10	3.90	1.31	1.13
Volume, (m^3)	0.00	0.33	0.04	0.07
Actual solution				
SED, (cm)	3.6	53.3	12.4	12.5
Length, (m)	0.20	5.20	1.71	1.19
Volume, (m^3)	0.00	0.33	0.04	0.07

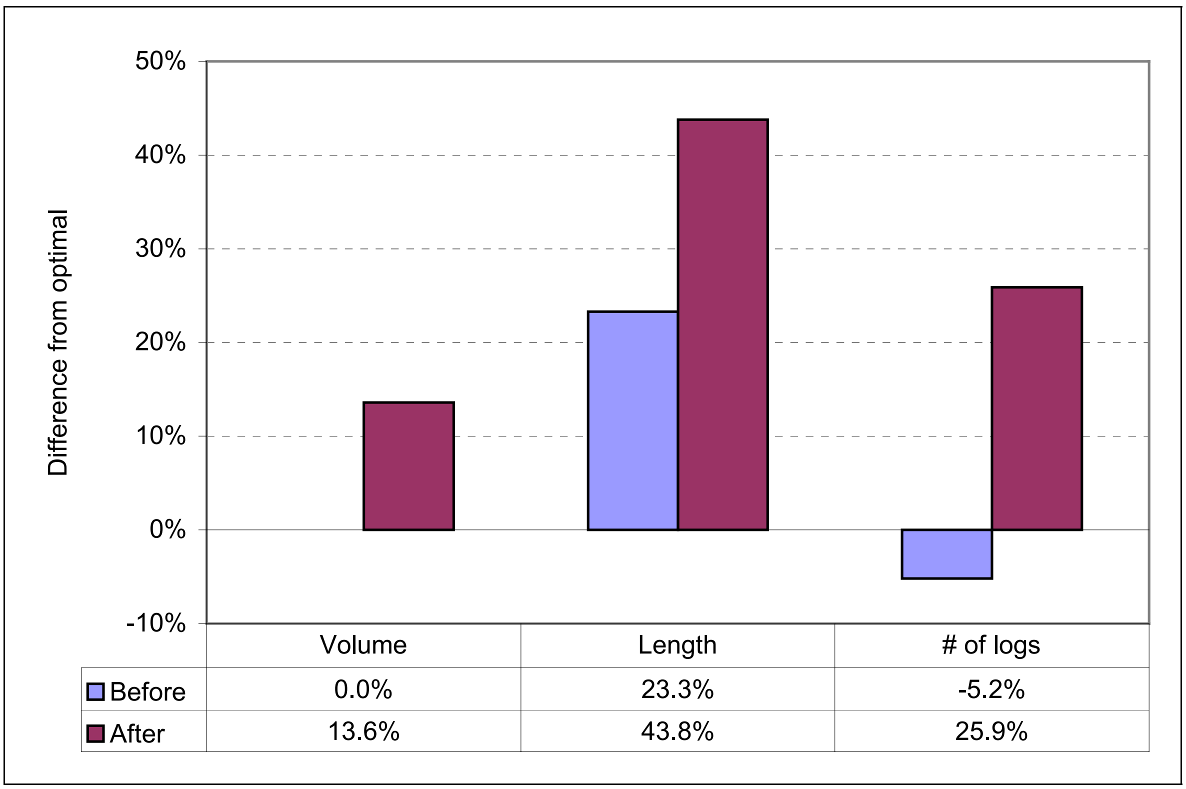


Figure 4.4. Over and under recovery of value, volume, length, and number of waste logs at site A before and after adjustments for out-of-specification logs.

According to the KS-test the unsigned difference $D = 0.803 > D_{0.01} = 0.295$. The two distributions (the optimal and the actual value loss percentage) were therefore significantly different at $\alpha \leq 0.01$. The average optimal value per stem was $26.18 while the actual value was $24.79. Hence, the average value loss per stem was $1.39.

In the optimal solution (before adjusting for out-of-specification) sawlogs made up 94.7% of the total value recovered, CNS logs 4.5%, and pulp 0.8% whereas in the actual solution sawlogs made up 87.4% of the total optimal value recovered, CNS logs 6.3% and pulp 0.9% (Table 4.10). The value loss accounted for the balancing amount of 5.3%. Thirty-four (14%) of the logs (five plylogs, three CNS logs and 26 pulp logs) in the actual solution were out-of-specification and the values of these logs were therefore decreased to reflect their true value. This resulted in an additional value loss of $33.45, thereby increasing the total value loss to $118.31 (7.4%) (Appendix 2) or $1.94 per stem.

4.1.3 Value recovery at site B

At site B 60 trees were optimized into four products (plylogs, sawlogs, scragg logs, and pulp logs) with a total recoverable volume of 35.0 m^3. The minimum and maximum stem volumes were respectively 0.12 and 1.44 m^3, with the average at 0.58 m^3.

4.1.3.1 Value recovery for plylogs

In the optimal solution, AVIS manufactured 34 plylogs with a total volume of 12.7 m^3 and a value of $445.27, whereas in the actual solution (before adjusting for out-of-specification logs) 29 plylogs with a total volume of 10.8 m^3 and a value of $383.31 were made (Appendix 4).

Table 4.10. Percentage of total optimal value per product and value loss.

	Optimal value ($)	% of total optimal value	Actual Value ($)	% of total optimal value	*% Over/ under recovery
Sawlogs	1512.92	94.7	1396.07	87.4	-7.3
CNS logs	71.91	4.5	101.00	6.3	1.8
Pulp	12.06	0.8	14.96	0.9	0.1
Value loss	-	-	84.86	5.3	5.3
Total	1596.89	100.0	1596.89	100.0	-

* A positive value = over recovery (actual > optimal)

* A negative value = under recovery (actual < optimal)

The volume recovery was therefore 15.0% (1.9 m^3) less, the value recovery was 13.9% ($6.96) less, and the number of plylogs was 14.7% (5 logs) less than the optimal solution (Appendix 4). Plylogs were therefore under recovered in terms of value, volume, and number of logs. The under recovery was caused by five potential plylogs that were cut into to sawlogs, although the SED value was sufficient to make plylogs. It therefore seems that the error may have been caused by the harvester's diameter measuring system.

The optimal solution produced plylogs with an average SED of 26 cm, a length of 5.4 m, and a volume of 0.37 m^3 (Table 4.11), while the corresponding numbers in the actual solution were 26.4 cm, 5.30 m, and 0.38 m^3. The specification for the minimum SED was 23 cm, while the only length specification was 5.4 m.

In the actual solution 26 plylogs (89.7%) were 5.3 m, whereas in the optimal solution all the logs were cut to the specification length of 5.4 m (Table 4.12). Therefore, the total length of the plylogs in the optimal solution came to 183.6 m, while the total length in the actual solution was 153.7 m, a difference of 29.9 m or 16.3% (Appendix 4).

Two plylogs were out-of-specification in terms of length (5.2 m instead of the minimum allowable length of 5.3 m) and were therefore downgraded to sawlogs. Hence, the under recoveries in the volume, number of plylogs, and cumulative lengths of the plylogs were therefore increased (Appendix 4 and Figure 4.5). The actual value of the plylogs was also reduced by $27.28, thereby increasing the total value loss of plylogs to $89.24. This represented an increase in the value loss of sawlogs from 13.9% to 20.0% (Appendix 4 and Figure 4.5).

Table 4.11. Plylog statistics at site B.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	23.0	34.4	26.0	2.9
Length, (m)	5.40	5.40	5.40	0.00
Volume, (m^3)	0.25	0.66	0.37	0.09
Actual solution				
SED, (cm)	23.1	34.5	26.4	2.9
Length, (m)	5.20	5.40	5.30	0.03
Volume, (m^3)	0.24	0.65	0.38	0.09

Table 4.12. Number of plylogs per length at site B.

Length (m)	Optimal	% of total	Actual	% of total
5.2			2	6.9
5.3			26	89.7
5.4	34	100.0	1	3.4
Total	34	100.0	29	100.0

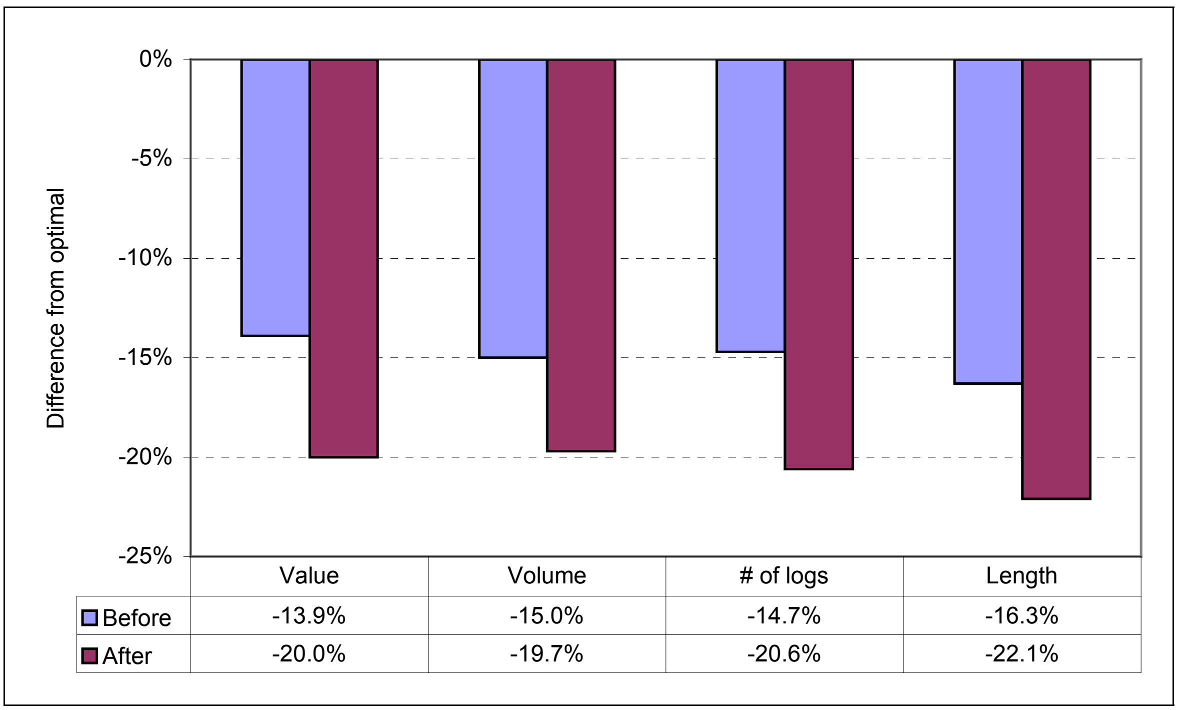


Figure 4.5. Under recovery of value, volume, length, and number of plylogs at site B before and after adjustments for out-of-specification logs.

4.1.3.2 Value recovery for sawlogs

In the optimal solution 29 sawlogs with a total volume of 6.7 m^3 and a value of \$133.82 were manufactured, whereas in the actual solution (before adjusting for out-of-specification logs) 26 sawlogs with a total volume of 6.5 m^3 and a value of \$130.05 were made (Appendix 4). Therefore, the volume recovery was 3.0% (0.2 m^3) less, the value recovery was 2.8% (\$3.77) less, and the number of logs was 10.3% (3 logs) less than the optimal solution (Appendix 4). Sawlogs were therefore under recovered in terms of value, volume, and number of plylogs. The under recovery was caused by eight potential sawlogs that were downgraded to scragg logs. The fact that five potential plylogs were cut into sawlogs was not sufficient for an over recovery to occur.

The optimal solution produced sawlogs with an average SED of 21.4 cm, a length of 5.1 m, and a volume of 0.23 m^3 (Table 4.13), while the corresponding numbers in the actual solution were 22.5 cm, 5.0 m, and 0.25 m^3. The specification for the minimum SED was 20 cm, while the only length specification was 5.1 m.

In the actual solution 24 sawlogs (92.2%) were 5.0 m, whereas in the optimal solution all the logs were cut to the specification length of 5.1 m (Table 4.14). The total length of the sawlogs in the optimal solution was therefore 147.9 m, while the total length in the actual solution was 130.3 m, a difference of 17.6 m or 11.9%. The two out-of-specification plylogs that were downgraded to sawlogs added \$15.38 to the value of sawlogs cut, thereby changing a \$3.77 under recovery to a \$11.61 over recovery. This adjustment changed the 2.8% under recovery to an over recovery of 8.7% (Appendix 4 and Figure 4.6).

Table 4.13. Sawlog statistics at site B.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	20.1	23.7	21.4	1.0
Length, (m)	5.10	5.10	5.10	0.00
Volume, (m^3)	0.19	0.30	0.23	0.03
Actual solution				
SED, (cm)	20.6	27.9	22.5	1.6
Length, (m)	4.90	5.20	50	0.05
Volume, (m^3)	0.19	0.38	0.25	0.05

Table 4.14. Number of sawlogs per length at site B.

Length (m)	Optimal	% of total	Actual	% of total
5.0			24	92.2
5.1	29	100.0	1	3.9
5.2			1	3.9
Total	29	100.0	26	100.0

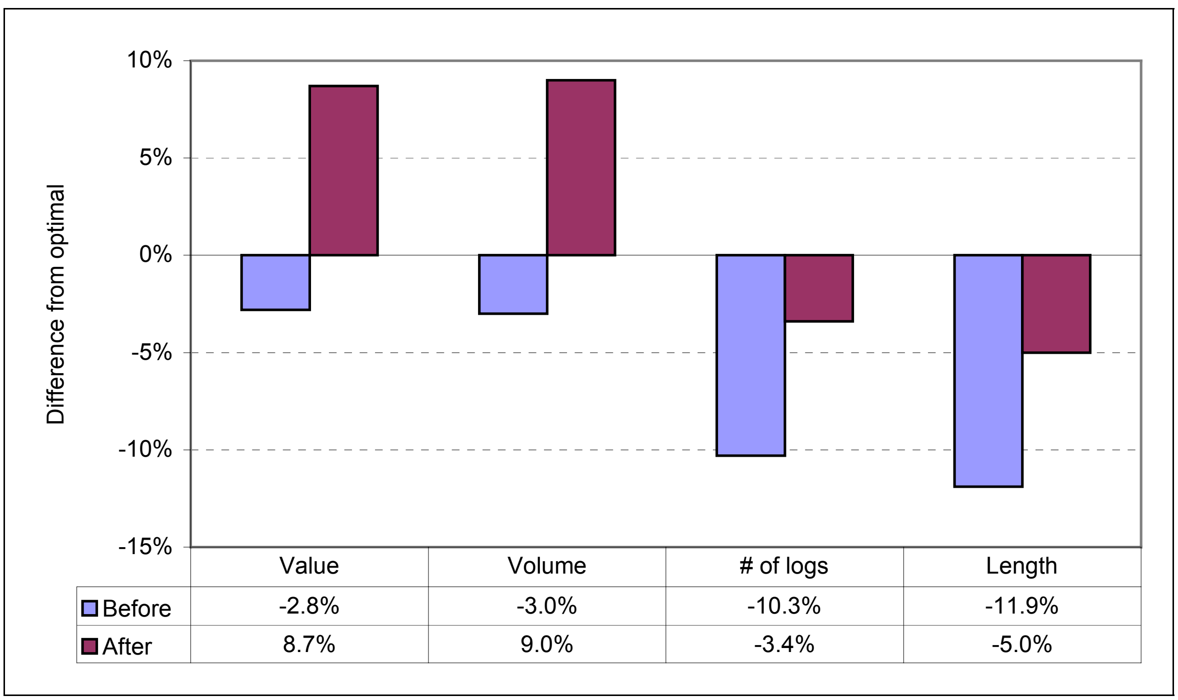


Figure 4.6. Under and over recovery of value, volume, length, and number of sawlogs at site B before and after adjustments for out-of-specification logs.

4.1.3.3 Value recovery for scragg logs

One-hundred-and-one (101) scragg logs with a total volume of 10.8 m^3 and a value of $107.68 were manufactured, whereas in the actual solution (before adjusting for out-of-specification logs) 92 logs with a total volume of 11.2 m^3 and a value of $111.01 were made (Appendix 4). The volume recovery was 3.7% (0.4 m^3) more, the value recovery was 3.1% ($3.33) more, and the number of logs was 8.9% (9 logs) less than the optimal solution (Appendix 4).

The optimal solution produced scragg logs with an average SED of 17.4 cm, a length of 3.63 m, and a volume of 0.11 m^3 (Table 4.15), while the corresponding numbers in the actual solution were 18.3 cm, 3.73 m, and 0.12 m^3. The specification for the minimum SED was 15 cm, while the length specifications were either 3.2 or 3.8 m.

In the actual solution 81 scragg logs (88.0%) were a nominal 3.8 m, whereas in the optimal solution 71.3% were 3.8 m (Table 4.16). The actual solution therefore favored making longer scragg logs. In the optimal solution the total length of all scragg logs was 366.6 m, while the equivalent length in the actual solution was 343.2 m, a difference of 23.5 m or 6.4% (Appendix 4).

As previously indicated the value and volume were over recovered for scragg logs. The over recovery was caused by the sawlogs that were actually cut into scragg logs, although some scraggs logs were in turn cut into pulp logs. However, the downgrading of sawlogs to scragg logs more than made up for the loss of scragg material to pulp logs.

Table 4.15. Scragg log statistics at site B.

	Minimum	Maximum	Mean	Std. deviation
Optimal solution				
SED, (cm)	15.0	24.5	17.4	1.9
Length, (m)	3.20	3.80	3.63	0.27
Volume, (m^3)	0.06	0.18	0.11	0.03
Actual solution				
SED, (cm)	15.2	22.4	18.3	1.8
Length, (m)	3.10	4.10	3.73	0.19
Volume, (m^3)	0.07	0.21	0.12	0.03

Table 4.16. Frequency distribution for scragg log lengths at site B.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.1					1	1.1	1	1.01
3.2	29	28.7	29	28.7	7	7.6	8	8.7
3.3			29	28.7	1	1.1	9	9.8
3.4			29	28.7	1	1.1	10	10.9
3.7			29	28.7	6	6.5	16	17.4
3.8	72	71.3	101	100.0	75	81.5	91	98.9
4.1					1	1.1	92	100.0
Total	101	100.0			92	100.0		

Two scragg logs in the actual solution were out-of-specification in terms of length (4.1 m instead of the maximum allowable length of 3.9 m and 3.4 m instead of the maximum allowable length of 3.3 m). The actual value of the scragg logs was reduced by $0.09, thereby decreasing the over recovery from 3.1 to 3.0% (Appendix 4 and Figure 4.7).

4.1.3.4 Value recovery for pulp logs

In the optimal solution, AVIS manufactured 91 pulp logs with a total volume of 4.8 m^3 and a value of $14.54, whereas in the actual solution (before adjusting for out-of-specification logs) 73 pulp logs with a total volume of 5.7 m^3 and a value of $16.99 were made (Appendix 4). The actual volume recovery was therefore 18.8% (0.9 m^3) more, the value recovery was 16.9% ($2.45) more, and the number of logs was 19.8% (18 logs) less than the optimal solution (Appendix 4).

The optimal solution produced pulp logs with an average SED of 7.8 cm, a length of 4.58 m, and a volume of 0.05 m^3 (Table 4.17), while the corresponding numbers in the actual solution were 10.5 cm, 4.94 m, and 0.08 m^3. The specification for the minimum SED was 5 cm and the length specifications allowed anything between 3.0 and 6.1 m.

In the actual solution 36 logs (49.3%) were 5.5 m, whereas in the optimal solution 17 logs (18.7%) were 3.0 m and 20 logs (22%) were 6.1 m (Table 4.18). In the optimal solution the total length of all pulp logs was 416.8 m, while the equivalent length in the actual solution was 363.5 m, a difference of 53.2 m or 12.8% (Appendix 4). None of the pulp logs were out-of-specification thus no further adjustments were required.

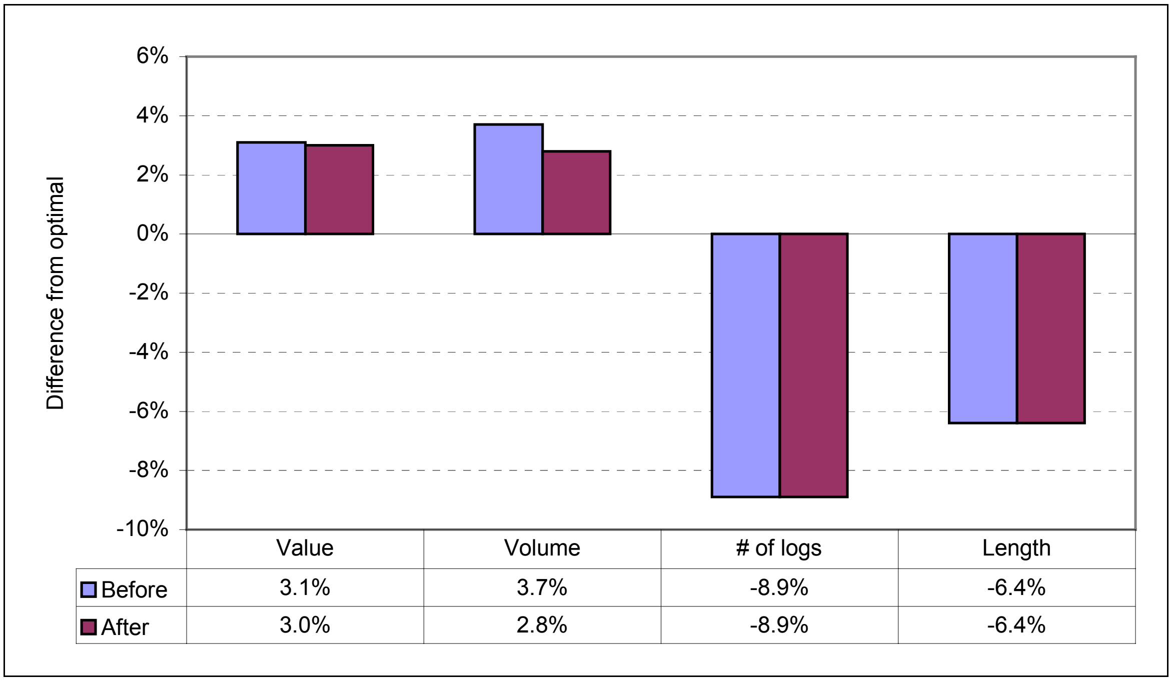


Figure 4.7. Under and over recovery of value, volume, length, and number of scragg logs at site B before and after adjustments for out-of-specification logs.

Table 4.17. Pulp log statistics at site B.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	5.0	13.7	7.8	2.7
Length, (m)	3.00	6.10	4.58	1.20
Volume, (m^3)	0.01	0.11	0.05	0.03
Actual solution				
SED, (cm)	5.8	15.8	10.5	2.3
Length, (m)	2.60	5.60	4.94	0.75
Volume, (m^3)	0.03	0.15	0.08	0.03

Table 4.18. Frequency distribution for pulp log lengths at site B.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.0	17	18.7	17	18.7				
3.1	2	2.2	19	20.9				
3.2	1	1.1	20	22.0	1	1.4	1	1.4
3.3	1	1.1	21	23.1			1	1.4
3.4	2	2.2	23	25.3			1	1.4
3.5	5	5.5	28	30.8			1	1.4
3.6			28	30.8	1	1.4	2	2.8
3.7	2	2.2	30	33.0	1	1.4	3	4.1
3.8	2	2.2	32	35.2	4	5.5	7	9.6
3.9	1	1.1	33	36.3	2	2.7	9	12.3
4.0	3	3.3	36	39.6	6	8.2	15	20.6
4.1	1	1.1	37	40.7	1	1.4	16	21.9
4.2	2	2.2	39	42.9	2	2.7	18	24.7
4.3	4	4.4	43	47.3			18	24.7
4.4	1	1.1	44	48.4	3	4.1	21	28.8
4.5	2	2.2	46	50.6	1	1.4	22	30.1
4.6	2	2.2	48	52.8			22	30.1
4.7	3	3.3	51	56.0	2	2.7	24	32.9
4.8	2	2.2	53	58.2	1	1.4	25	34.3
4.9			53	58.2	2	2.7	27	37.0
5.0	1	1.1	54	59.3	2	2.7	29	39.7
5.1	1	1.1	55	60.4			29	39.7
5.2	2	2.2	57	62.6	2	2.7	31	42.5
5.3	1	1.1	58	63.7			31	42.5
5.4	2	2.2	60	65.9	2	2.7	33	45.2
5.5	2	2.2	62	68.1	36	49.3	69	94.5
5.6			62	68.1	4	5.5	73	100.0
5.7	2	2.2	64	70.3				
5.8	4	4.4	68	74.7				
5.9	2	2.2	70	76.9				
6.0	1	1.1	71	78.0				
6.1	20	22.0	91	100.0				
Total	91	100.0			73	100.0		

4.1.3.5 Value recovery for waste logs

In the optimal solution, AVIS manufactured six waste logs with a negligible volume, whereas in the actual solution 55 logs with a total volume of 0.7 m^3 were made (Appendix 4). The optimal solution produced waste logs with an average SED of 4.4 cm and a length of 0.23 m. In the actual solution the average SED and length were respectively 6.1 cm and 2.28 m with a log volume of 0.01 m^3 (Table 4.19). In the optimal solution the total length of all waste logs was 1.4 m, while the equivalent length in the actual solution was 125.6 m, a difference of 124.2 m (Appendix 4). The downgrading of certain portions of out-of-specification ply and scragg logs did not influence the recoveries of waste logs measurably (Appendix 4).

4.1.3.6 Summary of value recovery for all products at site B

Only three of the 60 stems were cut so that no value loss (0%) occurred. On another 15 stems the value loss was limited to 1%. The value loss for individual stems ranged from 0 to 55% (Appendix 5). The optimal solution (excluding waste logs) manufactured 255 logs with a total volume of 35.0 m^3 and a value of \$701.31, whereas in the actual solution (excluding waste logs and before adjusting for out-of-specification logs) 220 logs with a total volume of 34.2 m^3 and a value of \$641.36 were made. The total value loss was therefore \$59.95 (8.5%) or 91.5% of the optimal value was recovered (Appendix 4). According to the KS-test the unsigned difference $D = 0.933 > D_{0.01} = 0.297$. The two distributions (the optimal and the actual value loss percentage) were therefore significantly different at $\alpha \leq 0.01$. The average stem value loss was \$1.00 (the average optimal and actual value per stem was \$11.69 and \$10.69 respectively).

Table 4.19. Waste log statistics at site B.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	3.8	5.1	4.4	5.0
Length, (m)	0.10	0.40	0.23	0.12
Volume, (m^3)	0	0	0	0
Actual solution				
SED, (cm)	3.8	13.7	6.1	1.8
Length, (m)	0.40	5.60	2.28	1.26
Volume, (m^3)	0.0	0.07	0.01	0.01

In the optimal solution (before adjusting for out-of-specification logs) plylogs made up 63.4% of the total value recovered, sawlogs 19.1%, scragg logs 15.4%, and pulp logs 2.1%, whereas in the actual solution plylogs made up 54.6% of the total optimal value recovered, sawlogs 18.6%, scragg logs 15.8%, and pulp logs 2.5% (Table 4.20). The value loss accounted for the balancing amount of 8.5%.

Four (1.8%) of the logs (two plylogs and two scragg logs) in the actual solution were out-of-specification and the values of these logs were therefore decreased to reflect their true value. This resulted in an additional value loss of \$11.99, thereby increasing the total value loss to \$71.94 (10.3%) (Appendix 4) or \$1.20 per stem.

4.1.4 <u>Value recovery at site C</u>

At site C 60 trees were optimized into two products (sawlogs and pulp logs) with a total recoverable volume of 25.90 m^3. The minimum and maximum stem volumes were respectively 0.04 m^3 and 1.71 m^3, with the average at 0.44 m^3.

4.1.4.1 <u>Value recovery for sawlogs</u>

In the optimal solution, AVIS manufactured 70 sawlogs with a total volume of 17.8 m^3 and a value of \$356.75, whereas in the actual solution (before adjusting for out-of-specification logs) 59 sawlogs with a total volume of 16.5 m^3 and a value of \$330.42 were made (Appendix 6). The volume recovery was therefore 7.3% (1.3 m^3) less, the value recovery was 7.4% (\$26.33) less, and the number of sawlogs was 15.7% (11 logs) less than the optimal solution (Appendix 6). The actual value, volume, and number of sawlogs were therefore less than the optimal.

Table 4.20. Percentage of total optimal value per product and value loss.

	Optimal value ($)	% of total optimal value	Actual value ($)	% of total optimal value	*Over/ under recovery
Plylogs	445.27	63.4	383.31	54.6	-8.8
Sawlogs	133.82	19.1	130.05	18.6	-0.5
Scragg	107.68	15.4	111.01	15.8	0.4
Pulp	14.54	2.1	16.99	2.5	0.4
Value loss	-	-	59.95	8.5	8.5
Total	701.31	100.0	701.31	100.0	-

* A positive value = over recovery (actual > optimal)
* A negative value = under recovery (actual < optimal)

The under recovery was caused by the actual solution favoring longer sawlogs over shorter ones. In the optimal solution more 3.8-meter sawlogs (34 logs or 48.6% of the total) were manufactured than in the actual solution (18 logs or 30.5% of the total) (Table 4.21). By cutting more, shorter sawlogs the optimal solution produced a greater cumulative length of sawlogs, 312.9 m in the optimal solution versus 275.5 m in the actual solution (Appendix 6).

The optimal solution produced sawlogs with an average SED of 23.8 cm, a length of 4.47 m, and a volume of 0.25 m^3, while the corresponding numbers in the actual solution were 24.5 cm, 4.67 m, and 0.28 m^3 (Table 4.22). The specification for the minimum SED was 19 cm, while the length specifications were 3.8 and 5.1 m. None of the sawlogs were out of specification, so no further adjustments were required (Appendix 6 and Figure 4.8).

4.1.4.2 Value recovery for pulp logs

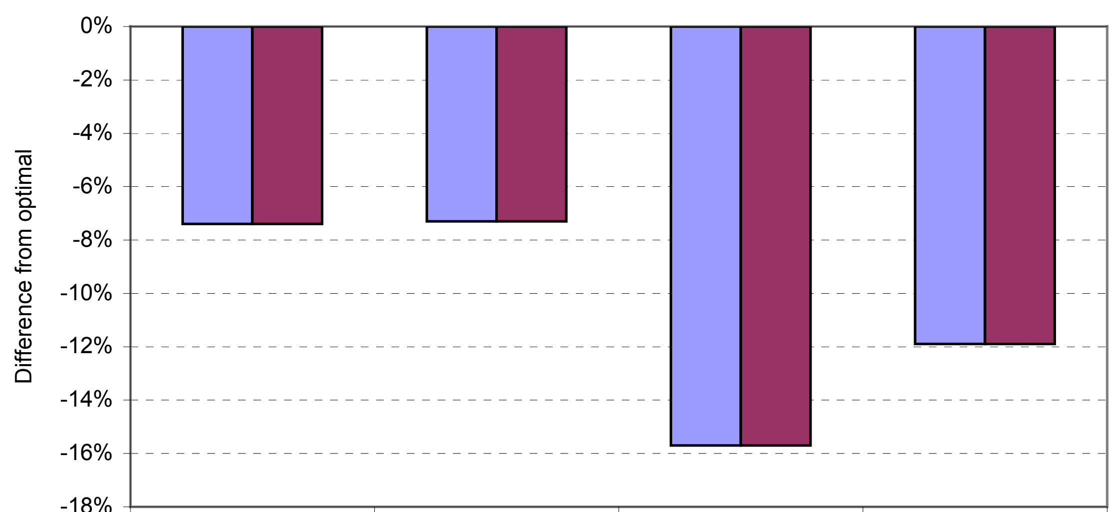
In the optimal solution, AVIS manufactured 91 pulp logs with a total volume of 8.1 m^3 and a value of $24.17, whereas in the actual solution 81 pulp logs (before adjusting for out-of-specification logs) with a total volume of 9.0 m^3 and a value of $27.04 were made (Appendix 6). The actual volume recovery was therefore 11.1% (0.9 m^3) more, the value recovery was 11.9% ($2.87) more, and the number of pulp logs was 11.0% (10 logs) less than the optimal (Appendix 6).

Table 4.21. Frequency distribution for sawlog lengths at site C.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
3.8	34	48.6	34	48.6	16	27.1	16	27.1
3.9			34	48.6	2	3.4	18	30.5
5.0			34	48.6	22	37.3	40	67.8
5.1	36	51.4	70	100.0	17	28.8	57	96.6
5.2			70	100.0	2	3.4	59	100.0
Total	70	100.0			59	100.0		

Table 4.22. Sawlog statistics at site C.

	Minimum	Maximum	Mean	Std. deviation
Optimal solution				
SED, (cm)	19.0	37.5	23.8	4.4
Length, (m)	3.80	5.10	4.47	0.65
Volume, m^3	0.12	0.81	0.25	0.12
Actual solution				
SED, (cm)	19.1	37.6	24.5	4.3
Length, (m)	3.80	5.20	4.67	0.58
Volume, m^3	0.12	0.80	0.28	0.12



	Value	Volume	Length	# of logs
Before	-7.4%	-7.3%	-15.7%	-11.9%
After	-7.4%	-7.3%	-15.7%	-11.9%

Figure 4.8. Under recovery of value, volume, length, and number of sawlogs logs at site C before and after adjustments for out-of-specification logs.

The optimal solution produced pulp logs with an average SED of 11.1 cm, a length of 5.26 m, and a volume of 0.09 m^3, while the corresponding numbers in the actual solution were 11.8 cm, 5.86 m, and 0.11 m^3 (Table 4.23). The specification for the minimum SED was 8 cm and the length specifications were 4.3, 4.9, 5.5, or 6 m.

In the actual solution 21 pulp logs (25.9%) were less than 6 m, whereas in the optimal solution 54 pulp logs (59.3%) were less than 6 m (Table 4.24). By cutting more, shorter logs the optimal solution produced a greater cumulative length of pulp logs, 478.7 m versus 474.7 m, a difference of 4 m (Appendix 6). However, the value loss caused by the preference for longer pulp logs was more than made up for by the added value from sawlog material that was sub-optimized into pulp logs.

A total of 15 pulp logs in the actual solution were out-of-specification. Eleven were too long, and another four were too long and the SED diameter too small. The values of these logs were reduced by \$0.10 in total so as to reflect their true value (Appendix 6 and Figure 4.9).

4.1.4.3 <u>Value recovery for waste logs</u>

In the optimal solution, AVIS manufactured 53 waste logs with a total volume of 0.6 m^3, whereas in the actual solution (before adjusting for out-of-specification logs) 38 waste logs with a total volume of 1.0 m^3 were made. The total length of waste logs in the optimal solution came to 67.3 m, whereas the total lengths in the actual solution were 108.7 m, a difference of 41.4 m or 61.5% (Appendix 6). In the actual solution the average SED and length were respectively of 7.7 cm and 2.86 m with a log volume of 0.03 m^3 (Table 4.25).

Table 4.23. Pulp log statistics at site C

	Minimum	Maximum	Mean	Std. deviation
<u>Optimal solution</u>				
SED, (cm)	8.0	17.9	11.1	2.9
Length, (m)	4.30	6.10	5.26	0.81
Volume, m^3	0.03	0.21	0.09	0.04
<u>Actual solution</u>				
SED, (cm)	7.6	20.2	11.8	3.4
Length, (m)	4.30	6.40	5.86	0.5
Volume, m^3	0.04	0.24	0.11	0.05

Table 4.24. Frequency distribution for pulp log lengths at site C.

	Optimal solution				Actual solution			
Length (m)	# of logs	% of logs	Cum freq	Cum freq (%)	# of logs	% of logs	Cum freq	Cum freq (%)
4.3	34	37.4	34	37.4	2	2.5	2	2.5
4.4			34	37.4	2	2.5	4	4.9
4.5			34	37.4	1	1.2	5	6.2
4.6			34	37.4			5	6.2
4.7			34	37.4	3	3.7	8	9.9
4.8			34	37.4			8	9.9
4.9	5	5.5	39	42.9	1	1.2	9	11.1
5.0			39	42.9			9	11.1
5.1			39	42.9			9	11.1
5.2			39	42.9	1	1.2	10	12.4
5.3			39	42.9	2	2.5	12	14.8
5.4			39	42.9	1	1.2	13	16.1
5.5	15	16.5	54	59.3			13	16.1
5.6			54	59.3	2	2.5	15	18.5
5.7			54	59.3	1	1.2	16	19.8
5.8			54	59.3	2	2.5	18	22.2
5.9			54	59.3	3	3.7	21	25.9
6.0			54	59.3	7	8.6	28	34.6
6.1	37	40.7	91	100.0	45	55.6	73	90.1
6.2					6	7.4	79	97.5
6.3					1	1.2	80	98.7
6.4					1	1.2	81	100.0
Total	91	100.0			81	100.0		

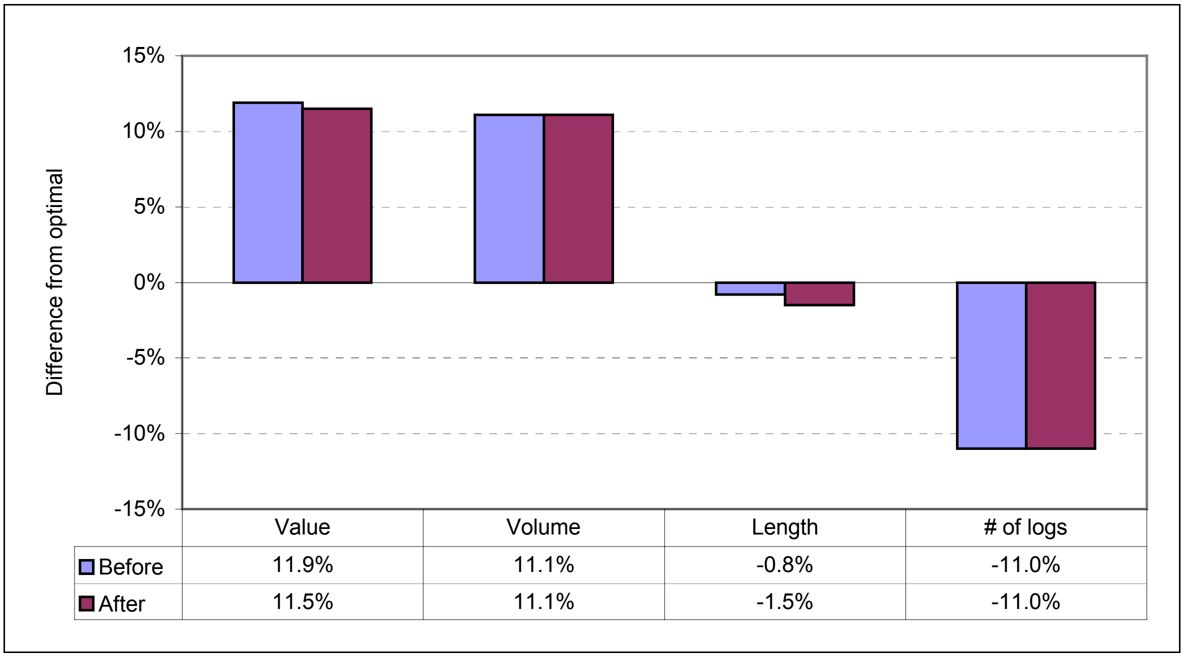


Figure 4.9. Under and over recovery of value, volume, length, and number of pulp logs at site C before and after adjustments for out-of-specification logs.

Table 4.25. Waste log statistics at site C.

	Minimum	Maximum	Mean	Std. Deviation
Optimal solution				
SED, (cm)	5.3	16.0	7.6	2.0
Length, (m)	0.10	5.80	1.27	1.24
Volume, m^3	0.00	0.11	0.01	0.02
Actual solution				
SED, (cm)	5.3	16.0	7.7	2.1
Length, (m)	0.10	6.00	2.86	1.52
Volume, m^3	0.00	0.11	0.03	0.02

In the actual solution the average SED and length were respectively of 7.7 cm and 2.86 m with a log volume of 0.03 m^3 (Table 4.25). The downgrading of certain portions of out-of-specification pulp logs did not influence the recoveries meaningfully (Appendix 6).

4.1.4.4 Summary of value recovered for all products at site C

Twenty-six of the 61 stems (43%) were cut so that no value loss (0%) occurred. On another six stems the value loss was limited to 1%. The value losses for individual stems ranged from 0 to 77% (Appendix 7).

The optimal solution (excluding waste logs) manufactured 161 logs with a total volume of 25.9 m^3 and a value of $380.92, whereas in the actual solution (excluding waste logs and before adjusting for out-of-specification logs) 140 logs with a total volume of 25.5 m^3 and a value of $357.46 were made. The total value loss was therefore $23.46 (6.2%) or 93.8% of the optimal value was recovered (Appendix 6). According to the KS-test the unsigned difference $D = 0.573 > D_{0.01} = 0.297$. The two distributions (the optimal and the actual value loss percentage) were therefore significantly different at $\alpha \leq 0.01$. The average optimal value per stem was $6.25 while the actual value was $5.86. Hence, the average value loss per stem was $0.38.

In the optimal solution (before adjusting for out-of-specification logs) sawlogs made up 93.7% of the total value recovered and pulp logs 6.3%, whereas in the actual solution plylogs made up 86.7% of the total optimal value recovered and pulp logs 7.1% (Table 4.26). The value loss accounted for the balancing amount of 6.2%.

Table 4.26: Percentage of total optimal value per product and value loss.

	Optimal value ($)	% of total optimal value	Actual value ($)	% of total optimal value	*% Over/ under recovery
Sawlogs	356.75	93.7	330.42	86.7	-6.9
Pulp	24.17	6.3	27.04	7.1	+0.7
Value loss	-	-	23.46	6.2	+6.2
Total	380.92	100.00	380.92	100.00	-

* A positive value = over recovery (actual > optimal)
* A negative value = under recovery (actual < optimal)

Fifteen (3.6%) of the logs (all pulp logs) in the actual solution were out-of-specification and the values of these logs were therefore decreased to reflect their true value. This resulted in an additional value loss of $0.10, which did not measurably influence the value loss per stem (Appendix 6).

4.2 CUT-TO-LENGTH SURVEY

In the second part of this chapter the surveys are analyzed with the ultimate objective to determine the undesirable effects (UDEs) that limit the use of CTL in the southeastern USA and the injections than can be taken to remove them.

4.2.1 Initial analysis of the surveys

From the total of 18 questionnaires sent to the participants, eleven were returned (Table 4.27). For the loggers who are currently using CTL, one survey was returned for each of GA, SC, LA, and AL. All the respondents were also operating other harvesting systems at the time of the survey (Table 4.28) with CTL not being the predominant system used by any of them. The loggers used CTL equipment in a range of harvests from pine first thinnings to hardwood third thinnings, as well as pine and hardwood clearcuts (Table 4.29). For the ex-CTL loggers one survey was returned for each of GA, SC, and AL. Economic reasons, the closure of the business, and the unavailability of suitable stands were cited as reasons why they discontinued to use CTL.

Table 4.27. Number and percentage of surveys returned for all stakeholder categories.

Category	# mailed	# returned	% returned
CTL loggers	9	4	44
Ex-CTL loggers	5	3	60
Equipment manufacturers	4	4	100
Total	18	11	61

Table 4.28. Percentage of wood harvested by CTL respondents per harvesting system.

Harvesting system	Respondent 1	Respondent 2	Respondent 3	*Respondent 4
CTL	7	30	8	Yes
Tree-length	88	70	17	Yes
Chipping	5	0	64	No
Other	0	0	10	No

* The results from respondent 4 are not expressed as percentages as they were not correctly provided.

Table 4.29. Percentage of wood harvested by CTL respondents per harvest type.

Harvest type	Respondent 1	Respondent 2	Respondent 3	*Respondent 4
Pine clearcut	10	10	8	Yes
Pine 1st thinning	50	40	10	Yes
Pine 2nd thinning	40	40	80	Yes
Pine 3rd thinning	0	0	0	Yes
Hardwood clearcut	0	0	2	Yes
Hardwood 1st thinning	0	0	0	Yes
Hardwood 2nd thinning	0	0	0	Yes
Hardwood 3rd thinning	0	10	0	Yes

* The results from respondent 4 are not expressed as percentages as they were not correctly provided.

Three of the four CTL loggers indicated that they would expand their CTL operations under the current conditions, whereas they would all expand their CTL operations if the UDEs were removed. One of the three ex-CTL loggers indicated that he would implement CTL under the current conditions, whereas all would implement CTL if the UDEs were removed. Only one of the CTL loggers received a premium for CTL logs, but only at 10% of the mills he supplied. None of the ex-CTL loggers received any premium for CTL logs.

Six of the seven CTL and ex-CTL loggers believed that value recovery is higher with CTL as compared to TL. The other felt that the question was not applicable as value is recovered at different places in CTL and TL operations. Only one in four equipment manufacturers believed that CTL is becoming a more acceptable system for the southeastern USA. Two of them commented that CTL would struggle to become the system of choice in the southeastern USA unless some dramatic environmental legislation (i.e. higher standards on rutting and water quality, prohibiting clearcuts, or severely limiting the size of clearcuts) or pressure from environmental groups changes the current status. Another manufacturer pointed out that there is plenty of interest in roadside processing (fell and skid trees the conventional way, and process them with a harvester head attached to an excavator-based carrier). Although there is plenty of interest in roadside processing very few sales were actually concluded.

The next step is to analyze the perceived advantages of CTL. A total of 27 advantages were identified (Table 3.30). Ninety-one percent of the respondents perceived better value recovery and the environmental friendliness of CTL as advantages.

Table 4.30. Advantages of CTL.

#	Advantages	CTL		Ex-CTL		Manufacturers		Total		Rank
		#	%	#	%	#	%	#	%	
1	Better utilization/merchandizing/value recovery.	4	100	2	67	4	100	10	91	1
2	Friendlier to the environment.	4	100	2	67	4	100	10	91	1
3	Not as sensitive to weather (ability to work more days per year).	4	100	3	100	1	25	8	73	2
4	Smaller and fewer/no landings.	3	75	1	33	3	75	7	64	3
5	More aesthetically pleasing.	2	50	0	0	2	50	4	36	5
6	Right product to the right place (less handling & transport costs).	1	25	1	30	3	75	5	45	4
7	Less damage to residual trees in thinnings.	2	50	1	30	0	0	3	27	6
8	Safer and more ergonomic working environment for personnel.	0	0	2	67	2	50	4	36	5
9	Better tree selection in thinnings.	1	25	0	0	1	25	2	18	7
10	Less moving costs (better for small tracts).	0	0	1	33	1	25	2	18	7
11	Easier to cut customer orders and manage assortments.	0	0	0	0	2	50	2	18	7
12	Consistent production rates (steady flow of wood to mill).	1	25	1	33	0	0	2	18	7
13	Safer load for highway transport (more visually pleasing to the public).	1	25	1	33	0	0	2	18	7
14	Improved mill productivity and recoveries.	1	25	0	0	1	25	2	18	7
15	Ability to night log (more hours worked per year).	1	25	1	33	0	0	2	18	7
16	Ability to cold log (more days worked per year).	0	0	1	33	0	0	1	9	8
17	Ability to inventory wood at roadside (reducing inventory at mills).	0	0	1	33	0	0	1	9	8
18	Better payload on transport vehicles in small trees.	0	0	1	33	0	0	1	9	8
19	Less employees required.	2	50	0	0	0	0	2	18	7
20	Less stress for operators (increased productive working hours).	0	0	0	0	1	25	1	9	8
21	Longer economical extraction distances (fewer forest roads).	0	0	0	0	1	25	1	9	8
22	Forest products are clean of any possible contamination.	0	0	0	0	1	25	1	9	8
23	Less fuel consumption.	1	25	1	33	0	0	2	18	7
24	Operators can work at their own pace.	1	25	0	0	0	0	1	9	8
25	Site preparation is easier.	1	25	0	0	0	0	1	9	8
26	Operating costs per ton is less than for conventional equipment.	0	0	0	0	1	25	1	9	8
27	Longer machine lives and higher trade in values.	0	0	0	0	1	25	1	9	8
	TOTAL	30		20		29		79		

Seventy-three (73) percent thought that the fact that CTL was less sensitive to weather (it could work in wetter conditions) was an advantage. The third most perceived advantage, with 64%, was smaller and fewer (or no) landings.

Seventeen (17) disadvantages of CTL were identified by the respondents (Table 4.31) with higher logging costs perceived by 73% to be disadvantageous. The high initial cost of CTL equipment and the higher skills required by CTL operators were each perceived by 64% and 55% to be disadvantages.

4.2.2 Creating the Current Reality Tree (CRT) and Future Reality Tree (FRT)

The respondents identified 16 UDEs that limit the use of CTL in the southeastern USA (Table 4.32). Limited markets for CTL, the high initial investment cost, and the high logging costs associated with CTL were each cited by 55% of respondents. The difficulty of finding suitable stands for CTL, the culture of the logging community, and the difficulty of finding competent operators were each perceived by 27% of respondents to limit the use of CTL. A summary of the relationships between the 16 UDEs will first be addressed, thereby giving the big picture before addressing any detail. These relationships, without showing all the detailed logic connecting the UDEs, are diagrammatically displayed in a summary current reality tree (CRT) (Figure 4.10). It shows that entity 115 (the white box at the bottom of the CRT), "the equipment to optimize value recovery is complex", directly or indirectly caused the following 11 out of 16 (69%) UDEs (green boxes in the CRT):

- UDE 1: The initial investment in CTL equipment is high (Appendix 8a);
- UDE 2: The logging cost of CTL wood is high (in $/ton) (Appendix 8a);

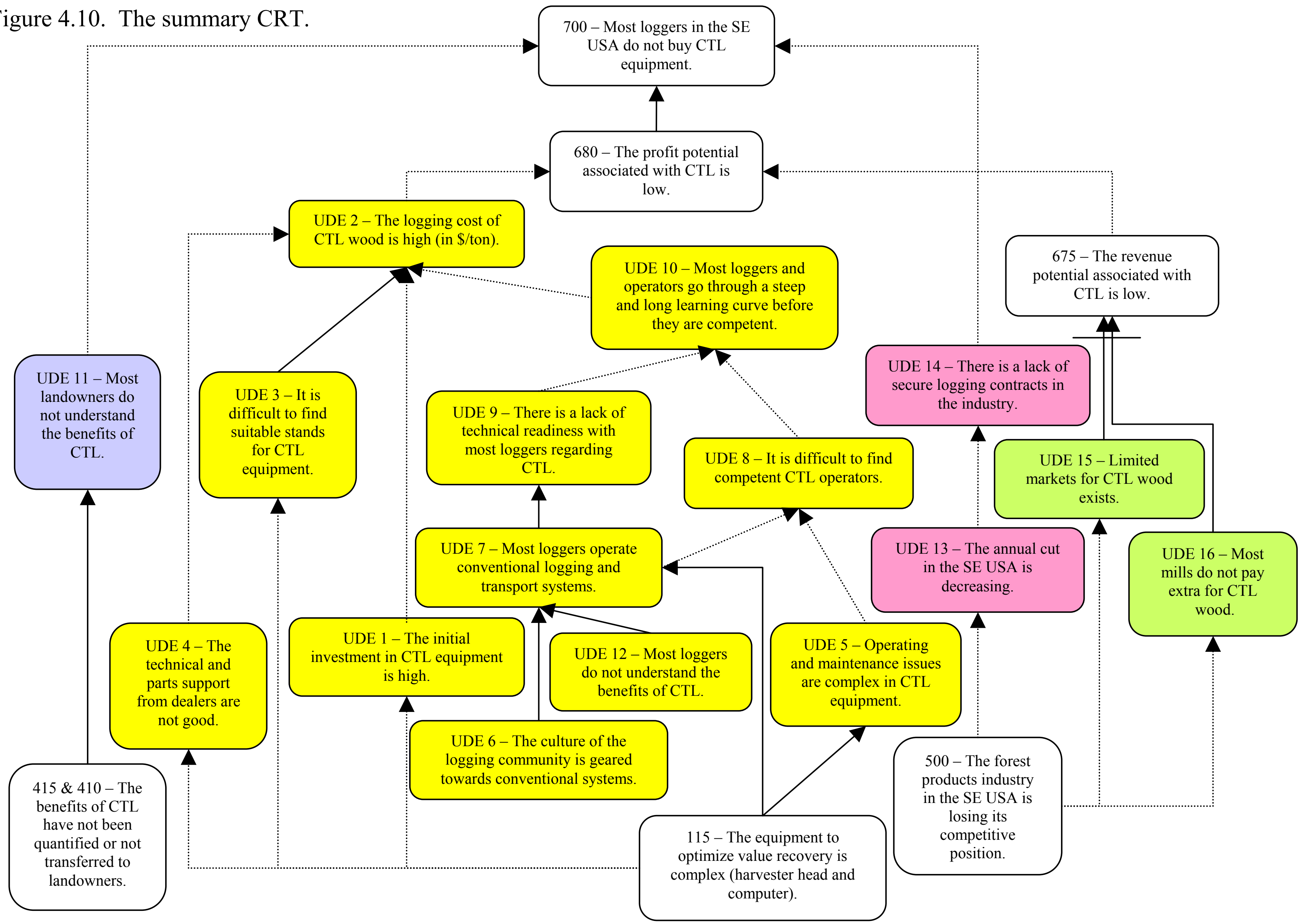
Table 4.31. Disadvantages of CTL.

#	Disadvantages	CTL		Ex-CTL		Manufacturers		Total		Rank
		#	%	#	%	#	%	#	%	
1	Higher logging cost.	2	50	3	100	3	75	8	73	1
2	High initial cost of equipment.	3	75	2	67	2	50	7	64	2
3	Relative low productivity compared to conventional systems.	1	25	2	67	2	50	5	45	4
4	Higher skill level requirement for machine operators.	2	50	1	33	3	75	6	55	3
5	Most mills have inventory and handling systems designed for tree-length.	2	50	1	33	0	0	3	27	5
6	The technology is complex.	0	0	1	33	2	50	3	27	5
7	Higher down time.	1	25	0	0	1	25	2	18	6
8	High maintenance on equipment.	1	25	1	33	0	0	2	18	6
9	Forest companies' accounting systems are designed for tree-length.	0	0	1	33	0	0	1	9	7
10	Operators have a steep and long learning curve.	1	25	1	33	1	25	3	27	5
11	Absolute limitations of handling large dimension trees.	0	0	0	0	1	25	1	9	7
12	Production sensitive to brush.	1	25	0	0	0	0	1	9	7
13	Higher skill level requirement for technical staff/owners.	1	25	0	0	1	25	2	18	6
14	Parts inventory must be kept by the logger (dealers do not stock parts).	1	25	0	0	0	0	1	9	7
15	A complete service truck is needed by the logger.	1	25	0	0	0	0	1	9	7
16	Parts and support from dealers are next to zero.	1	25	0	0	0	0	1	9	7
17	Dealers do not have qualified personnel.	1	25	0	0	0	0	1	9	7
	TOTAL	19		13		16		48		

Table 4.32. UDEs that limit the wider of CTL.

#	UDEs	CTL		Ex-CTL		Manufacturers		Total		Rank
		#	%	#	%	#	%	#	%	
1	Limited markets for CTL wood exist.	1	25	1	33	4	100	6	55	1
2	The initial investment in CTL equipment is high.	3	75	2	67	1	25	6	55	1
3	The logging cost of CTL wood is high ($/ton).	1	25	3	100	2	50	6	55	1
4	It is difficult to find suitable stands for CTL equipment.	1	25	0	0	2	50	3	27	2
5	Most loggers and operators go through a steep and long learning curve.	1	25	0	0	1	25	2	18	3
6	It is difficult to find competent CTL operators.	1	25	0	0	2	50	3	27	2
7	The culture of the logging community is geared towards conventional systems.	0	0	2	67	1	25	3	27	2
8	There is a lack of secure logging contracts in the industry.	0	0	0	0	2	50	2	18	3
9	There is a lack of technical readiness with most loggers regarding CTL.	0	0	0	0	2	50	2	18	3
10	Operating and maintenance issues are complex in CTL equipment.	1	25	1	33	0	0	2	18	3
11	Most landowners do not understand the benefits of CTL.	0	0	1	33	1	25	2	18	4
12	The annual cut in the southeastern (SE) USA is decreasing.	0	0	0	0	1	25	1	9	4
13	Most loggers operate conventional logging and transport systems.	0	0	0	0	1	25	1	9	4
14	Mills do not pay extra for CTL wood.	1	25	0	0	0	0	1	9	4
15	Technical and parts support from the dealers are not good.	1	25	0	0	0	0	1	9	4
16	Loggers do not understand the benefits of CTL equipment.	1	25	1	33	0	0	2	18	3
	TOTAL	12		11		20		43		

Figure 4.10. The summary CRT.



- UDE 3: It is difficult to find suitable stands for CTL equipment in terms of tree size, underbrush, and value to recover (Appendix 8b);
- UDE 4: The technical and parts support from dealers are not good (Appendix 8b);
- UDE 5: Operating and maintenance issues are complex in CTL (Appendix 8c);
- UDE 6: The culture of the logging community is geared towards conventional systems (Appendix 8c);
- UDE 7: Most loggers operate conventional logging and transport systems (Appendix 8c);
- UDE 8: It is difficult to find competent operators (Appendix 8c);
- UDE 9: There is a lack of technical readiness with most loggers regarding CTL (Appendix 8c);
- UDE 10: Most loggers and operators experience a steep and long learning curve before they are competent (Appendix 8c); and
- UDE 12: Most loggers do not understand the benefits of CTL (Appendix 8d).

It is also clear from the summary CRT that the previously mentioned UDEs (except of course for UDE 2 itself) caused UDE 2, “the logging cost of CTL wood is high”.

The summary CRT (Figure 4.10) also shows that entity 500 (the white box at the bottom of the CRT), “the forest products industry in the southeastern USA is losing its competitive position”, directly or indirectly caused the following four out of 16 (25%) UDEs (yellow and lime boxes in the CRT):

- UDE 13: The annual cut in the southeastern USA is decreasing (Appendix 8e);
- UDE 14: There is a lack of secure logging contracts in the logging industry (Appendix 8e);

- UDE 15: Limited markets for CTL wood exist (Appendix 8f); and
- UDE 16: Most mills do not pay extra for CTL wood (Appendix 8f).

It can be seen from the summary CRT that UDEs 15 and 16 caused entity 675, "the revenue potential associated with CTL is low". The combination of UDE 2 and entity 675, caused entity 680, "the profit potential associated with CTL is low".

UDE 11 (the light blue box in Figure 4.10), "most landowners do not understand the benefits of CTL", was caused by entities 415 and 410 (the white box at the bottom of the CRT). The combination of UDE 11, entity 680 and UDE 14 caused entity 700, "most loggers in the southeastern USA do not buy CTL equipment". All of the UDEs therefore contribute to the fact that most loggers in the southeastern USA do not buy CTL equipment, although none of them are the core problem. They are all symptoms of a deeper underlying problem. The complexity of the equipment to optimize value recovery is the core problem as it caused nearly 70% of the UDEs. Hence, "what to change" has been identified. It is recommended that the detailed logic in the CRT be consulted to see how the core problem was identified, and how to read the CRT (Appendix 8a-8f, and Appendix 9a-9b).

There are also three negative loops in the CRT that worsens the situation over time: If "most loggers in the southeastern USA do not buy CTL equipment (entity 700 in Figure 4.10 and Appendix 8f)" then it indirectly causes UDE 4 (Appendix 8b), "the technical and parts support from dealers are not good", which in turn indirectly causes the original entity (700). The same is true for UDE 6 (Appendix 8c), if "the culture of the logging community is geared towards conventional systems", then "most loggers in the southeastern USA do not buy CTL equipment (700)", which in turn keeps the culture same, which in turn stops loggers from buying CTL equipment. A negative loop also exists between entity 320 (Appendix 8c), “there is a lack of CTL training facilities in the southeastern USA” and entity 700. Hence, these negative loops perpetuate the problem.

It was shown that the complexity of the equipment to optimize value recovery is the core problem, therefore if the equipment was simple, 70% of the UDEs would no longer exist (e.g. if the equipment was simple the initial investment and logging cost wouldn’t be high, competent operators would be available, the learning curve would be flat and short, it wouldn’t be difficult to find suitable stands, etc.). The effect of making the equipment simple and other actions were tested with one of the other tools of the TP, the Future Reality Tree (FRT).

As the CRT contains all the causal relationships between UDEs it helps to identify and develop an integrated strategy to solve the problem at different points in the value chain, e.g. equipment manufacturers/dealers, landowners, wood dealers, loggers and mills. As part of the survey the respondents identified 16 injections to remove the constraints (Table 4.33). Educating the industry (landowners, loggers and mills) and the development of training programs for operators were perceived by 46% as injections that would make CTL more acceptable. Twenty-seven percent thought that increasing the price on CTL wood would solve the problem. Eighteen percent though that secure logging contracts would alleviate the problem. The remaining 13 injections were only perceived by one respondent each to address the problem. These injections and some others that were later identified were tested on the CRT, thereby creating the future reality tree (FRT) (Appendix 10a-10f). The injections therefore identified “<u>what to change to</u>”.

Table 4.33. Injections to remove the constraints.

#	Injections	CTL		Ex-CTL		Manufac.		Total		Rank
		#	%	#	%	#	%	#	%	
1	Educate the industry (landowners, loggers, mills) in the benefits of CTL.	1	25	1	33	3	75	5	45	1
2	Set-up training programs for operators with the help of manufacturers.	2	50	1	33	2	50	5	45	1
3	Increase the price for CTL wood to reflect additional processing.	1	25	2	67	0	0	3	27	2
4	Educate the industry on overall operating costs.	1	25	0	0	0	0	1	9	4
5	Industry accepts responsibility to fully utilize resources and protect the environment.	1	25	0	0	0	0	1	9	4
6	Supply the logging contractors with secure contracts.	0	0	1	33	1	25	2	18	3
7	Invest in systems at mills, which are able to handle CTL wood.	0	0	0	0	1	25	1	9	4
8	Design and manufacture CTL equipment as cost effective as conventional systems.	0	0	0	0	1	25	1	9	4
9	Create understanding and collaboration between mills, loggers & landowners.	0	0	0	0	1	25	1	9	4
10	Design and manufacture more CTL equipment with the US loggers in mind.	0	0	0	0	1	25	1	9	4
11	The mill must benefit from the better merchandizing.	0	0	0	0	1	25	1	9	4
12	Landowners accept lower stumpage prices for more, higher value products.	0	0	0	0	1	25	1	9	4
13	Loggers/wood dealers to develop markets for CTL wood.	1	25	0	0	0	0	1	9	4
14	Loggers/wood dealers to find tracts suitable for CTL equipment.	1	25	0	0	0	0	1	9	4
15	Create a technical support network between equipment companies.	1	25	0	0	0	0	1	9	4
16	Create strategic partnerships in terms of finance and preferred suppliers.	1	25	0	0	0	0	1	9	4
	TOTAL	10		5		12		27		

Injection 1, and all the others, were tested in the following manner: If injection 1 "Manufacturers design and manufacture simple, cost effective CTL equipment with the USA loggers in mind that can mass produce while still optimizing value" is applied to block 115 of the CRT (Appendix 8a), then a future reality is created where "The equipment to optimize value recovery is simple and cost effective" (block 115, Figure 4.11, Figure 4.12, and Appendix 10a), which has repercussions through the whole tree. Therefore, if the equipment is simple and cost effective, then "[Desirable effect (DE) 1] The initial investment in CTL equipment is not high", which in turn causes "(135) The depreciation on the equipment not to be high", which in turn causes "(150) The fixed cost of operating CTL not to be high", etc. This injection is the only one that addresses the core problem and it is interesting that only one of the respondents, an equipment manufacturer, identified this as an injection. This equipment manufacturer therefore saw it as a core problem that he can control (and therefore fix), while the loggers all saw it as a core driver (something they have no control over).

As the core problem would only be solved over time, 20 other possible injections (Table 4.34) were identified and applied to different blocks on the CRT, and verified by making the appropriate cause-effect-cause changes on the FRT (Figure 4.12 and Appendix 10a-10f). The big picture is addressed in the summary FRT (Figure 4.12), which shows where the injections were applied and how the current reality changed. As the summary FRT does not include all the logic but only the DEs and some other entities, the exact position where an injection was applied could not always be shown in the summary FRT. In such cases the location of the injection is shown on the first DE it affected.

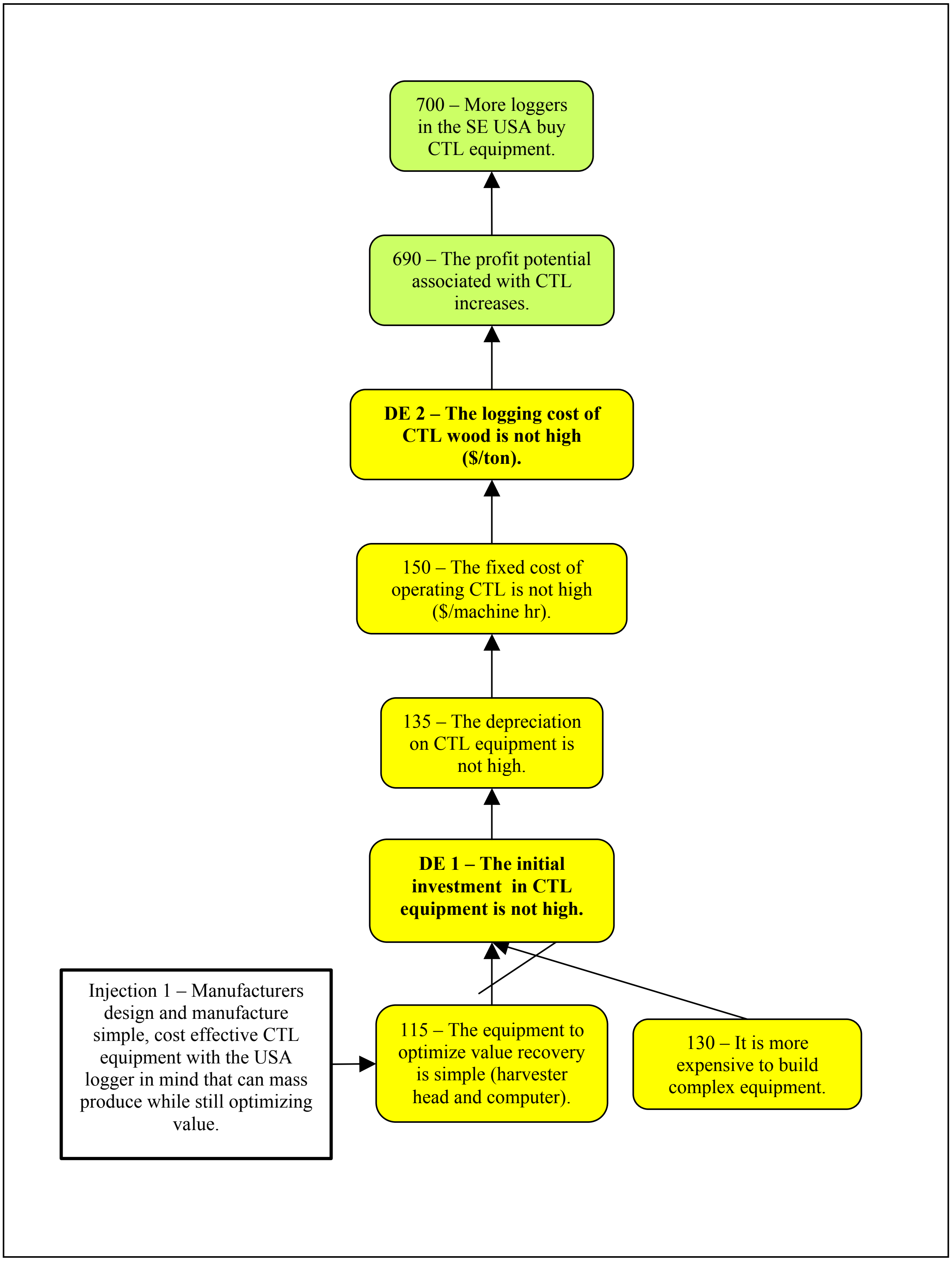


Figure 4.11. Testing injection 1 on one leg of the CRT to create the FRT.

Figure 4.12. The summary FRT.

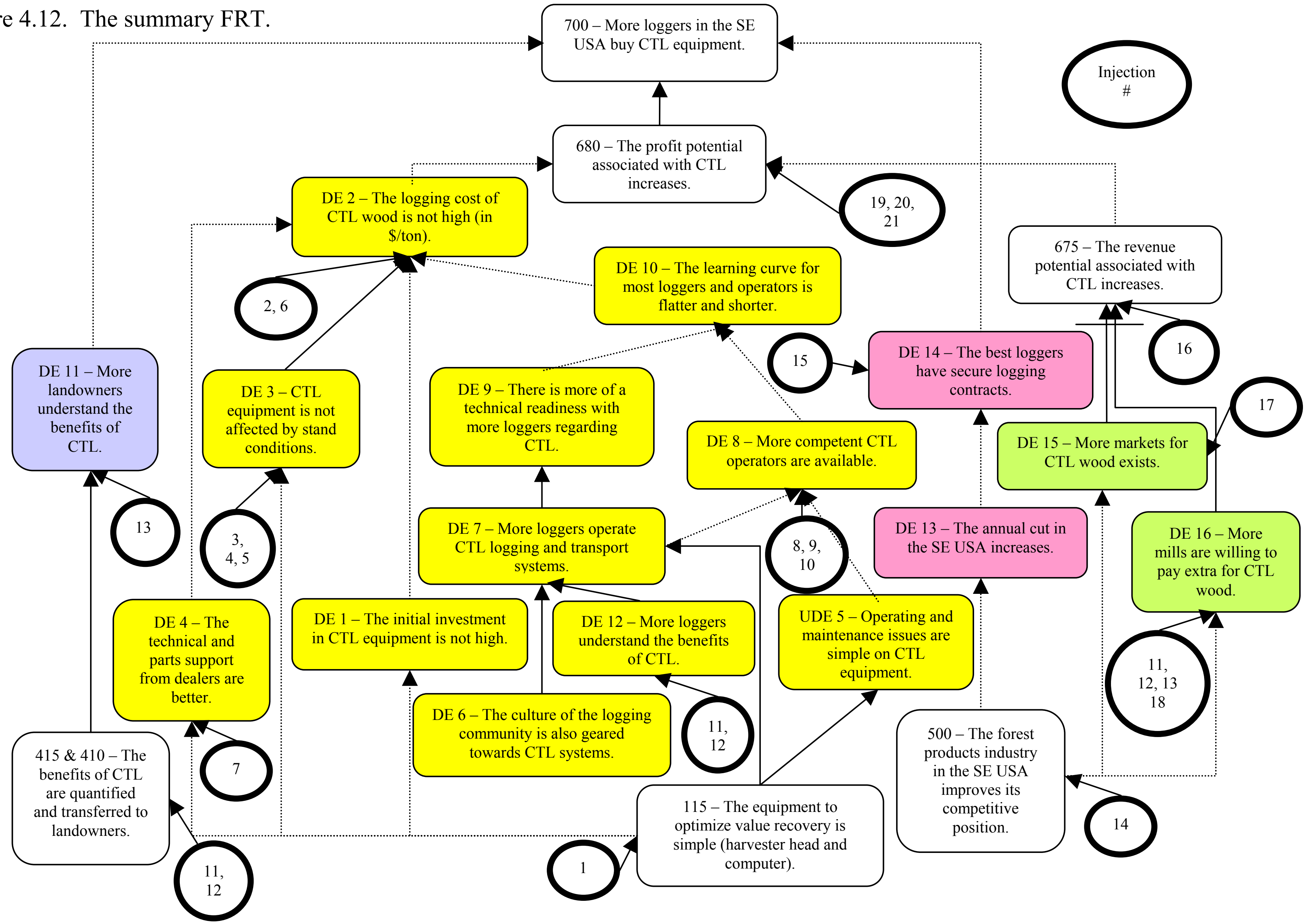


Table 4.34. Injections to increase the use of CTL by stakeholder category.

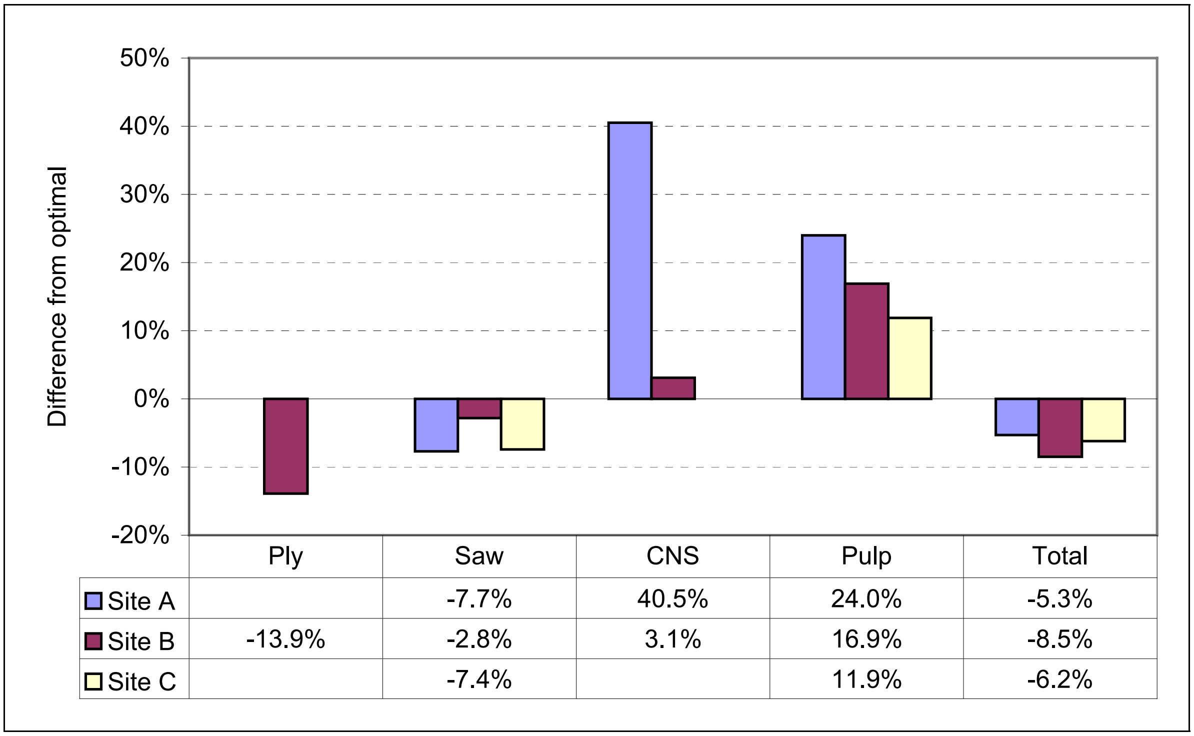
Injection #	Injection description	Equipment manufacturer	Landowner	Wood dealer	Logger	Mill	Appendix #
1	Manufacturers design and manufacture simple, cost effective CTL equipment with the USA loggers in mind that can mass produce while still optimizing value.	x					10a
2	Increase the number of hours worked (e.g. double shifts).				x		10a
3	Take the trees to the harvester/processor (not vice versa).				x	x	10b
4	Reduce adverse stand conditions (e.g. burns to remove under brush).		x	x	x		10b
5	Actively seek suitable tracts of land for CTL equipment.			x	x		10b
6	Create a technical support network between loggers.				x		10b
7	Create a technical support network between equipment suppliers/dealers	x					10b
8	Import CTL operators from other parts of the USA or abroad.	x			x		10c
9	Send people abroad for training.	x			x		10c
10	Develop training facilities in the southeastern USA.	x	x	x	x	x	10c
11	Conduct the research to quantify the benefits and costs associated with CTL for the value chain.	x	x	x	x	x	10d
12	Do technology transfer of applicable studies.	x	x	x	x	x	10d
13	Manufacturers adapt their marketing strategies to include landowners and mills.	x					10d
14	The forest products industry develops innovative products.					x	10e
15	Most forest products companies give their best loggers good, reliable contracts.			x		x	10e
16	Use existing CTL equipment to recover the optimal value from stands while protecting the environment (utilize the wood resource fully and responsible).				x		10f
17	Wood dealers and loggers actively develop markets for CTL wood.			x	x		10f
18	Mills develop markets for products manufactured from CTL wood.					x	10f
19	Change the productivity measurements for CTL from an output/time basis (loads/day) to a profit measure/time basis (profit/day).				x		10f
20	Wood dealers and loggers negotiate win-win contracts with landowners for stumpage (pay them less per product, but they receive more for the total harvest as more high value products are recovered from the tract).		x	x	x		10f
21	Create strategic partnerships in the value chain in terms of finance and preferred supplier contracts.	x	x	x	x	x	10f

It is important to understand that the injection used by a particular stakeholder (equipment manufacturers, landowners, wood dealers, loggers and mills) will depend on their specific circumstances. For ease of use all the injections were therefore classified in terms of the stakeholders (equipment manufacturers/dealers, landowners, wood dealers, loggers and mills) who could use them (Table 4.34). As Table 4.34 and Figure 4.12 are only summaries it is recommended that the logic in the detailed FRT be consulted to see how the injections ultimately change the current reality, "most loggers in the southeastern USA do not buy CTL equipment", to a future reality where "more loggers in the southeastern USA buy CTL equipment".

CHAPTER 5. DISCUSSION AND CONCLUSION

Ten out of 11 survey respondents perceived value recovery as a major advantage of CTL over tree-length (TL) systems. The value recovery part of the study therefore quantified the performance of CTL harvesting systems using this measure at three sites in the Piedmont. The respective value recoveries were 92.6%, 89.7%, and 93.8%, which were similar to the value recovery of 94% reported by Boston and Murphy (in press) in a similar study conducted in the southeastern USA. These value recoveries are also at the higher end of the range as reported by Murphy (2003) from 39 mechanized value recovery studies conducted worldwide that had an average value recovery of 80%. However, to achieve this level of infield value recovery CTL equipment has become inherently complex, which contributed to it not being adopted as the system of choice in the southeastern USA, given the current expertise and level of training of the logging workforce in the region. Gellerstedt and Dahlin (1999), Guimier (1999), Brink (2001) and Murphy (2003) agree that harvesting systems have become more sophisticated.

At all the sites the under recovery of higher-value products (plylogs and/or sawlogs) was associated with an observed over recovery of lower-value products (CNS/scragg and/or pulp logs) (Figure 5.1). The under recovery of sawlogs at both sites A and C was caused by a preference for cutting longer logs. The harvesters at both these sites appeared to have been programmed to prefer longer sawlog lengths over shorter ones. At site A the harvester first optimized the 6.2-meter sawlogs, then the 5-meter ones and finally the 3.8-meter ones.



	Ply	Saw	CNS	Pulp	Total
Site A		-7.7%	40.5%	24.0%	-5.3%
Site B	-13.9%	-2.8%	3.1%	16.9%	-8.5%
Site C		-7.4%		11.9%	-6.2%

Figure 5.1. Percentage over and under recovery of value for all products at all sites before adjustments for out-of-specification logs.

At site C the 5.1-meter sawlogs were optimized before the 3.8-meter ones. The rationale behind this could be that the logger preferred to handle fewer, longer logs or that the mills also preferred the longer lengths. The higher portion of longer lengths could be achieved by programming the computer with a higher relative price for such logs. At site A the total value loss increased from 5.3% to 7.4% after the value of out-of-specification logs were reduced appropriately (Figure 5.2). The average stem value loss therefore increased from $1.39 to $1.94. The corresponding increase in value loss at site C was negligible (Figure 5.2).

At site B, both plylogs and sawlogs were under recovered in value which resulted in an over recovery of scragg logs and pulp logs (Figure 5.1). The under recovery of the plylogs was caused by the cutting of potential plylogs into sawlogs. Some potential sawlogs were also cut into scragg logs. The error was caused by the harvester's diameter measuring system as it was shown in the optimal solution that the SED values were within specification. This downgrading of sawlogs led to an over recovery of scragg logs. In turn some scragg logs were downgraded leading to an over recovery of pulp logs. At this site the actual solution also preferred to first cut longer scragg and pulp log lengths. The value loss this preference caused, was more than made up for by the downgrading of higher-value logs to lower-value logs. The total value loss increased from 8.5% to 10.3% after out-of-specification logs were downgraded appropriately (Figure 5.2). The average stem value loss therefore increased from $1.00 to $1.20.

The forwarder operator at site B indicated that it was sometimes difficult to distinguish between some of the products, although the harvester operator tried to separate the different products into different piles during the optimization process.

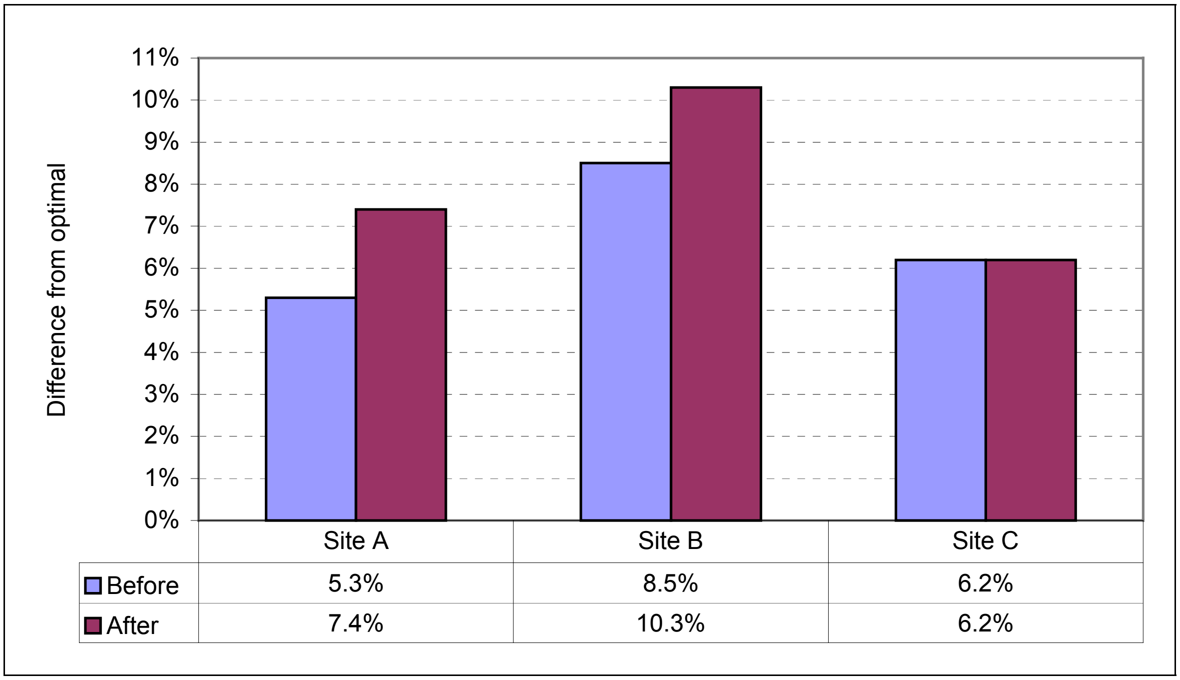


Figure 5.2. Value loss at all sites before and after adjustments for out-of-specification logs.

Installing an automated color marking system that has the ability to mark different products with different colors of paint can solve this problem.

The underbrush at site C was thick in some places, which not only slowed the harvester operator down, but also caused him to leave higher stumps, as he could not always clearly see the bottom of the tree he was about to fell. The average stump height at site C was 13 cm compared to the 9 cm at both sites A and B. The effect of the higher stumps on value recovery was not quantified in the study, but the survey did identify the difficulty to find suitable stands for CTL as an UDE that limited the use of CTL in the southeastern USA.

As the log specifications at both sites B and C were under bark but interpreted as over bark, better communication between the loggers, machine operators, and mills is needed regarding specifications and what level of compliance is expected. If the specifications are under bark but interpreted as over bark, the mills will in effect adjust their prices downwards to reflect their perceived value of the products. In the southeastern USA log specifications are mostly generously interpreted, especially on lower-value products. It will be in the best interest of the whole value chain if this practice does not continue as mills will then have greater control over their recoveries, and loggers will know exactly what log specifications the mills enforce.

The following recommendations should ensure that high value recovery is consistently achieved:

- Educate the harvester operators on the importance of attaining high value recovery consistently. Reports such as this and the use of AVIS can assist in the educational task.

- Ensure that all parties in the value chain interpret the log specifications the same.
- Explore ways to encourage cutting shorter logs to optimize value recovery.
- Educate the harvester operators on the importance of identifying quality defects (i.e. catfaces) that cannot be recognized automatically by the optimization system.
- Managers must constantly emphasize the importance of value recovery.
- Ensure that the harvester operator is properly trained in all the functions of the harvester, including all the applications in the optimization software, and the calibration of the equipment.
- Ensure that the harvester head is accurately calibrated in terms of length and diameter measurements. Check and calibrate the head in accordance with the time intervals recommended by the manufacturer or whenever measurements are suspect. Loggers should have a standard operating procedure for when to check the head.
- Ensure that the correct target lengths are programmed into the optimization system.
- Ensure that the harvester operator cuts different products into easily recognized piles for the forwarder operator.
- Use an automated color marking system to mark different products for the forwarder operator.
- Find suitable stands for CTL equipment, such as ones with little underbrush, where tree sizes are neither too small nor too big, and the potential exists to optimize in-between size products (e.g. CNS logs, scragg logs, or super pulp logs). The equipment should also be matched with the right species.
- Ensure that the forwarder operator loads the correct products onto the correct vehicle so that the correct product is going to the correct processing facility.

Value recovery could play an important role in increasing profitability, but in order to increase value recovery in CTL systems the equipment has become inherently complex. The cause-and-effect analysis showed that the complexity of the harvester was the core problem why CTL is rarely used in the southeastern USA. Some of the previously mentioned recommendations to achieve high value recovery are also the result of the complexity of the equipment.

Compared to a conventional system the harvester head is far more complex than the equivalent felling head on a feller-buncher. The processing and optimizing equipment in CTL (harvester head and computer) is also far more complicated than the delimbing gates, pull-through delimbers, and sawbucks used in conventional systems. Even the extraction equipment, the forwarder in CTL, is more complex than the grapple skidder in conventional systems. The complexity of a "true" CTL system with purpose-built equipment might also be the reason why loggers are showing interest in roadside processors with a harvester/processor head on an excavator carrier. In such a system the carrier is far less complex, which makes back-up service less problematic. The optimizing systems are also normally less complex. Instead of using the top-of-the-range measuring and control systems that are fitted to harvesters, processors use less-complicated systems. Some of the processing heads are also less complex as they are unable to perform the felling function. Comparing the task of the harvester operator to the task of the processor operator also shows differences in complexity. A processor operator does not have to fell trees, select trees for thinnings, maneuver the harvester in the forest, and all the other accompanied intricacies associated with working in the forest. Gellerstedt and Dahlin (1999) are also of the opinion that excavator-based roadside processing is simpler. In the longer-term roadside processing could get the markets accustomed to taking shorter logs instead of TL wood. It could also give loggers a way to phase into CTL, while they are still using their fellerbunchers and skidders in a TL system.

The question still remains why CTL, with all its complexities, has been adopted in Scandinavia but not in the southeastern USA? According to Gellerstedt and Dahlin (1999), and Harstela (1999), some of the reasons are:

- Scandinavia never adopted TL systems since the early days as they saw shorter logs as the most rational approach to handling and transporting wood;
- Environmental concerns caused final fellings areas to become smaller and irregular with thinnings making up a big portion of the area;
- The average stem volumes are low;
- Operational flexibility;
- Transport distances are long;
- CTL extends the logging season; and
- There is a big interest in good quality timber with minimum losses.

Just-in-time and Lean Management (an application of Goldratt's drum-buffer-rope system) have also been applied in Scandinavia to design a customer-oriented management system from the markets to the forest, and from the mill demand to the purchase of timber and bucking for value and demand.

Gellerstedt and Dahlin (1999), Guimier (1999) and Harstela (1999) emphasize the importance of skillful and motivated operators, which are often lacking in the southeastern USA, as a prerequisite for a successful CTL operation. In Scandinavia special forestry machine and vocational schools exist that supply the industry with a steady stream of competent operators (Gellerstedt and Dahlin 1999, Harstela 1999). According to Gellerstedt and Dahlin (1999) on-the-job training is the training method of choice in USA, but that it gives lower skills levels and a narrow specialization. They also believe that the lack of maintenance support for the advanced technology, the capital invested in other logging systems, the high capital investment required for CTL systems, the culture of buying powerful machines, lower productivity, and the many small family contractors are reasons why CTL has not been adopted by more loggers in the southeastern USA. In the survey all these reasons were also identified. In addition, southern mills have invested in wood supply systems to deliver tree-length material.

The difference between this study and what the previous authors tried to do was that they only tried to identify why CTL worked in Scandinavia and not in the USA, whereas this study wanted to find the causal relationships between the reasons. The Scandinavians see the complexity of the equipment as a core driver (a given), not a core problem (something that can be changed), as they already adopted the technology. This underlines the importance of this study as it identified the core problem that might influence equipment manufacturers to rethink their strategies on value recovery in the southeastern USA. The negative loops emphasized that the lack of technical support and CTL training facilities, and the culture of the logging community perpetuate the fact that CTL is hardly used in this region. The causal relationships identified by the Thinking Tools of TOC therefore placed the whole problem in perspective.

According to Brink (2001), the most important change drivers in harvesting during the last decade, and expected for the next decade are technological and productivity improvements, environmental impacts, and social pressure. Environmental impacts and social pressures are inextricably linked and should influence the future acceptability of CTL in the southeastern USA. This was confirmed by comments made by two equipment manufacturers in the survey: “CTL would struggle to become the system of choice in the southeastern USA unless some dramatic environmental legislation or pressure from environmental groups changes the current status”. The technological aspect, according to Domb and Dettmer (1999), will be influenced by some of the patterns of technical evolution, of which one is to go from increasing complexity to simplicity. The optimizing equipment should therefore become simpler in the long-term although it may first become more complex. Mann (2003) and De Bono (1998) suggest that there are no clear guidelines on when the shift to simplicity will take place. Mann (2003) suggests that the shift occurs at a point of maximum viable complexity beyond which the problems that come with increased complexity outweigh the benefits to a critical mass of customers. It therefore seems that the loggers in the southeastern USA reached this point much earlier than their counterparts in Scandinavia. Guimier (1999) also acknowledges that operators have some ability to adapt to technological changes, although technology itself must also adapt to meet the needs of the available workers.

Another pattern of technical evolution, which could have an effect on CTL equipment, is the transition to the use of “fields” (e.g. surgery with knives has been replaced by the use of “fields” such as focused acoustic energy to destroy kidney stones and laser energy to reshape the eye’s cornea) (Domb and Dettmer 1999). The next generation of forestry equipment might just look a lot different to current expectations.

Hence, if the change drivers identified by Brink (2001) (environmental standards, social pressures, and technology) stay more or less the same, CTL will not become the system of choice in the southeastern USA. In this scenario, limited numbers of loggers who know how to exploit the competitive edge of CTL and the niche markets it creates, will continue (or start) to use CTL. They will use many of the injections identified in the FRT to increase their competitive edge and profitability. They are fully aware that the profit equation has both a revenue and a cost side, and they place much emphasis on ways to increase their revenues. They no longer live in the world of cost savings but have made the transition to the world where profit is driven by increased revenue. These loggers will buy their own stumpage from repeat customers (landowners) who are willing to accept lower stumpage prices for higher value recovery and other intangible benefits (e.g. reduced establishment costs, less damage to residual trees, etc.). Mills will probably not change their materials handling systems to accommodate large quantities of CTL wood. Should one or any combination of the abovementioned change drivers take on a dramatically different direction, the adoption of CTL could increase markedly in the southeastern USA.

The following additional studies are recommended:

- Determine the reasons why loggers prefer to cut longer length logs and if the perceived cost savings from making and handling fewer logs make-up for the loss in value recovery. The cost-benefit analysis should include the whole value chain from the forest to the mill.
- Determine the accuracy of the forwarder operator in recognizing different products infield and the potential value loss from loading a higher-value product onto a vehicle with a lower-value product.

- Perform a cost-benefit analysis on installing an automated, color marking system on the harvester head.
- Conduct a similar study on a TL system in which AVIS is used to determine the optimal and actual value recovery as this will allow a comparison to be made between the value recovery potential of CTL and TL.
- Use the Prerequisite Tree and the Transition Tree of the Thinking Process to develop an implementation plan on how the injections in the FRT can be used to exploit the advantages of CTL. This could be especially useful for equipment manufacturers in developing marketing strategies and for loggers who want to increase their profitability.

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APPENDIX 1

QUESTIONNAIRES

Questionnaire for loggers who are currently using CTL.

1. What percentage of the wood you harvest per year is done by the following harvesting systems? How many crews do you have for the different systems?

	% wood harvested	# crews
Cut-to-length (harvester/forwarder)		
Tree-length (fellerbuncher/grapple skidder)		
Chipping		
Other		

2. Of the wood you harvest by CTL, what percentage is harvested in the following operations? The total must be 100%.

	Pine	Hardwood
Clearcut		
Thin – 1st		
Thin – 2nd		
Thin – 3rd		
Other		

3. In which of the operations in question 2 do you prefer to use CTL and why?
4. In which of the operations in question 2 do you prefer NOT to use CTL and why?
5. What, in your opinion, are the ADVANTAGES of CTL?
6. What, in your opinion, are the DISADVANTAGES of CTL?
7. What, in your opinion, are the constraints that limit the wider use of CTL?
8. What, in your opinion, needs to be done to remove the constraints in question 7?
9. Would you expand your CTL system with the current constraints present?
10. Would you expand your CTL system if the constraints were removed?
11. What percentage of processing plants you deliver wood to, pays a PREMIUM for CTL logs?
12. In your opinion, is the value recovered from the tree higher with a CTL system?

Questionnaire for loggers who used to operate CTL.

1. In which operations did you use CTL? Tick the appropriate boxes.

	Pine	Hardwood
Clearcut		
Thin – 1st		
Thin – 2nd		
Thin – 3rd		
Other		

2. In which of the operations in question 1 did you prefer to use CTL and why?
3. In which of the operations in question 1 did you prefer NOT to use CTL and why?
4. What, in your opinion, are the ADVANTAGES of CTL?
5. What, in your opinion, are the DISADVANTAGES of CTL?
6. What were the reasons for discontinuing your CTL operation?
7. What, in your opinion, are the current constraints that limit the wider use of CTL?
8. What, in your opinion, needs to be done to remove the constraints in question 7?
9. Would you consider using a CTL system with the current constraints present?
10. Would you consider using a CTL system if the constraints were removed?
11. What percentage of processing plants you delivered wood to, paid a PREMIUM for CTL logs?
12. In your opinion, is the value recovered from the tree higher with a CTL system?

Questionnaire for equipment suppliers.

1. What, in your opinion, are the ADVANTAGES of CTL?
2. What, in your opinion, are the DISADVANTAGES of CTL?
3. What, in your opinion, are the constraints that limit the wider use of CTL in the Southeastern USA?
4. What, in your opinion, needs to be done to remove the constraints in question 4?
5. In your opinion, do you believe that CTL is becoming a more acceptable harvesting system for the Southeastern USA?

APPENDIX 2

OPTIMAL AND ACTUAL NUMBER OF LOGS, VOLUME, VALUE AND LENGTH RECOVERED AT SITE A.

	Saw	CNS	Pulp	Sub-total	Waste	Total
Before adjustments for out-of-specification logs						
# of logs optimal	173	50	66	289	58	347
# of logs actual	117	53	71	241	55	294
*Optimal – actual	-56	+3	+5	-48	-3	-52
*% Difference	-32.4	+6.0	+7.6	-16.6	-5.2	-15.0
Volume optimal (m^3)	48.8	5.5	6.1	60.4	2.2	62.5
Volume actual (m^3)	45.1	7.8	7.5	60.4	2.2	62.5
*Optimal – actual (m^3)	-3.7	+2.3	+1.4	0.0	0.0	0.0
*% Difference	-7.6	+41.8	+23.0	0.0	0.0	0.0
Value optimal ($)	1512.92	71.91	12.06	1596.89	-	1596.89
Value actual ($)	1396.07	101.00	14.96	1512.03	-	1512.03
*Optimal – actual ($)	-116.85	+29.09	+2.90	-84.86	-	-84.86
*% Difference	-7.7	+40.5	+24.0	-5.3	-	-5.3
Length optimal (m)	752.6	209.0	292.4	1253.9	76.3	1330.2
Length actual (m)	652.9	251.8	331.6	1236.2	94.1	
*Optimal – actual (m)	-99.7	+42.8	+39.2	-17.7	+17.8	0.0
*% Difference	-13.2	+20.5	+13.4	-1.4	+23.3	0.0
After adjustments for out-of-specification logs						
# of logs optimal	173	50	66	289	58	347
# of logs actual	115	50	74	239	73	312
*Optimal – actual	-58	0	+8	-50	+15	-35
*% Difference	-33.5	0.0	+12.1	-17.3	+25.9	-10.1
Volume optimal (m^3)	48.8	5.5	6.1	60.4	2.2	62.5
Volume actual (m^3)	44.1	7.3	8.6	60.0	2.5	62.5
*Optimal – actual (m^3)	-4.7	+1.8	+2.5	-0.4	+0.3	0.0
*% Difference	-9.6	+32.7	+41.0	-0.7	+13.6	0.0
Value optimal ($)	1512.92	71.91	12.06	1596.86	-	1596.86
Value actual ($)	1366.42	95.04	17.12	1478.58	-	1478.58
*Optimal – actual ($)	-146.50	+23.13	+5.06	-118.31	-	-118.31
*% Difference	-9.7	+32.2	+42.0	-7.4	-	-7.4
Length optimal (m)	752.6	209.0	292.4	1253.9	76.0	1329.9
Length actual (m)	641.7	237.0	341.9	1220.6	109.3	1329.9
*Optimal – actual (m)	-110.9	+28.0	+49.5	-33.3	+33.3	-0.0
*% Difference	-14.7	+13.4	+16.9	-2.7	+43.8	-0.0

* A positive value = over recovery (actual > optimal)
* A negative value = under recovery (actual < optimal)

APPENDIX 3

OPTIMAL AND ACTUAL VALUES RECOVERED AT SITE A.

Stem #	Length	Volume	Optimum $	Skid $	Diff.$	% Loss	Comments
1	21.3	0.98	27.55	26.62	0.92	3	
2	21.6	0.76	19.37	18.37	1.00	5	
3	22.0	0.78	21.02	18.10	2.92	14	
4	21.3	0.83	22.35	22.32	0.03	0	3c less than optimal
5	23.2	0.90	23.43	23.81	0.00	0	38c more than optimal
6	22.6	0.97	26.67	26.77	0.00	0	10c more than optimal
7	21.3	0.83	22.60	21.76	0.84	4	
8	21.3	0.59	13.74	10.37	3.37	25	
9	25.9	2.06	61.81	58.56	3.25	5	
10	23.8	1.45	41.48	40.29	1.20	3	
11	20.4	1.43	24.61	31.88	0.00	0	$7.27 more than optimal
12	25.0	2.03	50.30	48.22	2.08	4	
13	22.9	0.62	13.25	13.35	0.00	0	10c more than optimal
14	26.8	2.85	73.71	72.41	1.31	2	
15	18.6	0.69	15.97	14.30	1.67	10	
16	22.9	1.14	31.28	29.98	1.29	4	
17	19.8	0.54	11.41	8.64	2.77	24	
18	16.5	0.94	18.90	18.61	0.29	2	
19	15.2	0.41	7.51	4.35	3.16	42	
20	21.6	1.38	41.78	33.11	8.68	21	
21	21.7	0.95	26.45	24.50	1.95	7	
22	19.6	1.58	33.58	33.58	0.00	0	optimal = skid
23	21.3	0.80	21.37	20.34	1.03	5	
24	19.1	0.72	19.04	19.04	0.00	0	optimal = skid
25	22.9	0.89	24.10	22.41	1.69	7	
26	22.7	0.73	18.73	15.89	2.84	15	
27	22.9	1.30	37.70	36.79	0.91	2	
28	21.3	2.19	43.76	43.23	0.52	1	
29	24.4	1.29	37.99	36.08	1.90	5	
30	20.4	1.69	50.69	48.59	2.10	4	
31	20.1	0.96	27.16	25.03	2.13	8	
32	20.7	0.44	4.54	4.27	0.28	6	
33	19.4	0.26	1.61	1.61	0.00	0	optimal = skid
34	25.6	1.00	26.88	24.16	2.72	10	
35	25.6	0.96	25.25	22.85	2.40	10	
36	24.4	0.76	17.08	15.25	1.82	11	
37	23.8	1.12	31.07	30.25	0.81	3	
38	23.5	1.21	34.80	34.02	0.77	2	
39	21.0	0.59	12.37	10.93	1.43	12	
40	23.3	1.28	36.83	36.91	0.00	0	8c more than optimal
41	20.5	0.97	27.43	23.92	3.51	13	
42	23.5	0.70	15.49	13.18	2.31	15	
43	21.3	0.60	10.14	9.65	0.50	5	
44	22.0	0.87	14.60	13.37	1.23	8	
45	20.7	0.47	8.11	4.74	3.38	42	
46	23.2	0.71	16.77	14.56	2.20	13	
47	21.3	0.79	21.02	20.49	0.53	3	
48	19.8	0.46	8.65	8.08	0.57	7	
49	22.4	1.30	38.56	37.52	1.04	3	
50	26.8	1.72	47.48	46.32	1.15	2	
51	27.4	1.74	50.08	50.32	0.00	0	24c more than optimal
52	25.4	1.90	56.06	51.34	4.71	8	
53	21.9	0.99	21.24	17.01	4.22	20	
54	19.8	0.41	5.42	4.27	1.15	21	
55	24.8	1.65	48.77	45.41	3.36	7	
56	22.3	1.20	34.74	34.65	0.09	0	9c less than optimal
57	19.2	0.57	10.89	9.17	1.72	16	
58	22.3	1.61	46.52	46.43	0.09	0	9c less than optimal
59	13.4	0.30	3.07	2.80	0.27	9	
60	13.7	0.12	0.23	0.21	0.02	9	
61	21.6	0.57	11.89	11.04	0.85	7	

APPENDIX 4

OPTIMAL AND ACTUAL NUMBER OF LOGS, VOLUME, VALUE AND LENGTH RECOVERED AT SITE B.

	Ply	Saw	Scragg	Pulp	Sub-total	Waste	Total
Before adjustments for out-of-specification logs							
# of logs optimal	34	29	101	91	255	6	261
# of logs actual	29	26	92	73	220	55	275
*Optimal – actual	-5	-3	-9	-18	-35	+49	+14
*% Difference	-14.7	-10.3	-8.9	-19.8	-13.7	-	+5.4
Volume optimal (m^3)	12.7	6.7	10.8	4.8	35.0	0	35.0
Volume actual (m^3)	10.8	6.5	11.2	5.7	34.2	0.7	35.0
*Optimal – actual (m^3)	-1.9	-0.2	+0.4	+0.9	-0.8	+0.7	0.0
*% Difference	-15.0	-3.0	+3.7	+18.8	-2.3	0.0	0.0
Value optimal ($)	445.27	133.82	107.68	14.54	701.31	-	701.31
Value actual ($)	383.31	130.05	111.01	16.99	641.36	-	641.36
*Optimal – actual ($)	-61.96	-3.77	+3.33	+2.45	-55.96	-	-59.95
*% Difference	-13.9	-2.8	+3.1	+16.9	-8.5	-	-8.5
Length optimal (m)	183.6	147.9	366.6	416.8	1114.9	1.4	1116.3
Length actual (m)	153.7	130.3	343.2	363.5	990.7	125.6	1116.3
*Optimal – actual (m)	-29.9	-17.6	-23.5	-53.2	-124.3	+124.2	
*% Difference	-16.3	-11.9	-6.4	-12.8	-11.1	-	0.0
After adjustments for out-of-specification logs							
# of logs optimal	34	29	101	91	255	6	
# of logs actual	27	28	92	73	220	59	279
*Optimal – actual	-7	-1	-9	-18	-35	+53	+18
*% Difference	-20.6	-3.5	-8.9	-19.8	-13.7	-	+6.9
Volume optimal (m^3)	12.7	6.7	10.8	4.8	35.0	0.0	35.0
Volume actual (m^3)	10.2	7.3	11.1	5.7	34.3	0.7	35.0
*Optimal – actual (m^3)	-2.5	+0.6	+0.3	+0.9	-0.7	+0.7	0.0
*% Difference	-19.7	+9.0	+2.8	+18.8	-2.0	-	0.0
Value optimal ($)	445.27	133.82	107.68	14.54	701.31	-	701.31
Value actual ($)	356.03	145.43	110.92	16.99	629.37	-	629.37
*Optimal – actual ($)	-89.24	+11.61	+3.24	+2.25	-71.94	-	-71.94
*% Difference	-20.0	+8.7	+3.0	+16.9	-10.3	-	-10.3
Length optimal (m)	183.6	147.9	366.6	416.8	1114.9	1.4	1116.3
Length actual (m)	143.1	140.6	343.2	363.5	990.4	125.9	1116.3
*Optimal – actual (m)	-40.5	-7.3	-23.5	-53.2	-124.6	+124.5	0.0
*% Difference	-22.1	-5.0	-6.4	-12.8	-11.2	-	0.0

* A positive value = over recovery (actual > optimal)
* A negative value = under recovery (actual < optimal)

APPENDIX 5

OPTIMAL AND ACTUAL VALUE RECOVERED AT SITE B.

Stem #	Length	Volume	Optimum $	Skid $	Diff.$	% Loss	Comments
1	20.4	0.98	28.09	27.78	0.31	1	
2	17.7	0.38	3.28	2.70	0.58	18	
3	13.4	0.19	1.12	0.54	0.58	52	
4	18.3	0.33	2.53	1.87	0.66	26	
5	20.7	0.65	9.04	8.51	0.53	6	
6	20.4	0.77	17.67	17.61	0.06	0	6c less than optimal
7	20.1	0.81	19.73	19.54	0.19	1	
8	21.7	0.81	18.58	17.85	0.73	4	
9	18.6	0.25	1.40	0.72	0.68	49	
10	18.7	0.65	10.65	10.58	0.07	1	
11	23.2	1.44	47.10	41.02	6.08	13	
12	19.2	0.46	4.07	3.23	0.84	21	
13	15.4	0.16	0.47	0.41	0.05	11	
14	22.0	0.76	17.70	17.08	0.62	4	
15	20.1	0.63	10.32	8.09	2.23	22	
16	17.1	0.30	2.25	1.76	0.49	22	
17	20.4	0.41	3.37	2.89	0.48	14	
18	21.3	0.60	8.14	5.45	2.68	33	
19	23.5	0.92	24.68	24.43	0.25	1	
20	22.0	0.54	7.00	4.88	2.12	30	
21	18.6	0.38	3.09	2.62	0.46	15	
22	20.4	0.46	4.17	3.62	0.55	13	
23	20.4	0.51	6.67	4.20	2.47	37	
24	18.9	0.73	15.11	16.58	0.00	0	$1.47 more than optimal
25	16.3	0.30	2.32	2.24	0.08	3	
26	18.6	0.68	17.03	14.73	2.30	13	
27	18.3	0.42	3.72	3.10	0.61	17	
28	18.0	0.46	6.25	6.14	0.11	2	
29	20.1	0.77	18.80	16.18	2.62	14	
30	19.2	1.00	28.89	28.60	0.29	1	
31	17.7	0.64	14.42	9.08	5.34	37	
32	19.8	0.82	19.75	19.54	0.22	1	
33	18.0	0.38	3.36	2.90	0.46	14	
34	21.0	0.92	21.67	21.33	0.34	2	
35	19.5	0.60	13.27	8.41	4.86	37	
36	19.2	0.49	6.69	4.21	2.48	37	
37	18.1	0.70	17.58	17.40	0.18	1	
38	20.1	0.94	26.71	26.40	0.31	1	
39	20.1	0.76	18.55	18.35	0.19	1	
40	17.5	0.33	2.43	2.43	0.00	0	optimal = skid
41	20.1	0.69	11.14	9.30	1.85	17	
42	14.3	0.16	0.47	0.41	0.05	12	
43	15.2	0.12	0.37	0.32	0.05	14	
44	18.6	0.40	3.43	3.41	0.02	1	
45	16.5	0.19	0.58	0.48	0.10	17	
46	16.6	0.23	1.31	0.59	0.72	55	
47	17.4	0.24	1.43	1.30	0.12	9	
48	18.0	0.69	16.63	16.30	0.33	2	
49	16.2	0.37	3.28	3.15	0.12	4	
50	19.2	0.64	13.68	13.51	0.16	1	
51	18.6	0.61	14.04	8.21	5.82	41	
52	18.3	0.75	18.52	18.33	0.19	1	
53	16.8	0.63	15.56	15.28	0.29	2	
54	12.8	0.29	2.43	2.42	0.02	1	
55	14.5	0.94	25.55	25.44	0.11	0	11c less than optimal
56	18.0	1.25	38.83	32.29	6.54	17	
57	18.3	0.68	15.27	15.11	0.16	1	
58	17.1	0.50	7.24	7.19	0.05	1	
59	18.9	0.43	3.85	3.65	0.21	5	
60	16.8	0.83	20.03	19.65	0.38	2	

APPENDIX 6

OPTIMAL AND ACTUAL NUMBER OF LOGS, VOLUME, VALUE AND LENGTH RECOVERED AT SITE C.

Before adjustments for out-of-specification logs					
	Saw	Pulp	Sub-total	Waste	
# of logs optimal	70	91	161	53	214
# of logs actual	59	81	140	38	178
*Optimal – actual	-11	-10	-21	-15	-36
*% Difference	-15.7	-11.0	-13.0	-28.3	
Volume optimal (m^3)	17.8	8.1	25.9	0.6	26.5
Volume actual (m^3)	16.5	9.0	25.5	1.0	26.5
*Optimal – actual (m^3)	-1.3	+0.9	-0.4	+0.4	0.0
*% Difference	-7.3	+11.1	-1.5	+66.7	0.0
Value optimal ($)	356.75	24.17	380.92	-	380.92
Value actual ($)	330.42	27.04	357.46	-	357.46
*Optimal – actual ($)	-26.33	+2.87	-23.46	-	-23.46
*% Difference	-7.4	+11.9	-6.2	-	-6.2
Length optimal (m)	312.9	478.7	791.6	67.3	
Length actual (m)	275.5	474.7	750.2	108.7	858.9
*Optimal – actual (m)	-37.4	-4.0	-41.4	+41.4	0.0
*% Difference	-11.9	-0.8	-5.2	+61.5	0.0
After adjustments for out-of-specification logs					
	Saw	Pulp	Sub-total	Waste	Total
# of logs optimal	70	91	161	53	214
# of logs actual	59	81	140	46	186
*Optimal – actual	-11	-10	-21	-7	-28
*% Difference	-15.7	-11.0	-13.0	-13.2	-13.1
Volume optimal (m^3)	17.8	8.1	25.9	0.6	26.5
Volume actual (m^3)	16.5	9.0	25.5	1.0	26.5
*Optimal – actual (m^3)	-1.3	+0.9	-0.4	+0.4	0.0
*% Difference	-7.3	+11.1	-1.5	+66.7	0.0
Value optimal ($)	356.75	24.17	380.92	-	380.92
Value actual ($)	330.42	26.94	357.36	-	357.36
*Optimal – actual ($)	-26.33	+2.77	-23.46	-	-23.56
*% Difference	-7.4	+11.5	-6.2	-	-6.2
Length optimal (m)	312.9	478.7	791.6	67.3	858.9
Length actual (m)	275.5	471.4	747.0	112.0	858.9
*Optimal – actual (m)	-37.4	-7.2	-44.6	+44.7	0.0
*% Difference	-11.9	-1.5	-5.6	+66.3	0.0

* A positive value = over recovery (actual > optimal)

* A negative value = under recovery (actual < optimal)

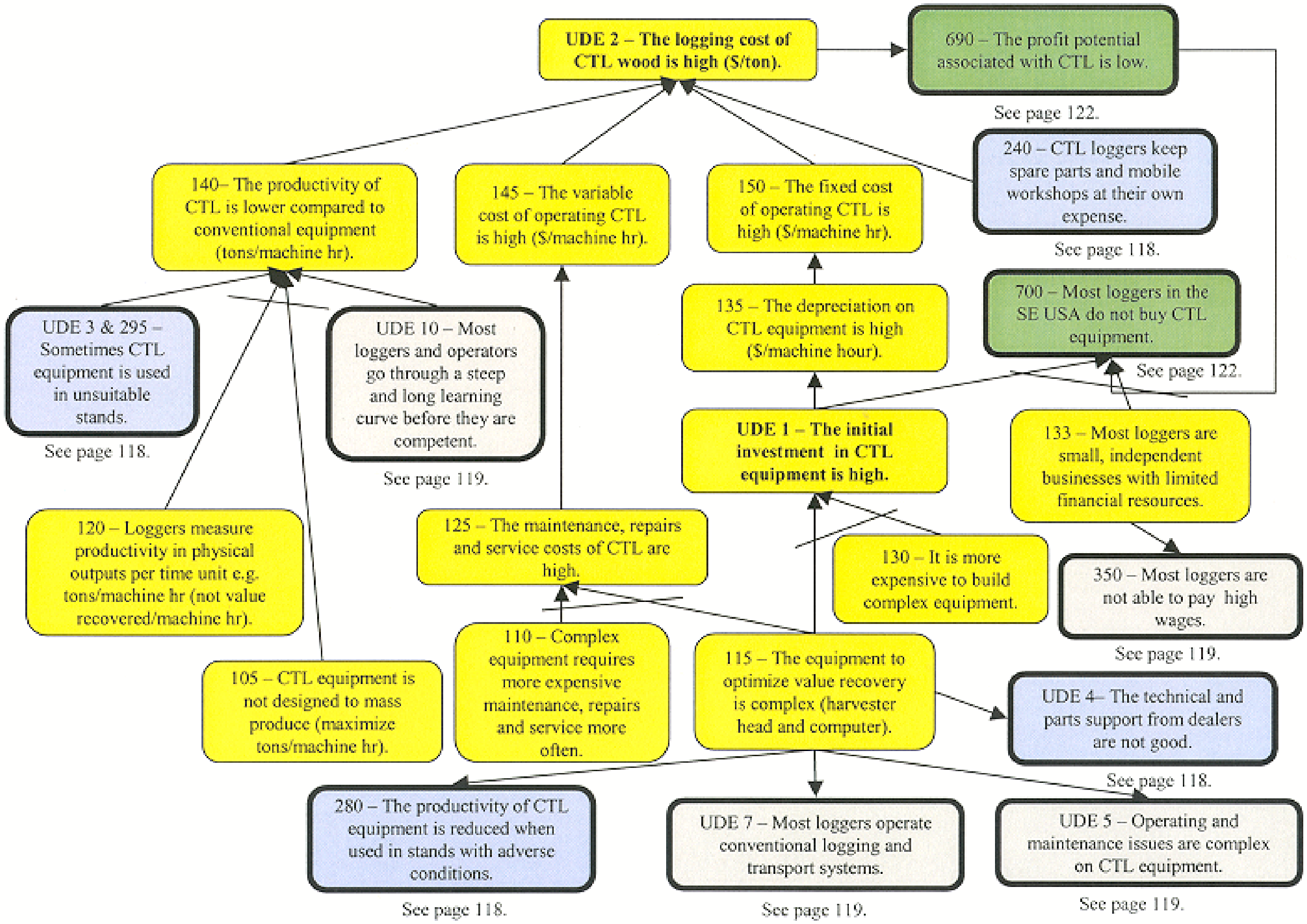
APPENDIX 7

OPTIMAL AND ACTUAL VALUE RECOVERED AT SITE C.

Stem #	Length	Volume	Optimum $	Skid $	Diff.$	% Loss	Comments
1	20.4	1.00	18.26	18.13	0.13	1	
2	20.1	0.65	10.87	9.45	1.42	13	
3	18.9	0.67	8.65	8.65	0.00	0	optimal = skid
4	17.4	0.55	8.11	5.89	2.23	27	
5	18.5	0.92	17.23	17.13	0.10	1	
6	8.2	0.09	0.22	0.22	0.00	1	
7	18.7	0.87	15.53	15.22	0.31	2	
8	17.1	0.39	1.15	1.02	0.14	12	
9	16.5	0.49	5.36	5.37	0.00	0	1c more than optimal
10	16.5	0.44	6.42	4.96	1.46	23	
11	19.2	0.54	7.68	7.63	0.06	1	
12	15.6	0.25	0.74	0.69	0.05	7	
13	14.9	0.23	0.69	0.65	0.04	6	
14	12.2	0.17	0.51	0.52	0.00	0	1c more than optimal
15	18.9	0.58	8.80	8.05	0.75	8	
16	18.8	1.25	23.71	23.51	0.21	1	
17	12.6	0.24	0.72	0.72	0.00	0	optimal = skid
18	19.8	0.99	17.65	17.89	0.00	0	24c more than optimal
19	19.5	0.68	10.62	10.62	0.00	0	optimal = skid
20	18.4	1.10	20.93	20.18	0.75	4	
21	10.6	0.17	0.49	0.50	0.00	0	1c more than optimal
22	9.2	0.32	4.17	3.82	0.35	8	
23	10.7	0.16	0.48	0.37	0.11	24	
24	10.4	0.16	0.47	0.47	0.00	0	optimal = skid
25	16.2	0.64	11.23	7.01	4.22	38	
26	11.7	0.20	0.58	0.59	0.00	0	1c more than optimal
27	12.2	0.15	0.45	0.45	0.00	0	optimal = skid
28	15.2	0.39	4.41	1.08	3.33	76	
29	15.2	0.35	1.04	0.97	0.07	7	
30	13.7	0.18	0.54	0.52	0.01	3	
31	12.2	0.13	0.37	0.38	0.00	0	1c more than optimal
32	12.0	0.24	0.71	0.71	0.00	0	optimal = skid
33	13.7	0.17	0.50	0.50	0.00	0	optimal = skid
34	18.9	0.72	12.59	11.02	1.57	12	
35	8.8	0.07	0.18	0.18	0.00	0	optimal = skid
36	11.3	0.13	0.38	0.29	0.09	25	
37	9.8	0.10	0.28	0.22	0.06	23	
38	16.4	0.36	4.17	0.97	3.19	77	
39	19.5	0.86	15.64	15.59	0.05	0	5c less than optimal
40	12.2	0.28	0.85	0.85	0.00	0	optimal = skid
41	18.3	0.88	16.24	16.24	0.00	0	optimal = skid
42	6.1	0.05	0.14	0.15	0.00	0	1c more than optimal
43	17.4	0.52	7.82	7.82	0.00	0	optimal = skid
44	5.3	0.04	0.12	0.12	0.00	0	optimal = skid
45	19.5	1.17	22.05	21.99	0.05	0	6c less than optimal
46	10.0	0.12	0.35	0.27	0.08	23	
47	6.1	0.06	0.19	0.19	0.00	0	optimal = skid
48	15.2	0.50	8.05	8.05	0.00	0	optimal = skid
49	14.0	0.20	0.58	0.56	0.02	3	
50	6.1	0.06	0.17	0.17	0.00	0	optimal = skid
51	17.7	1.71	33.57	32.51	1.06	3	
52	18.6	0.99	18.05	17.15	0.90	5	
53	8.2	0.09	0.24	0.23	0.01	5	
54	7.0	0.06	0.16	0.13	0.03	21	
55	18.5	0.92	17.23	17.13	0.10	1	
56	12.1	0.12	0.35	0.37	0.00	0	2c more than optimal
57	20.1	0.65	10.50	9.70	0.80	8	
58	15.7	0.28	0.82	0.75	0.07	9	
59	8.8	0.14	0.40	0.32	0.08	19	
60	12.2	0.17	0.51	0.52	0.00	0	1c more than optimal

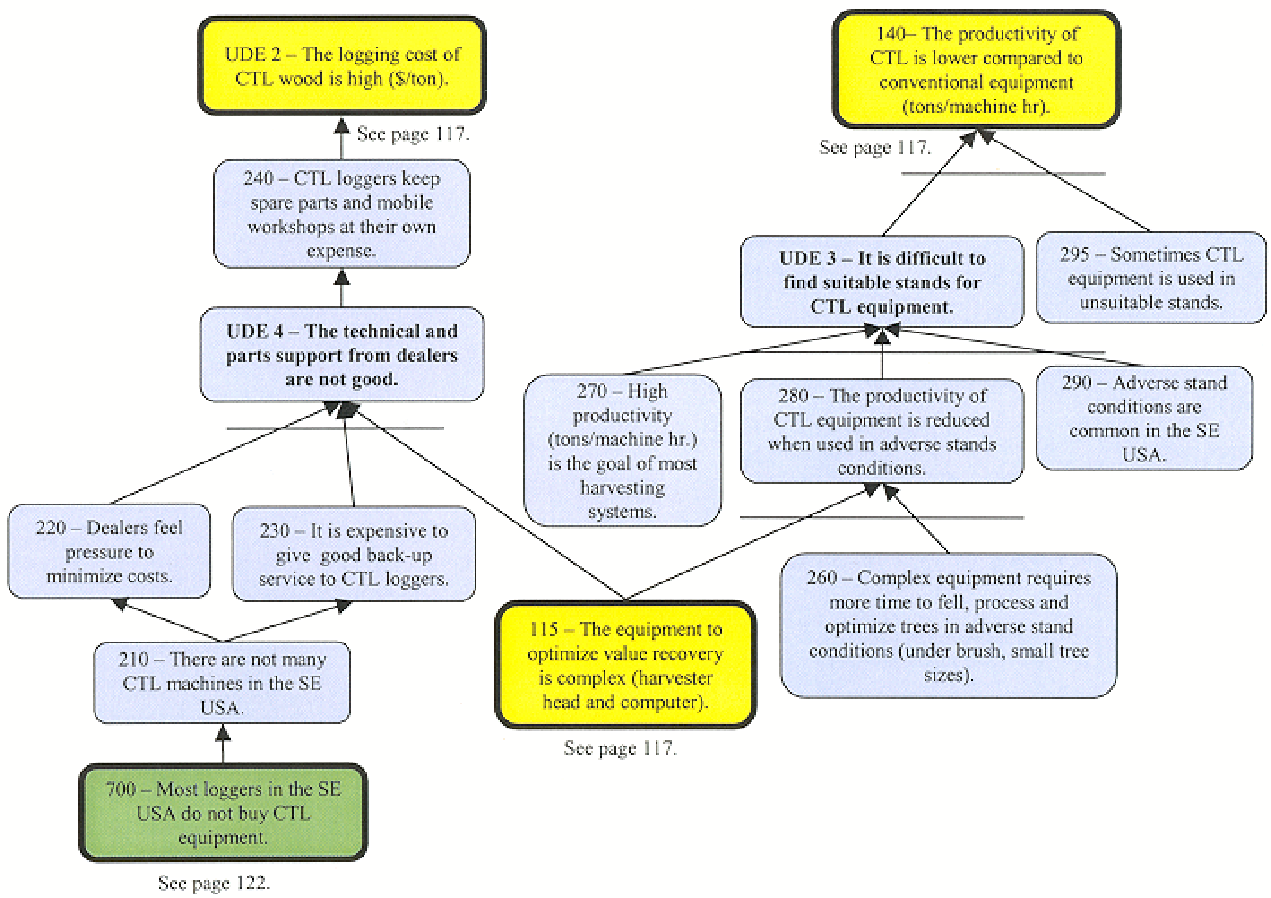
APPENDIX 8a

CURRENT REALITY TREE FOR HIGH LOGGING AND INVESTMENT COSTS.



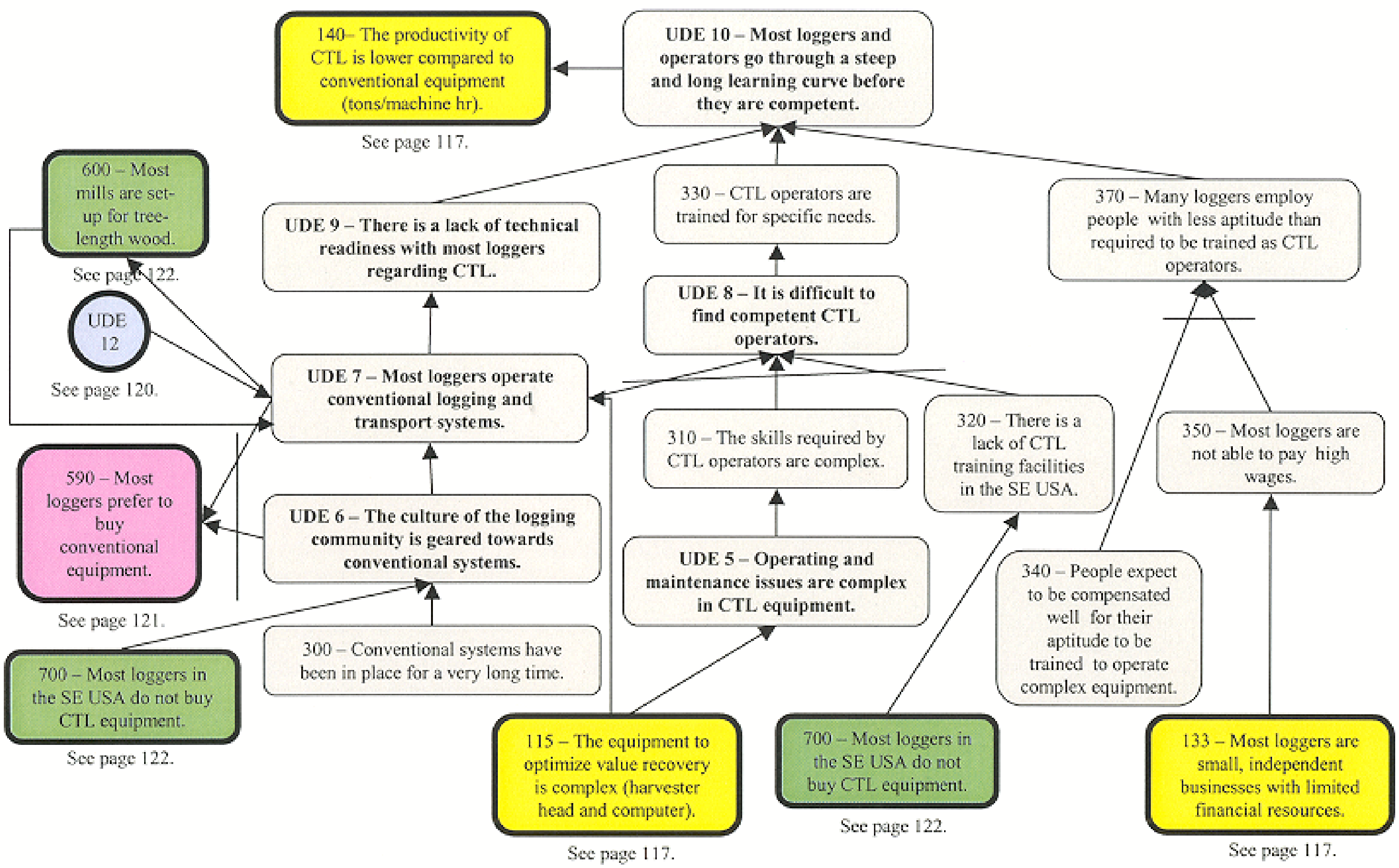
APPENDIX 8b

CURRENT REALITY TREE FOR POOR TECHNICAL AND PARTS SUPPORT, AND THE DIFFICULTY TO FIND SUITABLE STANDS.



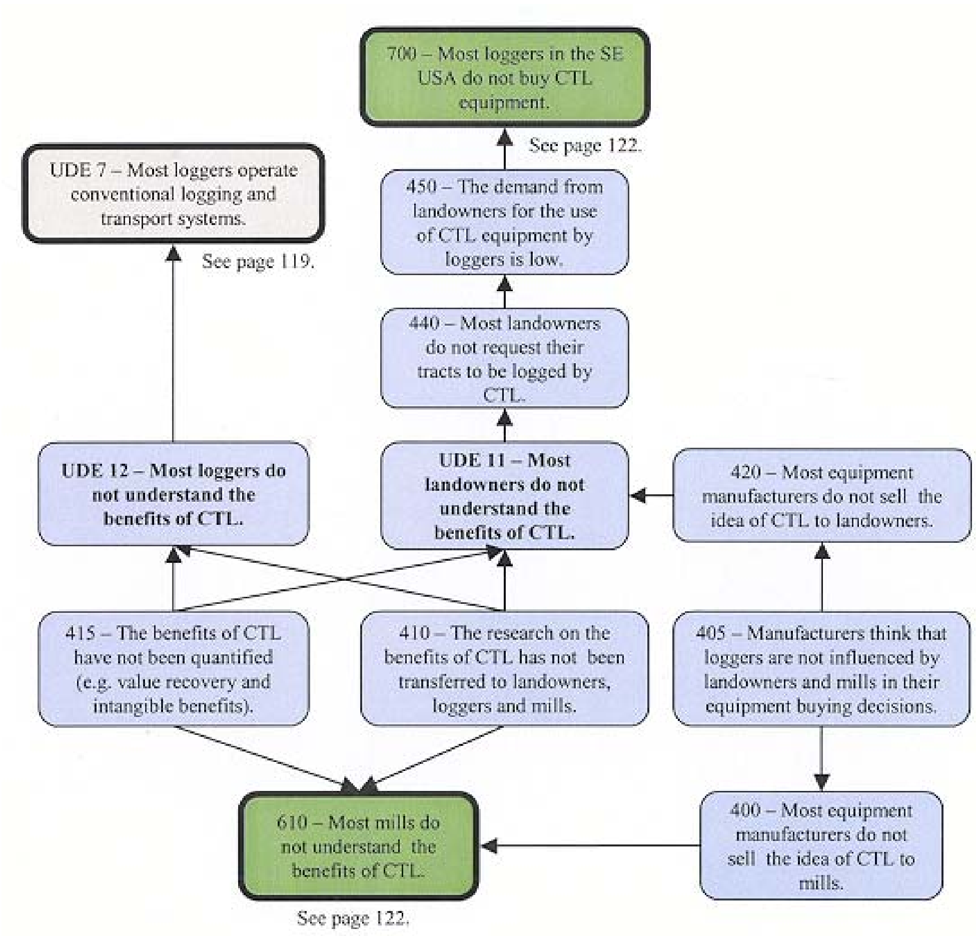
APPENDIX 8c

CURRENT REALITY TREE FOR CONVENTIONAL CULTURE, COMPLEX OPERATING AND MAINTENANCE ISSUES, LACK OF COMPETENT OPERATORS, STEEP AND LONG LEARNING CURVE, AND LACK OF TECHNICAL READINESS.



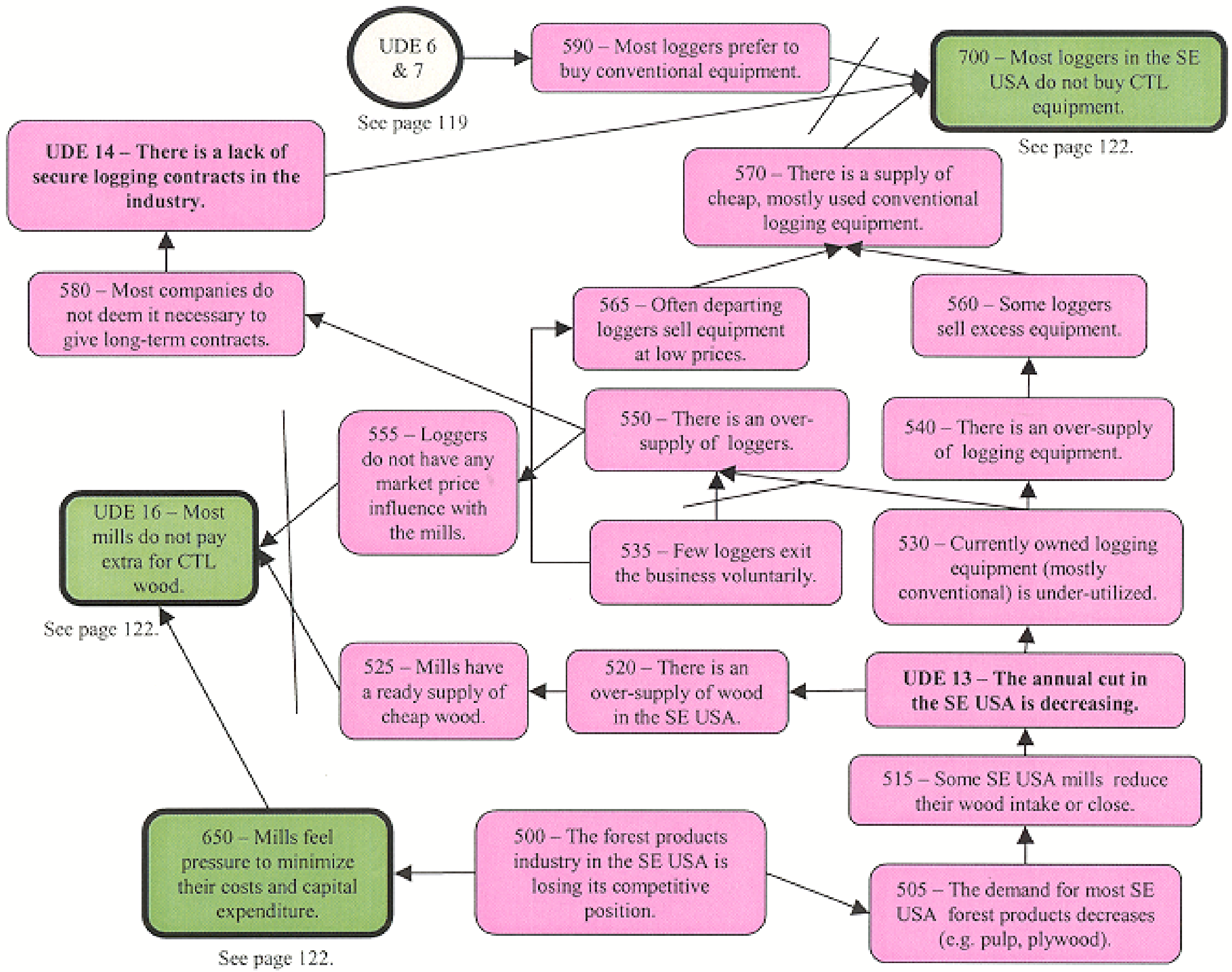
APPENDIX 8d

CURRENT REALITY TREE FOR LACK OF UNDERSTANDING OF CTL BY LANDOWNERS AND LOGGERS.



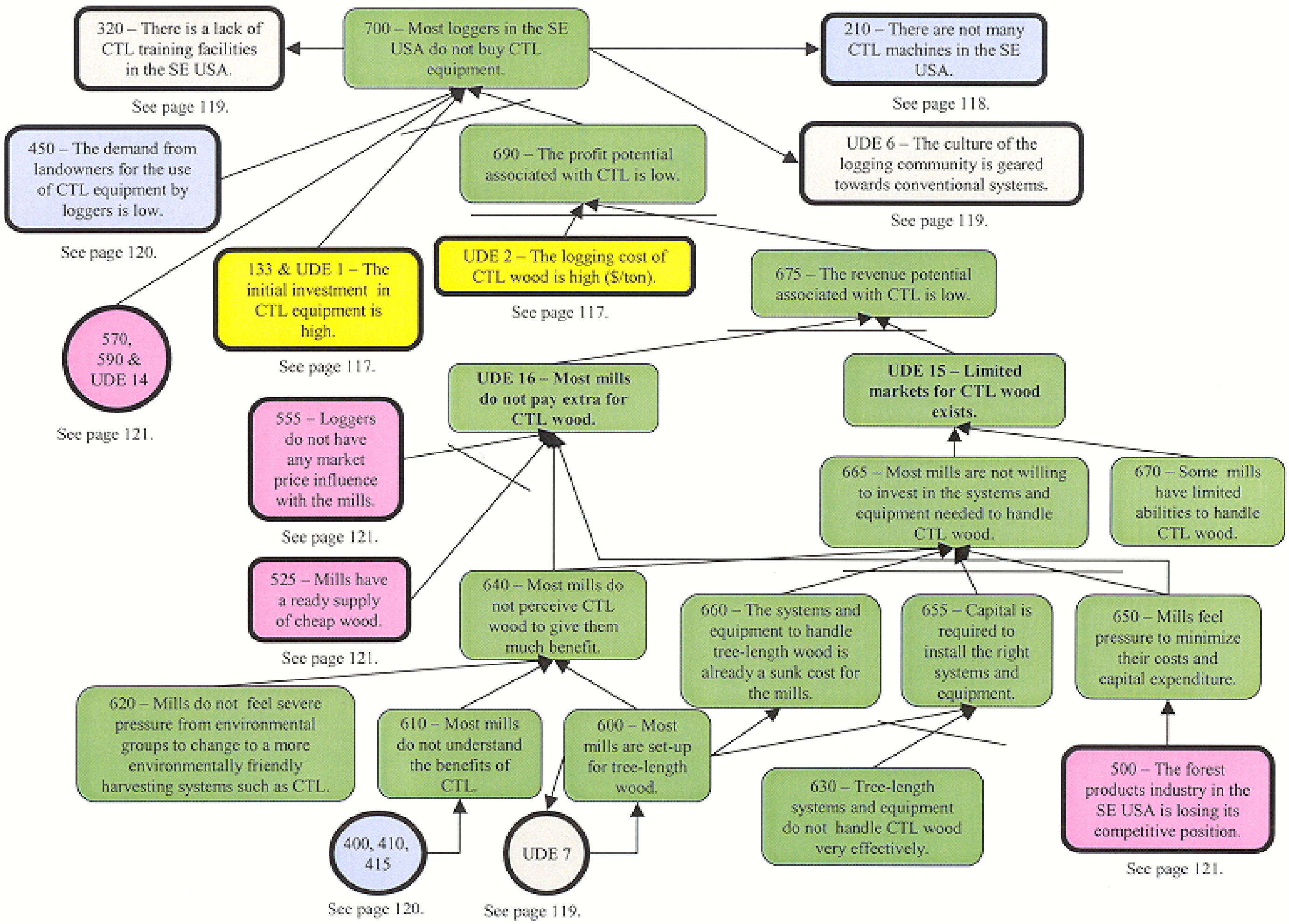
APPENDIX 8e

CURRENT REALITY TREE FOR DECREASING CUT AND LACK OF CONTRACTS.



APPENDIX 8f

CURRENT REALITY TREE FOR MILLS.



APPENDIX 9a

HOW TO READ THE CRT?

Always start at the bottom of the page with a block that has an arrow facing upwards, e.g. entity 115, **Appendix 9b**. In **Appendix 9b** one leg of the logic in **Appendix 8a and 8f** is followed through from the beginning to the end.

IF (115) the equipment to optimize value recovery is complex (the cause) AND
(130) it is more expensive to build complex equipment (the cause) THEN
(UDE 1) the initial investment in CTL equipment is high (the effect).

IF (UDE 1) the initial investment in CTL equipment is high (the cause) THEN
(135) the depreciation on CTL equipment is high in terms of $/machine hour" (the effect).

IF (135) the depreciation on CTL equipment is high in terms of $/machine hour (cause) THEN
(150) the fixed cost of operating CTL equipment is high in terms of $/machine hour (the effect).

IF (150) the fixed cost of operating CTL equipment is high in terms of $/machine hour (the cause) THEN
(UDE 2) the logging cost of CTL wood is high in terms of $/ton (the effect).

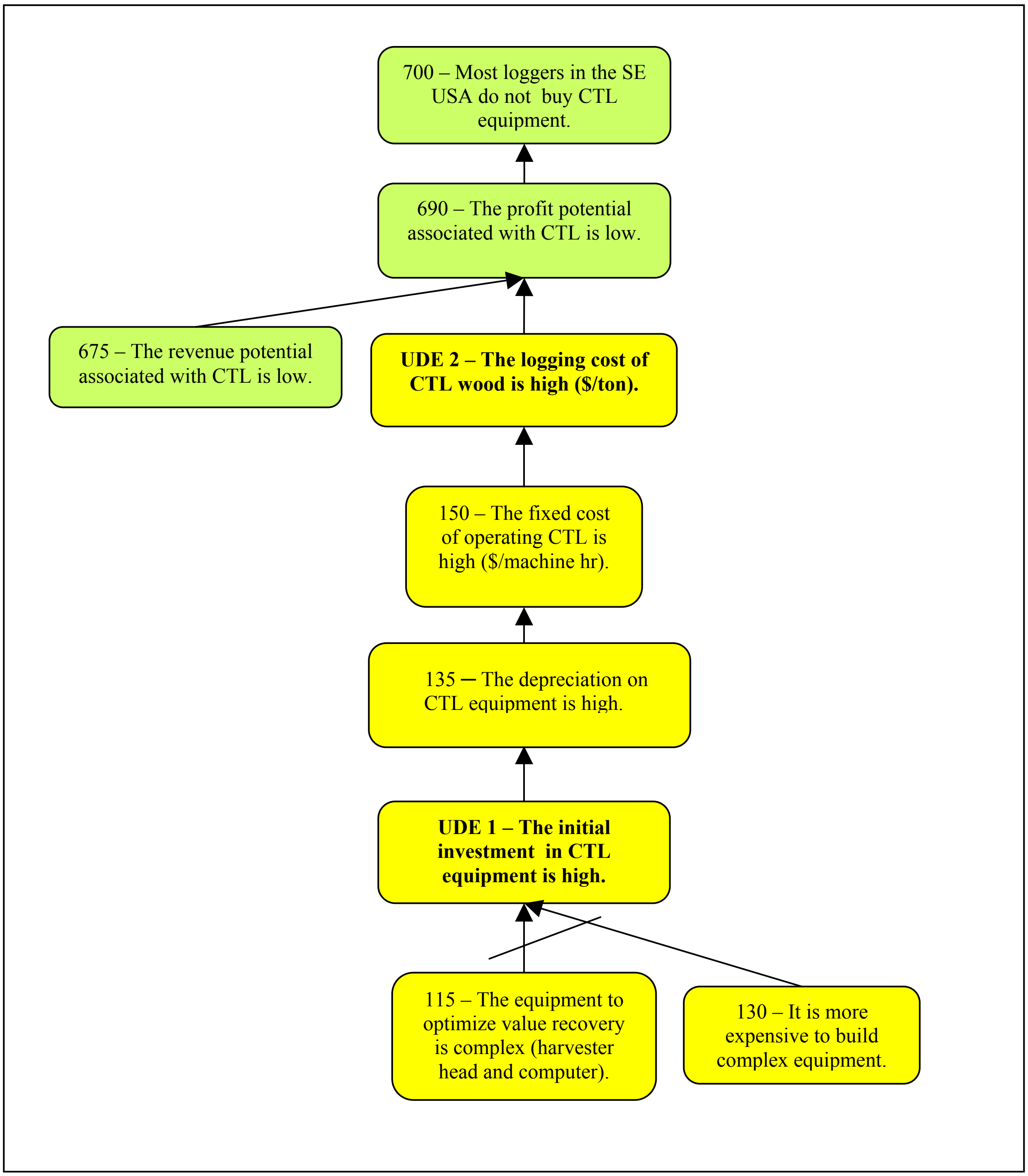
IF (UDE 2) the logging cost of CTL wood is high in terms of $/ton (the cause) AND
(675, **Appendix 8f)** the revenue potential associated with CTL is low (the cause) THEN
(585) the profit potential associated with CTL wood is low (the effect).

IF (585) the profit potential associated with CTL wood is low (the cause) THEN
(700) most loggers in the southeastern USA do not buy CTL equipment (the effect).

The previously described procedure is also followed for all the other entities, which are all ultimately connected to entity 700.

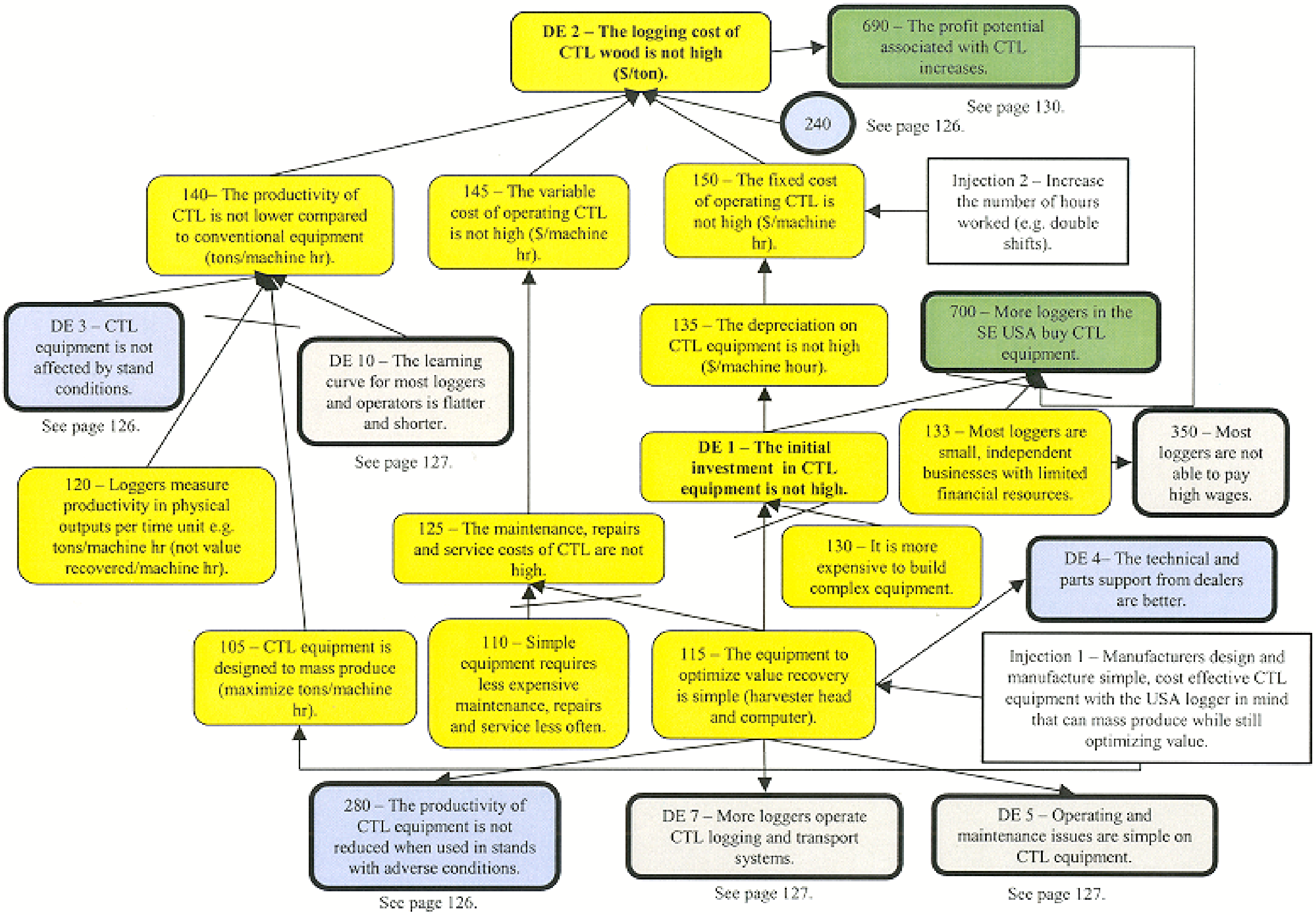
APPENDIX 9b

ONE LEG OF THE CRT FROM BOTTOM TO TOP.



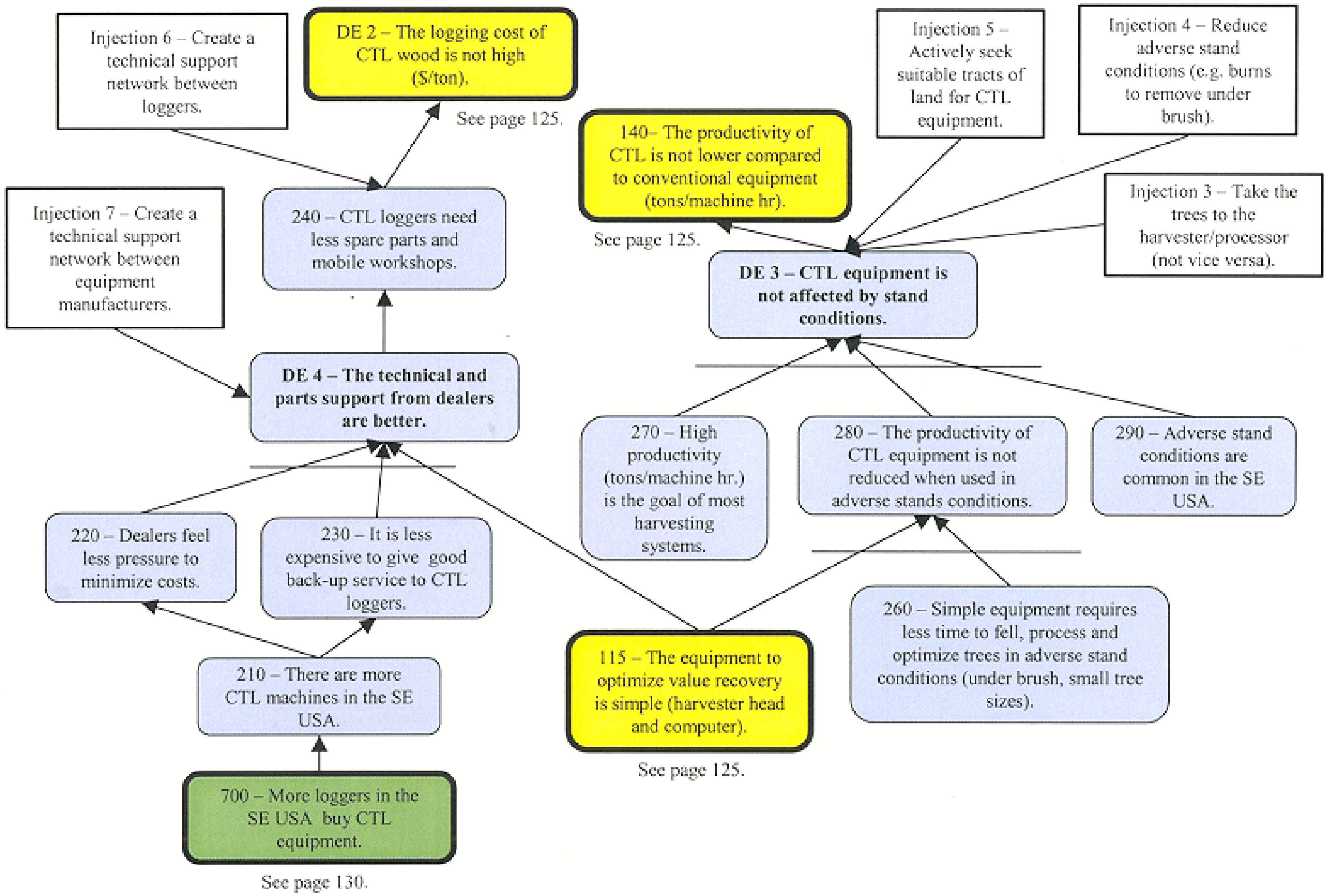
APPENDIX 10a

FUTURE REALITY TREE FOR LOGGING AND INVESTMENT COSTS.



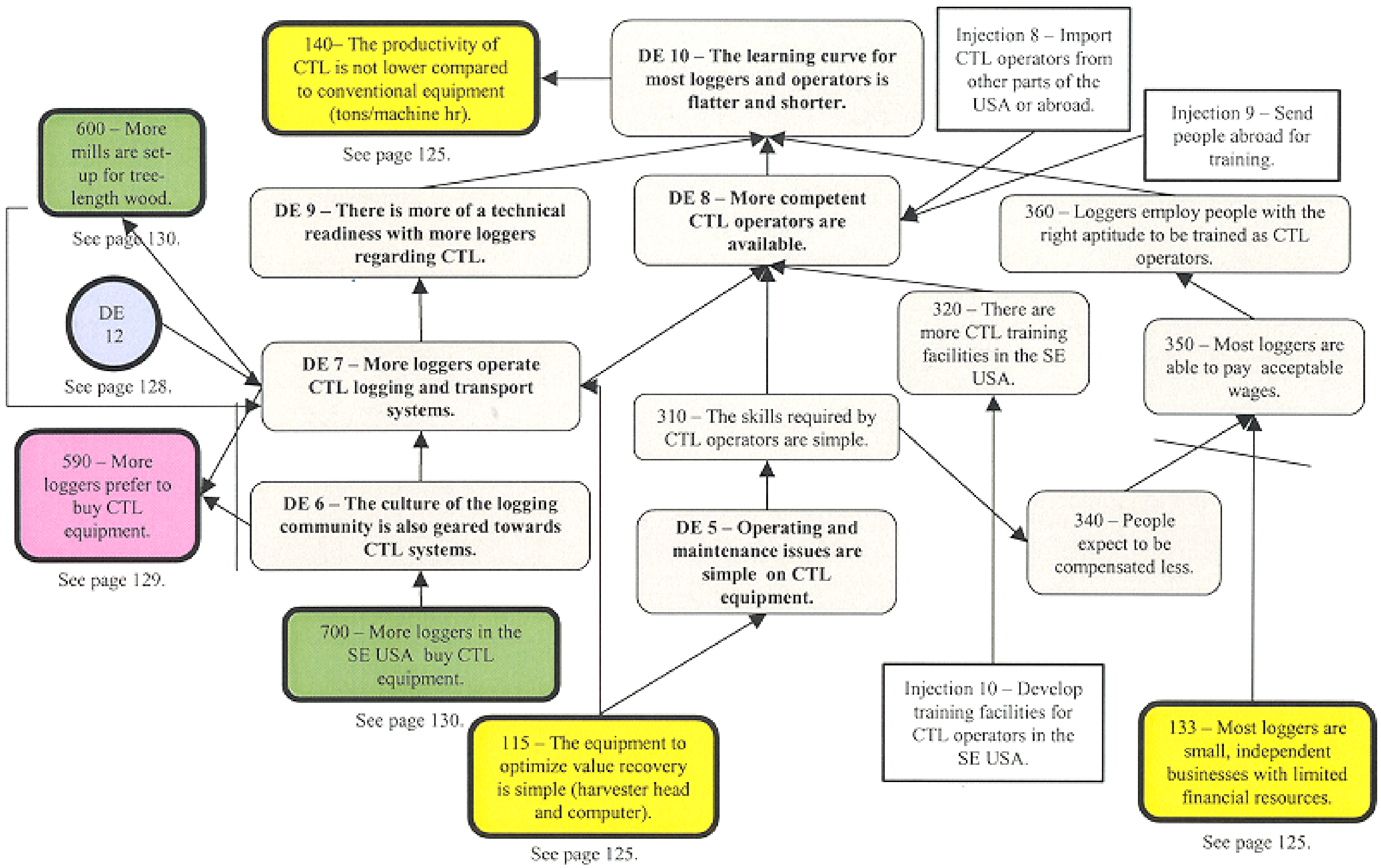
APPENDIX 10b

FUTURE REALITY TREE FOR TECHNICAL AND PARTS SUPPORT, AND STAND CONDITIONS.



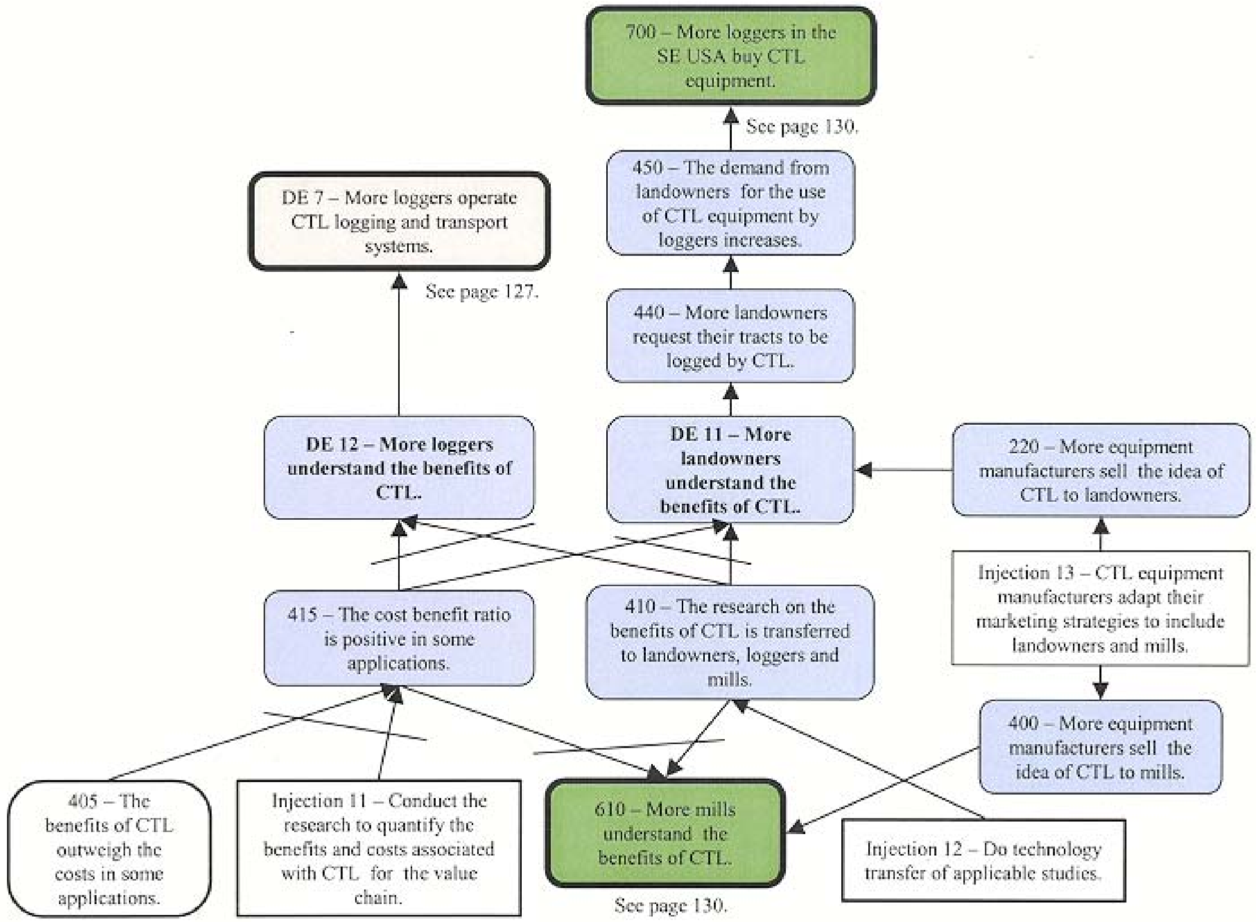
APPENDIX 10c

FUTURE REALITY TREE FOR CULTURE, OPERATING AND MAINTENANCE ISSUES, COMPETENT OPERATORS, LEARNING CURVE, AND TECHNICAL READINESS.



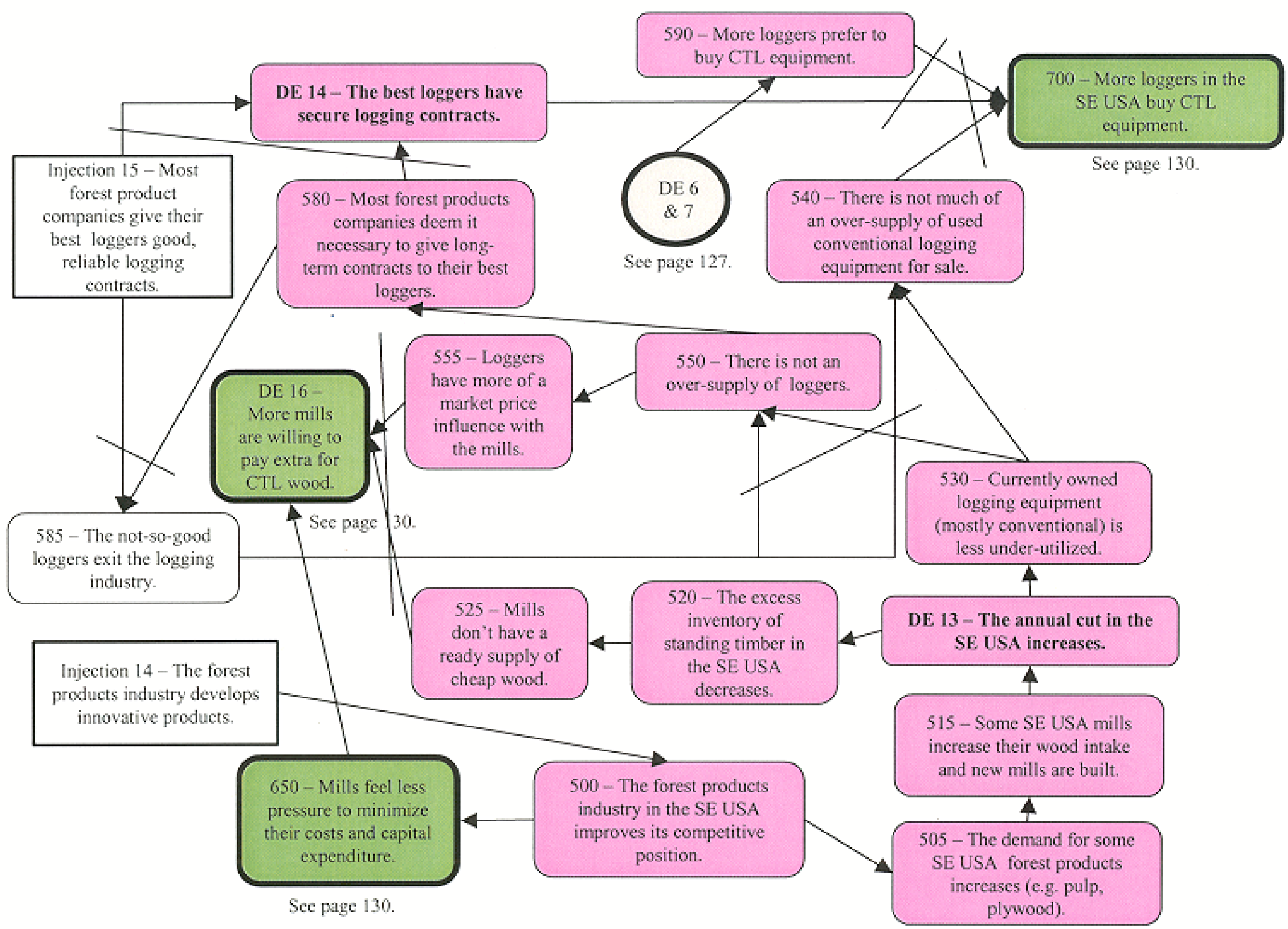
APPENDIX 10d

FUTURE REALITY TREE FOR UNDERSTANDING OF CTL BY LANDOWNERS AND LOGGERS.



APPENDIX 10e

FUTURE REALITY TREE FOR ANNUAL CUT AND SECURE CONTRACTS.



APPENDIX 10f

FUTURE REALITY TREE FOR MILLS.