Predicting Pallet Part Yields

From Hardwood Cants

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Abstract

Pallet cant quality directly impacts pallet part processing and material costs. By knowing the quality of the cants being processed, pallet manufacturers can predict costs to attain better value from their raw materials and more accurately price their pallets. The study objectives were 1) to develop a procedure for accurately predicting hardwood pallet part yield as a function of raw material geometry and grade, processing equipment, and pallet part geometry, 2) to develop a model for accurately predicting raw material costs for hardwood pallet parts as a function of yield, 3) to examine current pallet industry methods of determining hardwood cant quality, and 4) to develop and evaluate hardwood cant grading rules for use in the pallet industry.

Yield studies were necessary to accurately quantify the relationship between yield and cant quality. Thirty-one yield studies were conducted throughout the Eastern United States at pallet mills producing pallet parts from hardwood cants. 47, 258 board feet of hardwood cants were graded, and the usable pallet part yield and yield losses were determined for each grade.

Yield losses were separated into three components: kerf loss, dimension loss, and defect loss. Kerf and dimension losses are a function of raw material and part geometry and were calculated without regard to cant quality. Defect loss is dependant on cant quality and was calculated for each cant grade as a function of total yield, kerf loss, and dimension loss.

Mathematical models were developed from twenty-eight mill studies to predict each yield loss component as a function of cant dimensions, grade, and orientation, cutting bill parameters, pallet part dimensions, and kerf. Dimension and kerf losses were predicted geometrically. Regression analysis was used to predict defect loss. Results indicated that these models accurately predicted the total yield of usable pallet parts and pallet part material costs as a function of cant quality and price.

Results also indicated that the pallet industry's current method of counting the number of "bad" ends per cant bundle to determine cant quality is not adequate. The effectiveness of the proposed cant grading rules was determined by grading cants and analyzing the cant grade distributions and corresponding pallet part yields. The grade rules produced statistically different quality divisions between grades. However, a more practical single cant grade based on the minimum quality for the proposed grade 2 rules is recommended.

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My parents, Fred and Eloise Mitchell have always provided me support and love. This project is dedicated to them along with my most heartfelt appreciation.

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1.1 Research Objectives

1.1.1 Primary Objective

To develop a procedure for accurately predicting hardwood pallet part yield as a function of 1) raw material geometry and grade, 2) processing equipment, and 3) pallet part geometry.

1.1.2 Secondary Objectives

1) To develop a model for accurately predicting raw material costs for hardwood pallet parts as a function of yield.
2) To examine current pallet industry methods of determining hardwood cant quality
3) To develop and evaluate hardwood cant grading rules for use in the pallet industry

2 Literature Review

2.1 Overview

The pallet and container industry is an integral part of the United States economy. Despite often being viewed as a low-value portion of the forest products industry, pallet and container manufacturers gross billions of dollars in sales and provide over 44,000 jobs (Christoforo, 1994). Furthermore, the industry has seen steady growth since W.W.II and projections show a continuation of this trend (McCurdy, 1990).

Pallets are portable platforms used as a base for transporting and storing goods in unit form (Random Lengths, 1993). As a transportation base, a pallet will typically support a product from the production facility, through the distribution system, and finally, to the retail seller (Scheerer, 1996). During the movement of goods, pallets provide protection from shipping hazards such as improper material handling, shock, and vibration. As a load bearing structure and the base of the unit load material handling system by which most products are transported and stored, pallets improve US competitiveness internationally, safety of the workplace, and the utilization of our timber resources.

Pallets are intended to support a variety of loads in different material handling devices. While most pallets are similar in function, thousands of designs are in use. These different designs are intended to support certain load types in specific support conditions (Minister of Supply and Services, Canada, 1976). However, the Grocery Manufacturers of America (GMA) has created a reusable, stringer-style pallet system with a 48 by 40 inch dimension (Anderson, 1987). Even though this dimension pallet has become a standard production size in the hardwood industry with market share of approximately 30 percent, various other sizes are still produced. Figure 1 is a typical 48-inch by 40 inch GMA pallet.

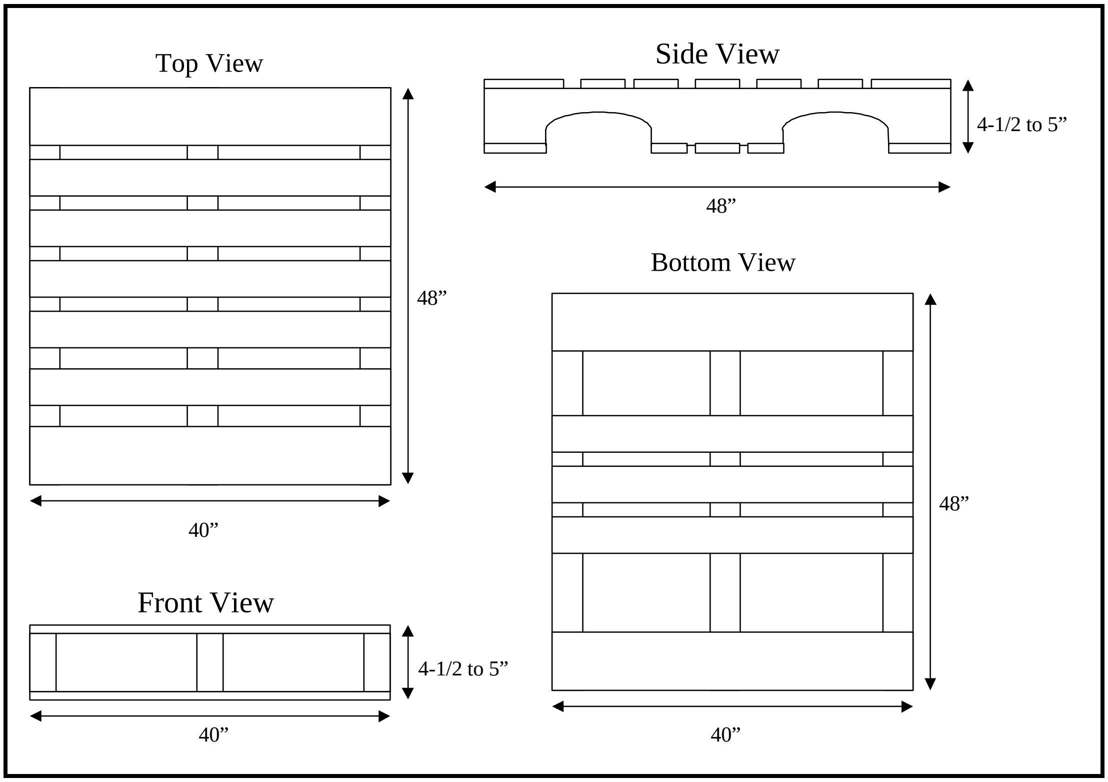


Figure 1. Schematic Diagram of 48" by 40" GMA Pallet

Obviously, pallet dimensions dictate pallet part sizes. Stringer-style pallets consist of stringers and deckboard members. Deckboards are typically sawn lumber in thickness ranging from ¼ to ¾ inches. These include top and bottom end-boards and interior deckboards of nominal six and four inch width, respectively. Stringers are members continuous over the length of the pallet that support the top deck and separate the top and bottom decks, while providing space for the entry of lifting devices (Minister of Supply and Services, Canada, 1976). They are often nominal two by four-inch members, typically 1-1/4 to 2 inches wide and 3-1/2 to 3-3/4 inches in depth. Figure 2 details the parts used in pallet design for stringer-style pallets.

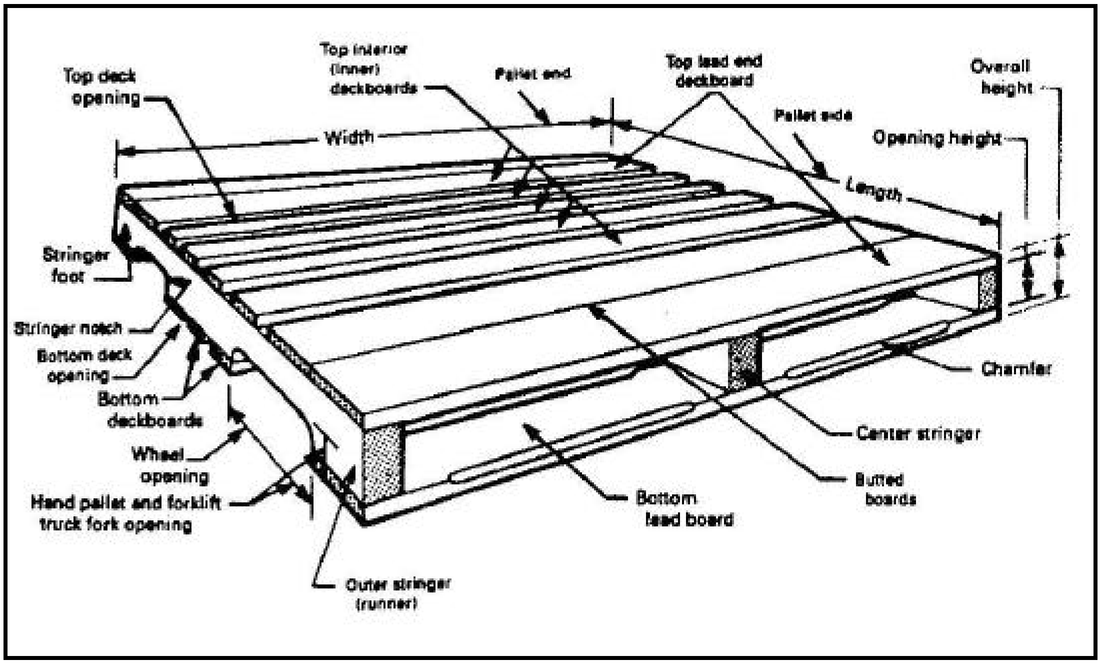


Figure 2. Schematic Diagram of Typical Stringer-Style Pallet

(Source: ASME MH1.8M – 1996)

As the single-largest consumer of hardwood in the United States, the pallet and container industry (Standard Industrial Classifications 2441, 2448, 2449) uses nearly 42 percent of the total US hardwood production (Bush, 1994). Pallet and container manufacturers consumed approximately 4.53 billion board feet of solid hardwood (lumber, cants, parts, and shooks) in 1995 (Reddy, 1997). This is a 2.3 percent decrease from 1992. An additional 1.79 billion board feet of solid softwood were used by the industry, bringing the 1995 consumption of solid-wood to 6.32 billion board feet. While pallet sales are expected to increase, projections indicate solid wood consumption in the pallet industry will continue to decline due to sales of repaired pallets. Using an average of 17.3 board feet (bf) of material per pallet, over 400 million solid-wood pallets were produced in 1995 (Scheerer, 1996).

Pallet manufacturers typically use low-grade cants as their raw material source, and the purchase price of this material is increasing. Over the last twenty years, cant prices have risen from an average of $160 per Mbf to $290 per Mbf, an increase of over

81 percent (Pallet Profile, 1979 – 1998). Pallet prices have remained relatively steady throughout the same time period. Figure 3 shows the price trends in mixed-species, hardwood cants and GMA pallet from February 1979 until May 1998.

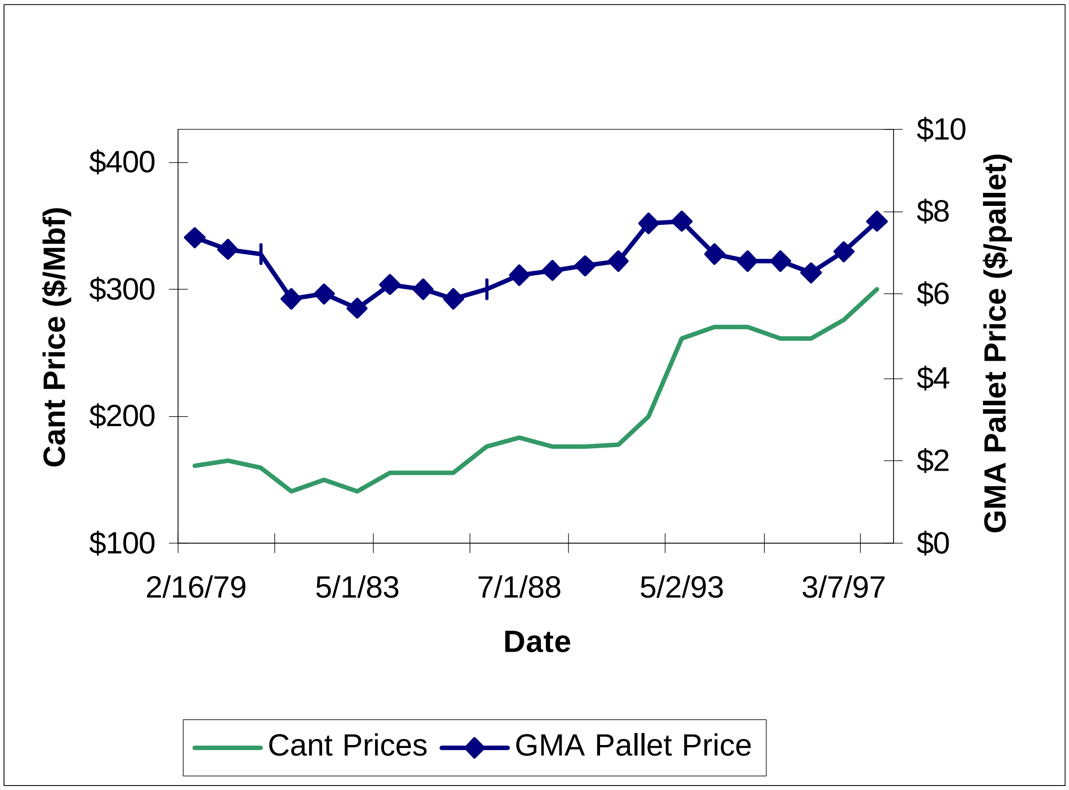


Figure 3. Historical Variation of Hardwood Pallet Costs and Hardwood GMA Pallet Prices

Recent increases in cant and pallet prices are also clearly visible in Figure 3. From April 5, 1997 to May 11, 1998, mixed species cant prices have risen from an average of $265 to $290 per Mbf (Hardwood Market Report, 1998). Cant price increases represent a nine-percent rise in raw material costs for pallet manufacturers over the last year. However, due to pallet market characteristics including increased competition, pallet prices have remained relatively stable throughout the last 20 years. Pallet manufacturers have been forced to sacrifice profit margins to offset the material price increases. As stumpage price and competition for raw material increases, the trend of rising cant prices is expected to continue.

Pallet manufacturers have lowered profit margins and raised production efficiencies to cover these costs, while hoping to stay competitive.   As these profit margins narrow, manufacturers must generate higher value from their raw material. Through better cant utilization, firms can generate higher earnings.

The pallet industry competes for raw materials with flooring, railroad ties, pulp and paper, and wood-based composite manufacturers. As the resource becomes more expensive, wooden pallet companies must find ways of becoming more efficient. The use of thin kerf band saws has helped. However, product quality may suffer as production capacity is pushed. Specifically, sawing variation may increase with thin kerf sawing (White, 1994).

Accurate assessment of pallet cant value will be a necessary prerequistite for improving processing efficiencies. In 1995, the industry used approximately 3.87 billion board feet of hardwood cants and lumber (Reddy 1997). Nearly 70 percent of all hardwood consumed in the industry was in cant form. Since the quality of pallet cants vary significantly and cant quality directly affects pallet part yields, both cant prices and quality affects the costs of producing pallets. Understanding yields as a function of cant quality could lead to a rational method of determining pallet cant value.

2.2 Related Studies

2.2.1 Quality Pallet-Part Yields from Red Oak Cants
(Witt, 1972)

This 1972 master thesis by E. Michael Witt examined the yield and quality of pallet parts produced from red oak cants. 114 four-inch by six-inch cants were manufactured from factory graded logs of lengths eight, ten, and twelve feet. The cants were then resawn on a circular headrig into nominal 1” X 4” or 6” lumber and graded according to the National Hardwood Lumber Manufacturers’ lumber grades. These boards were subjected to crosscutting simulations to compare the effect of gang versus select crosscutting techniques. The resulting 40- and 48-inch simulated pallet parts were then classified into two quality classes based on the US Forest Service’s pallet part grading rules. Quality part yields were then determined for each crosscutting method for lumber grade and cant length.

The objectives of the study included quantifying pallet part yields from red oak cants and evaluating the impacts on yield from crosscutting methods. While not mentioned as an objective, the research examined the cost feasibility of utilizing cants for pallet part manufacturing.

Total yields for each cant length and crosscutting technique were determined. However, due to the manufacturing techniques and thick saw kerfs used in the study, the data cannot be used to determine the value of cants being sawn today. Technological improvements have drastically increased potential yields and the component sizes being produced have changed.

Gang crosscutting, 12’, 10’, and 8’ cants yielded 45, 37, and 29 percent, respectively. Select crosscutting increased the yields to 48, 39, and 31 percent, respectively. Cant length and crosscutting technique greatly impacted pallet part yields. Longer cants and select crosscutting seemed to provide higher material returns. Based on then current publications about part yields from lumber, the author predicted that “from the relatively low yield recoveries of this study and current raw material costs, it appears that the best source of quality class pallet-part material for pallet producers may be graded red oak lumber, rather than low yielding 4- by 6-inch red oak cant material.”

Compared to current manufacturing techniques, the part yields from the study seem to be quite low. This is in part due to the use of nominal dimensions. New processing equipment and raw material costs and availability have driven the pallet industry to the use of cants as their primary raw material source. The use of pallet cants has helped sawmills reduce production costs and allowed pallet manufacturers access to increasing difficult to find low-grade hardwood.

2.2.2 Yield Of Pallet Cants and Lumber from Hardwood Poletimber Thinnings

(Craft and Emanuel, 1981)

This 1981 research paper by E. Paul Craft and David M. Emanuel of the US Forest Service examines the yield of 4” X 4”and 4" X 6”pallet cants cut from poletimber thinnings in West Virginia. The study quantified cant yields from timberpoles and employed a cant grading system.

The poletimbers were cut into bolts that were required to have a six-inch minimum diameter and length of at least 4 feet. The bolts were then sawn into 4”X 4” and 4" X 6”pallet cants. Yields were calculated as a function of initial bolt volume from the produced cants and lumber.

The cant and lumber yields from the bolts ranged from 45 to 55 percent. Yields were highest for six-inch wide cants. The authors concluded that a cant grading system warranted further research in order to determine usable pallet part yields from cant grades. The cant grading system used in this study appears to be too complex and impractical for use by the pallet industry.

2.2.3 Quality Distribution of Pallet Parts from Low-Grade Lumber

(Large and Frost, 1974)

This 1974 US Forest Service research by Hollis Large and Richard Frost investigates the quality of pallet material produced from low-grade lumber (2 common and lower). Additionally, the impacts of species and cutting method on pallet part quality were examined.

The study randomly selected nearly 18,000 deckboards from mills throughout the eastern US. The pallet parts were then classified into 5 grades according to the National Wooded Pallet and Container Association pallet part specifications.

The researchers found that low-grade lumber produced sufficient amounts of high quality pallet parts. Gang crosscutting methods on 3A Common lumber (the predominant pallet lumber grade in the study) yielded 42 percent of Grade 2 and higher pallet parts. The selective crosscutting method yielded 58 percent of Grade 2 and higher pallet parts. This showed that selective crosscutting provided significantly higher yield returns than gang crosscutting techniques. However, there appeared to be no difference in yield between selective and gang ripping methods. Additionally, there seemed to be a significant difference in the pallet part quality distribution cut from different grades of lumber. Lastly, species appeared to have no effect on quality distribution.

As intended, this research provides information about pallet part quality distribution. However, the study does not provide for yields as a function of raw material inputs. Also, new processing equipment and techniques, the dominant use of pallet cants as raw material sources, and the increased competition for low-grade hardwood warrants additional research on this subject.

2.2.4 Pallet Manufacturing Costs

(Yaptenco, Harold, and Wylie, 1968)

In 1968, Rudolfo Yaptenco, Monte Harold, and Aubrey Wylie of Michigan State University performed a pallet production simulation to study the pallet yield, processing time as a function of raw material sizes, and productivity as a function of processing centers. The study focused on the efficiency differences between the use of cants and bolts. Bolts were defined as logs cut to pallet part length (36, 42, 48, 54, and 60 inches) with a diameter of greater than four to five inches. Cants were assumed to vary in size with four inches being the minimum width.

A single plant was used for the study, which had the capacity for processing logs, cants, bolts, or dimension stock. Pallet part yield was studied from the initial raw material source to pallet "slat" formation. Deckboards with the dimensions ½-inch by 5-1/2-inches were adopted as the standard production size.

The first step in the study process was to fix raw material "piles" of 100 cubic feet. 837 bolts were separated to produce ten material groups, while 686 cants were used to produce another ten material bundles. The material was then processed, and the yields and processing times for each group was calculated.

The results of the study followed the predictions of the researchers. Bolts resulted in a much lower ratio of raw material costs to pallet production costs. Specifically, bolt costs consisted of about 35 to 40 percent of the cost for producing deckboards, while cant cost were much higher at 75 percent. However, bolts required more processing time and costs. Additionally, the number of bolts and cants per unit had a greater effect on production cost than did unit length. This means that larger cross sectional area in the raw material produced higher yields and less processing time. Lastly, the major difference in cost elements between bolts and cants was in the raw material purchase price. The saving from buying raw material in bolt form outweighed the additional processing costs.

While this study provides sound statistical analysis and adequate study methodology, bolts are rarely used in the production of pallets. This study fails to analyzes yields as a function of cant dimension, pallet part dimension, and processing equipment.

2.3 Justification and Rationale

In "price taker" markets, successful firms are the low cost producers, and pallet manufacturers are no exception. The pallet market operates under nearly perfect competition. There are many, small producers of solid wood pallets, so competition tends to dictate sale prices (Smith, 1996).

The single largest cost in pallet production is raw material costs. These costs account for over 60 percent of the costs associated with producing wood pallets (White, 1997). Furthermore, cant costs account for 75 percent of the costs associated with producing pallet parts (Yaptenco, 1968). This means that reductions in pallet manufacturing costs are best achieved through control of raw material costs. The costs of raw materials include purchase price and processing cost per unit volume of parts produced.

In the last two decades, cants have replaced lumber as the primary raw material source for hardwood pallet manufacturers. Pallet costs are therefore directly related to cant costs and quality.

As cant costs increase, so do the costs to produce pallets. As previously mentioned, from April 5, 1997 to May 11, 1998, mixed species cant prices have risen from $265 to $290 per Mbf (Hardwood Market Report, 1998). Thus, cant price increases have meant a nine-percent rise in raw material costs for pallet manufacturers over the last year. As stumpage price and competition for raw material increases, the trend of rising cant prices will continue.

Despite the direct correlation between cant prices and production costs, pallet producers often have limited knowledge of raw material value. Typically, pallets are priced according to what the market will bear. This means that pallet companies may be unaware of their operating margins. These firms need the ability to accurately estimate the value of their raw materials.

Cant value is a function of the value of the parts sawn from the cant and the costs of processing the cant. Increased part volume and decreased processing costs provide for a higher return in cant value. Both part value and processing costs are a function of yield. Higher yield provides increased part volume and decreased processing costs. Thus, pallet part yield determines cant value. Table 1 shows the relationship between cant quality, yield, and part value. As cant quality decreases, yield decreases. In turn, the raw material cost for producing each pallet part increases.

Table 1. Pallet Deckboard Costs as a Function of Hardwood Cant Grade

Cant Grade	Cant Volume (bf)	Part Volume (bf)	Salvage (bf)	Yield (%)	Deckboard Cost (per bf)	Deckboard Cost (9/16 X 3-1/2" X 40")
1	719	555	18	80	$0.37	$0.20
2	129	76	4	58	$0.48	$0.26
3	187	46	37	25	$0.95	$0.52

As seen in Table 1, deckboard cost increases from $0.20 to $0.52 as cant grade declines from grade 1 to grade 3, respectively. The cost per board foot also reflects the decline in cant quality. As cant grade worsens from 1 to 3, part cost per board foot increases from $0.37 to $0.95. Cant quality directly impacts yield and part costs.

To evaluate cant quality, most pallet manufactures simply inspect the ends of the cants. This inspection often takes place as the cants are being delivered to the pallet mill. Typically, the number of "bad" ends per cant bundle must fall below a certain percentage to meet the quality criteria for the mill.

A manufacturer in North Carolina inspects each cant bundle as it is delivered to the mill. For this manufacturer, a bad cant end is "not square on all four corners (usually caused by wane) and/or contains unsound defects." After inspection, the number of bad ends per bundle is compared to the total number of cants ends. The mill will reject any cant bundles that contain more than 20 percent bad ends and return them to the cant supplier. While this inspection allows for some cant quality assessment, the ends of a cant only represent a small portion of total cant volume. This pallet manufacturer noted that his suppliers are aware of the quality inspections and often place low quality cants in the center of the bundles or paint the cant ends to make them more difficult to detect.

Pallet manufacturers must be able to better determine the quality of their raw material. Since cant quality directly impacts yield, knowing the quality of the cants being processed will help pallet manufacturers more accurately predict processing and material costs. Pallet manufacturers can then use these predicted costs to attain better value from their raw materials and more accurately price their pallets.

3 Experimental Methods

3.1 Overview

Yield studies were necessary to accurately predict pallet part yields, create applicable cant grading rules, and assess the pallet industry's current methods for evaluating raw material quality. To accurately predict pallet part yields, the relationship between yield and pallet part raw material quality must be determined.

Pallet part yield is the ratio of part and salvage (for future use) volume to raw material volume. This definition relates all usable material volume to total raw material volume. The difference between total and usable material volume is determined by the production process and cant quality. Material that is not usable is referred to as yield loss.

Yield loss was separated into three components: kerf loss, dimension loss, and defect loss. Kerf and dimension losses are a function of raw material and part geometry and can be calculated without regard to cant quality. However, defect loss is a function of cant quality and must be measured.

The effectiveness of the proposed cant grading rules were determined by grading cants and analyzing the cant grade distributions and corresponding part yields. Proper cant grading rules provide significant yield differences between grades. In turn, the effect of grade dependant yield justifies price differences between grades and the use of the cant grading system.

To assess the pallet industry's current methods for evaluating raw material quality, the results of the current quality evaluation technique of counting bad ends to cants were compared the total part yields produced from the analyzed cants. A weak correlation between the percentage of bad ends and total part yield indicates inadequacy in the technique of counting bad ends to access cant quality.

3.2 Mill Site Selection

Processing data was collected from hardwood pallet mills throughout the central and eastern regions of the United States. In order to account for pallet material and processing diversity, a convenience sample of 31 mill studies was selected. This sample size ensures a distribution of processing equipment and cant and part characteristics that are influenced by market variations. Specifically, study mills included circle and bandsaw manufacturing of deckboards and stringers.

For convenience, a higher concentration of sites was chosen in Virginia and North Carolina. Mills were then randomly selected from the North Central, South Central, and Mid-East and the remaining South East regions. While no mill studies were exact duplicates of part and cant dimensions, three studies were performed at the same mill site. These three studies includued different cant and part dimensions. Since several mill managers requested that their processing equipment and raw material information not be divulged, each mill was assigned a number. Mills 1 through 28 were used for prediction analysis. Mills 29, 30, and 31 were used to verify and evaluate yield and costing procedures. Figure 4 shows the random mill site distribution by state throughout the Eastern United States.

Figure 4. Locations of Pallet Mills by Mill Study Number

Figure 4 lists the state in which the mill is located and the mill study numbers performed in the state.

Table 2. Mill Studies by State

State	Mill Number
Alabama	1, 12
Arkansas	11
Georgia	7, 23, 27
Illinois	13
Indiana	5
Kentucky	30
Louisiana	26
Michigan	9, 24
Mississippi	4
North Carolina	15, 18
Pennsylvania	2, 14, 22, 25
South Carolina	3
Tennessee	29
Virginia	6, 8, 16, 17, 19, 20, 21, 28, 31
West Virginia	10

3.3 Data Collection

Hardwood cant were sawn into pallet parts at each site. To ensure that data properly represented diversity in cant and part sizes, the studies were performed using the cant and part sizes that the mills were scheduled to cut at the time of the study. As the first step of the study process is to grade the cants to be processed for the study, cant size selection was not determined until arrival at the mills. By viewing the cutting bill for the days part requirements, the plant managers were asked to estimate what cant size their cut-up lines would be processing in about an hour. The hour delay between production scheduling of different cant sizes permitted for the grading of the cants prior to processing. By grading the cants prior to processing, study related production delays at the mills were avoided.

Two bundles or approximately 2000 bf of cants were graded for each study. The cant bundles were usually selected by the forklift operators at the mill sites. They were instructed to choose two cant bundles without regard to appearance. The cants were then separated into three grades using the proposed cant grading rules in Table 3. These rules were prepared by White, 1989 and represent a three-level partitioning of the range of cant quality observed during previous mill studies. Two people were required to separate and re-stack the cants.

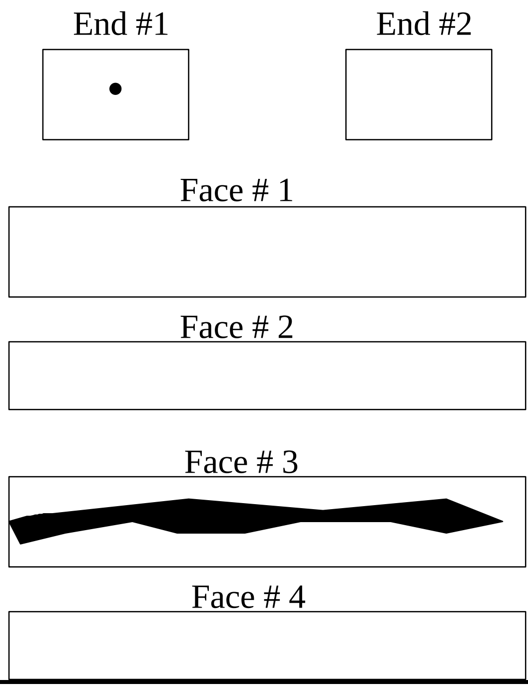
Table 3. Proposed Grade Rules for Hardwood Cants

Pallet Cant Grade	Grade Description		
	Percent of Unsound Wood	Faces	Ends
1	0 – 15 %	3 faces sound 4 faces sound	1 end sound no sound ends
2	16 – 30 %	2 faces sound 3 faces sound	1 end sound no sound ends
3	Over 30 %		

- Grade decisions should be made using percent unsound rules when internal defects govern cant quality.
- Unsound wood includes splits, wane, shake, insect holes, rot, and decay (not drying checks).
- A sound face or end contains 90% of the face area in sound wood.

Hardwood cants were graded by first determining the extent of internal or volumetric defects such as heart rot, decay, shake, and splits. If these defects were substantial enough to render more than 30 percent of the cant volume unsound, the cant grade was then based on the percentage of unsound cant volume. A cant with 15 percent or less unsound volume was assigned a preliminary cant grade of one. Cants with 16 to 30 percent unsound were assigned a preliminary grade of two, and cants with more than 30 percent unsound volume were graded as number three. Cants receiving the primary grade of one or two were then further graded by examining the cants' two ends and four faces. A cant end or face was determined to be sound if it contained more than 90 percent of it's area as sound wood. Unsound wood in end and face grading included splits (except drying related end splits), wane, shake, insect holes, and decay. The number of sound ends and faces were then determined and final grades were assigned to the cants. Figure 5 and Figure 6 depict the cant grading process for a grade 1 and grade 3 cant.

Cant Grading Process



Grading Steps

1. Determine % unsound volume
   - less than 15%

2. Determine preliminary grade
   - Grade 1

3. Determine number of sound ends and faces
   - three sound faces (face # 3 is unsound)
   - two sound ends

4. Determine final cant grade
   - Grade 1

Figure 5. Schematic Diagram Showing Allowable Defects in a Grade 1 Hardwood Pallet Cant

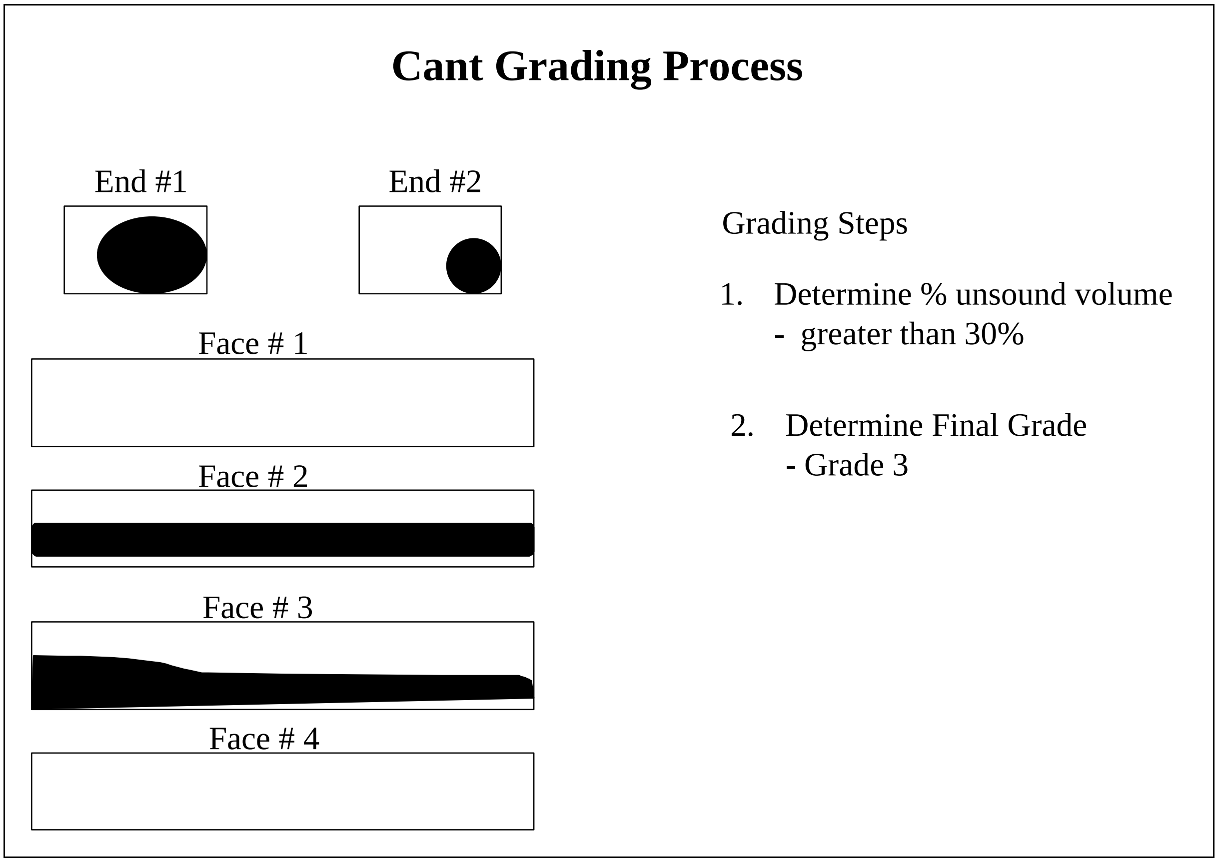


Figure 6. Schematic Diagram Showing Allowable Defects in a Grade 3 Hardwood Pallet Cant

As the cants were graded, they were then placed into graded stacks, one stack for each grade. Figures 7, 8, and 9 show typical hardwood pallet cants of grades 1, 2, and 3, respectively.

Figure 7. Typical Grade 1 Hardwood Cants

Figure 8. Typical Grade 2 Hardwood Cants

Figure 9. Typical Grade 3 Hardwood Cants

Once the cant grading process was completed, the following information was recorded:

1. Cant thickness (to the nearest 1/16")
2. Cant width (to the nearest 1/16")
3. Cant length (to the nearest foot)
4. Number of cants per grade
5. Number of unsound cant ends per grade

Cant thicknesses and widths were recorded as average values due to cant variation. Thus, if cant thickness ranged from 3-7/8" to 4-1/8" per study, a thickness of 4" was assumed for the entire study. Studies performed with random width or length material required the width or length of each cant to be recorded for volume calculations.

Next, the cants were sent to the processing lines. To prevent contaminating the study with material from other production runs, previously manufactured parts and raw material not related to the study were removed from the processing line. Inspection of the processing line was required to locate material salvage areas. Salvaged material included cant sections and parts that were pulled from the production run to be further processed at a later time. It was necessary to accurately track material flow to the salvage areas for data collection.

At this point in the data collection, the cants had been sorted into their corresponding grade stacks. Each grade stack was then processed individually to allow for grade based part yielding. In each study, cants were first crosscut to length using a single-blade trim saw. Figure 10 was taken during a mill study. The picture shows a grade 1 cant entering the trim line.

Figure 10. Hardwood Cants Entering the Trim Line of a Pallet Part Sawing System

During this stage of processing, cants are typically defected, cut to part length, trimmed to cant salvage length, and/or unusable cant sections were culled. Figure 11 shows a typical combination of section cross-cuttings.

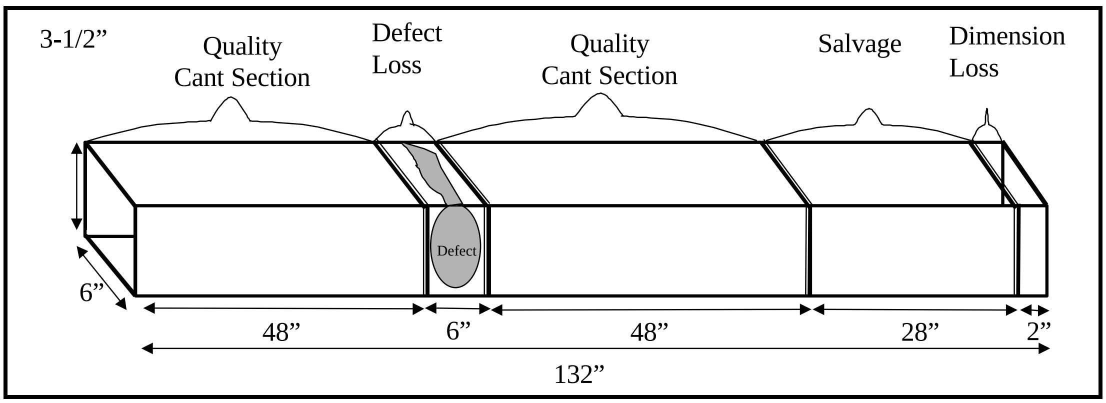


Figure 11. Schematic Diagram Showing Typical Defect and Dimension Trim Losses in Hardwood Pallet Cants

Figure 11 shows defect loss and dimension loss cant sections were discarded during processing. Typically, these cant portions are sent directly to a hog or chipper. After the unusable cant sections have been removed, the quality cant sections now cut to length continue through the processing line. Cant salvage material was pulled from the line and typically stacked for processing at a later time. This material was free from major defects, but cut to length not desirable for immediate processing. Often, manufacturers cut salvaged cant material to different part sizes than those used for the study.

For example, if the cutting bill used during the study called for part dimensions of 9/16" X 4" X 40" and the salvaged cant material had been trimmed to a length of 32", the manufacturers would often store the material until parts of 32" in length were needed. The 32" long parts may not be required in 9/16" thickness.

The dimensions, including thickness, width, and length were recorded for all salvage material. The immediately useable cant sections were then sent to the next stage of product, the rip line.

Figure 12. Quality Cant Sections Entering a Circle Gang Ripsaw in a Typical Pallet Manufacturing Plant

Ripsaws studied during data collection included two basic machinery classifications, circle gang saws and multiple bandsaws. Since saw kerf directly impacts yield and bandsaws typically have thinner kerfs, saw classification and kerf measurements were recorded during each study. During this production stage, the quality cant sections, already trimmed to length were ripped into parts.

Figure 13. Pallet Parts Exiting a Circle Gang Ripsaw in a Typical Pallet Manufacturing Plant

Cant orientation was recorded to ensure proper yield calculations. Cant orientation is defined by the placement of the ripsaw lines without regard to actual cant measurements. Cant thickness is measured parallel to rip saw lines. Cant width is then perpendicular to rip saw lines. Figure 14 depicts the relationship between saw line placement and cant orientation measurements.

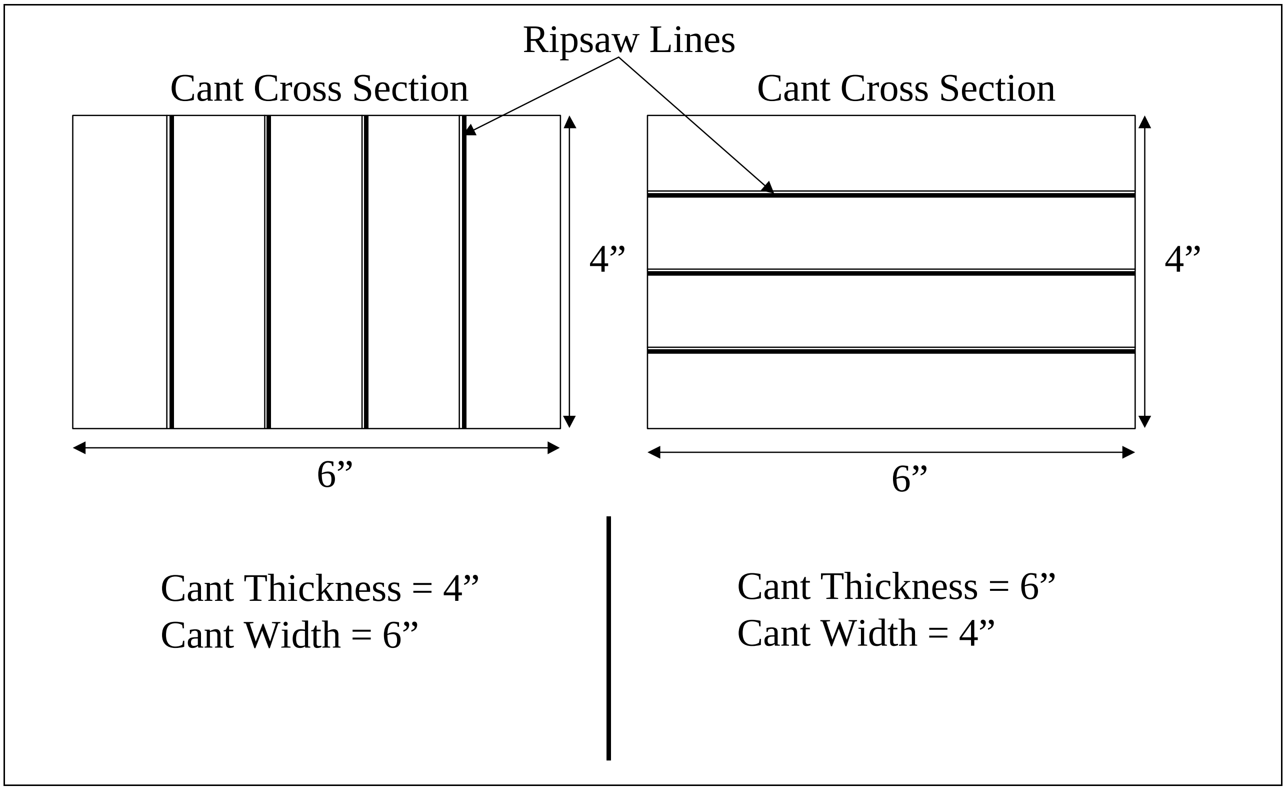


Figure 14. Schematic Diagram Showing the Different Sawing Orientations for a 4” X 6” Hardwood Pallet Cant

As cants were processed through the ripsaws, below quality parts were discarded, and the remaining parts were sorted and stacked by size. While each mill discarded parts with serious defects, the decisions were discretionary and different at each mill. A single set of part quality criteria was developed to assure yield information was comparable between mills. This criteria reflects actual part acceptability criterion used by the pallet industry. The acceptance criteria for parts was based on the Hardwood Pallet Standards’ limitation of permissible defects (NWPCA, 1992), the Certified Pallet Repair (CPR) Pallet Specifications nailing schedule, and the repaired pallet standards for missing wood (ASME MH1.8M-1996). Table 4 describes the acceptance criteria.

Table 4. Acceptance Criteria for Hardwood Pallet Parts

Member description	Limit of unsound material on nailing face	
	Nailing area (function of part width)	Remaining area (function of part width)
Deckboard (> 5" width)	¼	1/3
Deckboard (< 5" width)	1/3	1/3
Stringer	1/3	1/3

- Unsound material includes splits, wane, shake, insect holes, rot, and decay.
- Nailing area includes end two inches and center four inches of board.
- Sound defects have no size limit.

Figure 15 depicts the application of the hardwood parts acceptability criteria for deckboards and stringers.

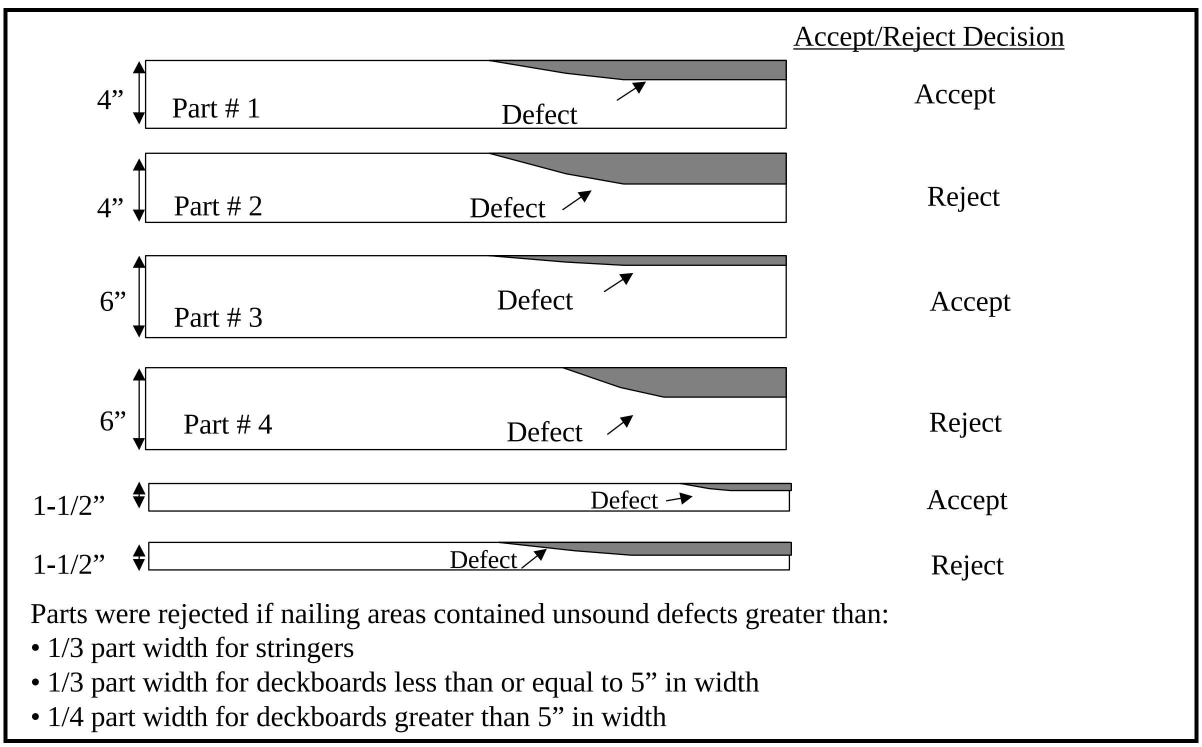


Figure 15. Schematic Diagram Acceptable and Unacceptable Defects in the Nailing Area of Pallet Parts

All mills discarded material that did not meet the acceptability level set for the study. However, parts below the acceptable standard were often not rejected at the rip lines, and these parts would be rejected during pallet assembly. To account for this at the cut-up line during the mill studies, parts were visually inspected after the rejected parts were pulled from the rip lines. Parts deemed not acceptable according to the part acceptability standards for the study were counted and subtracted from total production numbers. For example, production of ¾" X 4" X 40 " parts may have been 500 total parts. If 50 parts of that dimension were deemed unacceptable by the visual inspection, yield calculations would reflect a total part production of 450. Thus, while the mills did not discard these unacceptable parts at the cut-up line, they were not included in part yield.

Parts were then sorted by dimensions and stacked. When part production for the particular grade was finished, the total number of parts per dimension were recorded. The same procedures followed for each of the remaining two grades.

Data collection for the mill studies is summarized as follows:

1. Cant thickness (to the nearest 1/16")
2. Cant width (to the nearest 1/16")
3. Cant length (to the nearest foot)
4. Number of cants per grade
5. Number of unsound cant ends per grade
6. Cant salvage thickness per grade
7. Cant salvage width per grade
8. Cant salvage lengths per grade
9. Number of cant salvage pieces per grade per length
10. Cant orientation

11. Rip line classification (circle gang saws or multi-head bandsaws)
12. Kerf
13. Number of unacceptable parts per grade not culled at rip line
14. Number of parts per grade per dimension
15. Part thicknesses
16. Part widths
17. Part lengths

3.4 Data Analysis

3.4.1 Overview

The collected data was used to generate an algorithm for predicting pallet part yields as a function of part and cant geometry and saw kerf. Yields losses for each mill were separated into three components: kerf, dimension, and defect losses.

Defect loss is directly related to cant quality, while kerf and dimension losses are a function of part and cant geometry and saw selection. Thus, to predict part yield as a function of material and part geometry and kerf, a cant defect loss prediction model was developed. An empirical defect loss model was ascertained using multivariable regression analysis of the collected mill study data. The units used were inches for dimension and kerf and board feet for all volume calculations and predictions.

3.4.2 Yield Calculations and Analysis

3.4.2.1 Total Yield Calculations

Data analysis began with total yield calculations. The collected data was compiled for each mill study. Yield was calculated as the ratio of quality pallet part volume to raw material less salvage volume. To examine the effect of cant grade on yield, it was necessary to calculate yield separately for each cant grade. Equation 1 was used to calculate total material yield from the mill study data.

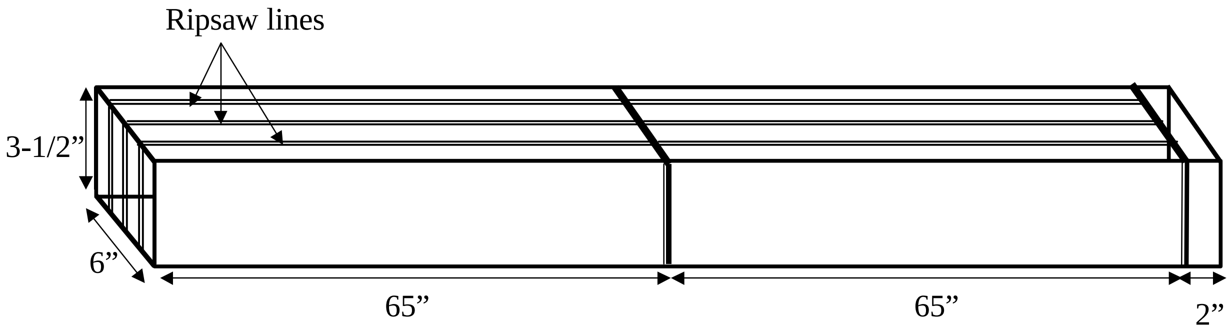
$$\text{Total yield} = (\text{Quality part volume}) / (\text{cant volume} - \text{salvage}) \qquad [1]$$

Since salvaged material will be used to produce quality pallet parts of different size, salvage was not considered a loss during yield calculations. Salvage material may still contain defects. For yield calculations, this material was subtracted from the raw material volume rather than added to the quality parts which contained no defects. Thus, all defect losses are related to part yield and not cant salvage material.

Next, kerf and dimension losses were calculated. Since, kerf and dimension losses are a function of processing technique, equipment, and cant and part geometry, they are not effected by cant grade. Therefore, kerf and dimension losses were calculated for each mill study rather than each cant grade.

3.4.2.2 Kerf Loss Calculations

Kerf loss (KL) is the proportion of kerf volume (KV) to total cant volume (CV). Since cants have variable trim allowances and are always purchased by length to the next lowest foot, kerf loss due to cutting cants to part length is negligible. Trim saw kerf loss does not significantly effect part yield. An example calculation is shown in Figure 16.



Kerf Loss = Kerf volume / Cant volume
= ((kerf * (# of parts produced per cant section - 1))*cant thickness * total length of optimal part length combination)) / (cant width * cant thickness * cant length)
= ((0.100 * 3) * 3.5 * 130) / (3.5 * 6 * 132)
= 0.049
= 4.9%

Figure 16. An Example Calculation of Kerf Loss During Rip Sawing of Hardwood Pallet Cants

Equation 2 was used to calculate kerf loss from the mill study data.

KL = KV/ CV [2]

where:

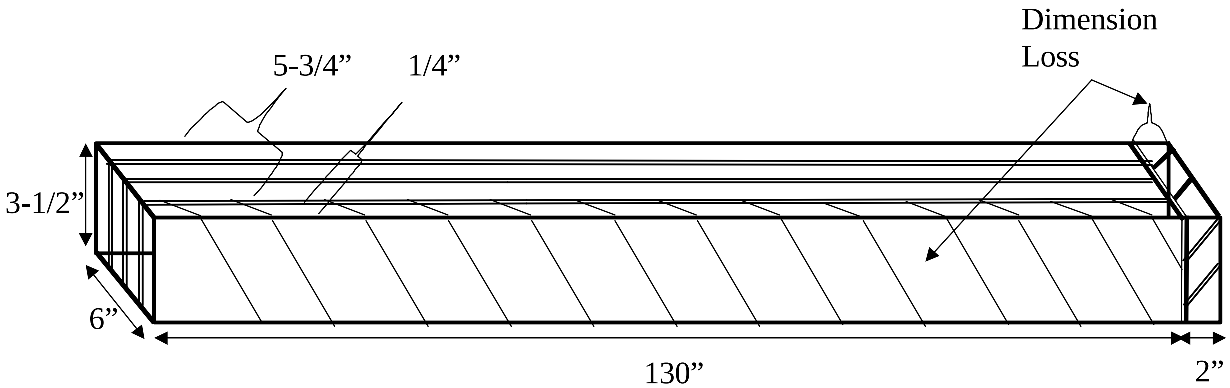
Kerf volume = ((kerf * (number of parts produced per cant section – 1)) * cant thickness * total length of optimal part length combination)

Cant volume = Cant thickness * Cant width * Cant length

3.4.2.3 Dimension Loss Calculations

Dimension losses (DIML) were calculated assuming each cant was processed using the combination of part lengths that resulted in the best possible yield. Since several part lengths were often processed during each production run, this assumption follows the ideal processing scenario provided by the cutting bill. This calculation ignores defect related yield losses incurred at the trim saw that effect dimension losses. Since defects may have changed the actual trim cut combination in a particular cant, assigning an optimal dimension loss to each production run and subsequently deducting defect losses will properly account for these resulting defect related volume losses.

Dimension loss, determined by the cutting bill, relates total part volume (TPV), kerf volume (KV), and salvage volume (SV) to cant volume (CV). Some mills produced multiple part thicknesses during each production run. While part thickness directly effects dimension loss, part thickness combinations were predetermined and assumed the same for the each production run. Figure 17 provides an example of dimension loss calculation.



Dimension Loss = 1 - [(PV + KV + SV) / (CV)]
= 1 - [(5.75 * 3.5 * 130) / (3.5 * 6 * 132)]
= 0.056
= 5.6%

Figure 17. Example Calculation of Dimension Loss during Sawing of Pallet Parts from Cants

Equation 3 was used to calculate dimension loss for the mill data.

Dimension loss = 1 – [(PV + KV + SV) / (CV)] [3]

where:

PV = (total length of optimal part length combination) * (total part thickness) * part width

KV = (kerf * number of saw lines) * part width * (total length of optimal part length combination)

SV = (total length of cant salvage section) * cant thickness * cant width

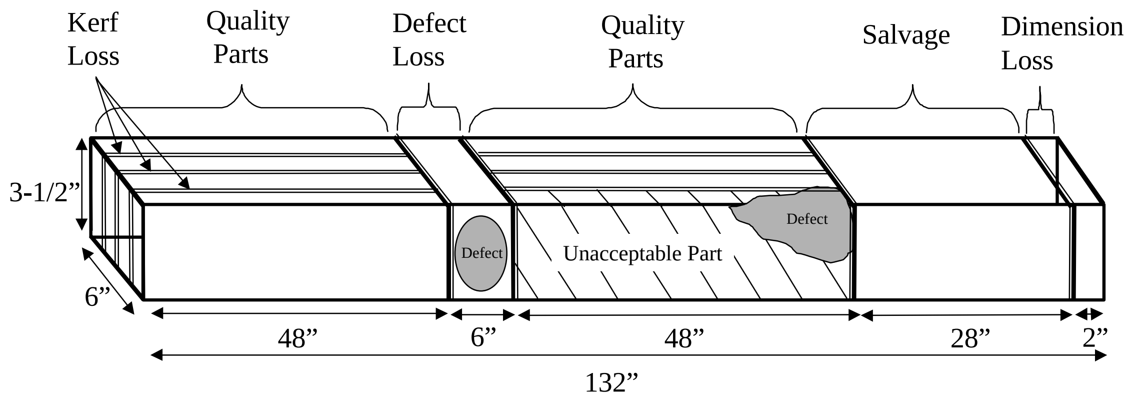
CV = cant thickness * cant width * cant length

3.4.2.4 Defect Loss Calculations

Defect loss was calculated as a function of total yield, kerf loss, and dimension loss. Defect loss is directly related to cant grade, so it was necessary to determine average defect losses for each pallet cant grade.

Defect losses occurred at two places during cant processing. First, large defects were removed at the trim saws when the cants were cut to part and salvage lengths. While cant over-length or trim allowances could reduce defect loss in this stage of processing, the impact was assumed negligible. Most cant over-length did not effect yield, and was used in the removal of drying-related end splits as cant ends were squared.

Defect losses also occurred after parts were ripsawn. Unacceptable parts that were culled from the production run were also considered defect losses. These parts were visually inspected and deemed unacceptable according to the unacceptable parts criteria used in this study (see Table 4). Also, defect losses included parts that contained machine or manufacturing related defects. While these parts do not actually contain grade-related defects, low cant quality often resulted in unacceptable parts. For example, cants containing large sections of rot were likely to twist or slip during ripsawing. These cant defects resulted in parts containing machine defects. Parts that were mismanufactured due to machinery set-up were included in total yield calculations if the parts were acceptable according to inspection rules. These parts were not considered defect losses. Mismanufactured parts were encountered at only one mill and included twelve parts. Defect loss included defected cant sections, unacceptable parts, and parts with machine defects caused by unsound material, but did not included mismanufactured parts. Figure 18 provides an example of defect loss calculation.



Total Yield = 82.2%
Kerf Loss = 3.6%
Dimension Loss = 1.5%
Defect Loss = 1 - (Total yield + Kerf loss + Dimension loss)
= 1 - (0.820 + 0.050 + 0.0150)
= 0.127
= 12.7 %

Figure 18. Defect Loss Calculation Example

Equation 4 was used to calculate defect losses from the mill study data for each cant grade 1, 2, or 3.

$$\text{Defect loss} = 1 - (\text{Total yield} + \text{Dimension loss} + \text{Kerf loss}) \quad [4]$$

3.4.3 Yield Loss Prediction Equations

The pallet industry often produces multiple part dimensions in one processing run. Part manufacturers can reduce dimension loss and increase yield by optimizing dimension combinations cut from pallet cants. Single run multiple part dimensions can include up to three part thicknesses, three part lengths, or a combination of part thicknessess and lengths. Multiple size part production can include numerous combinations of part dimensions. To maintain simplicity for single sized part production, single and multiple part sizes are predicted with different equations.

Dimension and kerf losses with multiple part sizes are predicted geometrically, but require different inputs than single part size prediction equations. Single part size prediction equations requires six input variables: cant width (CW), thickness (CT), and length (CL), part thickness (PT), width (PW), and length (PL), and kerf (K). Predicting dimension and kerf losses when multiple part sizes are produced requires the input of total part thicknesses and quality cant section lengths produced from each cant. For multiple dimension parts, a maximum limit of three part thickness and three part length combinations will be allowed in the calculation.

3.4.3.1 Kerf Loss Prediction Equation for Single Size Parts

The kerf loss equation estimates the proportion of ripsaw kerf volume to cant volume. The equation determines the number of rip saw lines in the transverse cant face or cross-section using truncation (Trunc). The equation also estimates the total length of parts cut from the cant to determine the length of the saw lines. Kerf volume is then determined and related to cant volume. Equation 5 is the kerf loss prediction equation for single size parts.

$$KL_{(SSP)} = KV / CV \quad [5]$$

where:

$$KV = \left(\left[\frac{CW + K}{PT + K} \right]^{Trunc} - 1 \right) * K * CT * \left(\left[\frac{CL}{PL} \right]^{Trunc} * PL \right)$$

$$CV = CT * CW * CL$$

To test the accuracy of the kerf loss prediction equation, actual kerf losses were compared to the predicted kerf loss values from a subsequent mill study.

3.4.3.2 Kerf Loss Prediction Equation for Multiple Size Parts

The multiple part size kerf loss prediction equation estimates kerf loss produced from rip sawing quality cant sections into parts. No kerf loss is associated with salvage or dimension loss material.

The equation for predicting kerf loss from multiple size parts requires 18 input variables. These inputs are determined from the cutting bill parameters from the individual production scenario. The following input variables are needed for predicting kerf loss: kerf, cant thickness, cant width, cant length, part thickness 1 (PT1), part thickness 2 (PT2), part thickness 3 (PT3), part width, part length, number of part thickness 1 (#PT1), number of part thickness 2 (#PT2), number of part thickness 3 (#PT3), length of cant section 1 (CSL1), length of cant section 2 (CSL2), length of cant section 3 (CSL3), number of cant section 1 (#CS1), number of cant section 2 (#CS2), and number of cant section 3 (#CS3). The number of part thickness 1, 2, and 3 refer to the total number of each part thickness cut from a single quality cant section. The number of cant section lengths 1, 2, and 3 refer to the total number of each section length to be cut from a single cant.

The kerf loss equation estimates the proportion of ripsaw kerf volume to cant volume. The equation determines the number of rip saw lines in the transverse cant face or cross-section. The equation also estimates the total length of parts cut from the cant to determine the length of the saw lines. Kerf volume is then determined and related to cant volume. Equation 6 is the kerf loss prediction equation for multiple size parts.

$$KL_{(MSP)} = KV / CV \qquad [6]$$

where:

$$KV = \left[((\#PT1 + \#PT2 + \#PT3) - 1) * K\right] * CT * \left[(CSL1 * \#CS1) + (CSL2 * \#CS2) + (CSL3 * \#CS3)\right]$$

$$CV = CT * CW * CL$$

To test the accuracy of the kerf loss prediction equation, actual kerf losses were compared to the predicted kerf loss values from three subsequent mill studies.

3.4.3.3 Dimension Loss Prediction Equation for Single Size Parts

Dimension loss is calculated assuming dimension loss material has not been defected and contains no rip saw kerf. Dimension loss material includes the cant volume not contained in the produced parts, salvage, and ripsaw kerf volumes. This material may be used for salvage or discarded if its dimensions are unacceptable. In the final costing prediction equation, this material will be salvaged if it meets certain dimension criteria.

Dimension loss is the ratio of cant volume not processed into parts, kerf, and salvage material to the total volume of the cant. Equation 7 is the dimension loss prediction equation for single size parts.

$$DimL_{(SSP)} = 1 - [(TPV + KV)] / CV \qquad [7]$$

where:

$$TPV = \left\lfloor \frac{CW + K}{PT + K} \right\rfloor^{Trunc} * PT * PW * \left\lfloor \frac{CL}{PL} \right\rfloor^{Trunc} * PL$$

$$KV = \left(\left\lfloor \frac{CW + K}{PT + K} \right\rfloor^{Trunc} - 1 \right) * K * CT * \left(\left\lfloor \frac{CL}{PL} \right\rfloor^{Trunc} * PL \right)$$

$$CV = CT * CW * CL$$

To test the accuracy of the dimension loss prediction equation, actual dimension losses were compared to the predicted dimension loss values from a subsequent mill study.

3.4.3.4 Dimension Loss Prediction Equation for Multiple Size Parts

Input variables include kerf, salvage length 1 (SL1), salvage length 2 (SL2), cant thickness, width, and length, part width, length, and thickness 1, 2, and 3, and number of part thickness 1, 2, and 3 to be cut from each quality cant section. Also, the length of cant sections 1, 2, and 3, and the number of cant sections 1, 2, and 3 to be cut from each cant will be required. Equation 8 is the dimension loss prediction equation for multiple size parts.

$$DimL_{(MSP)} = 1 - [(TPV + KV + SV) / CV] \quad [8]$$

where:

$$TPV = [(PT1 * \#PT1) + (PT2 * \#PT2) + (PT3 * \#PT3)] * CT * \left[(CSL1 * \#CS1) + (CSL2 * \#CS2) + (CSL3 * \#CS3)\right]$$

$$KV = \left[((\#PT1 + \#PT2 + \#PT3) - 1) * K\right] * CT * \left[(CSL1 * \#CS1) + (CSL2 * \#CS2) + (CSL3 * \#CS3)\right]$$

$$SV = [(SL1 * \#SL1) + (SL2 * \#SL2)] * CT * CW$$

$$CV = CT * CW * CL$$

To test the accuracy of the dimension loss prediction equation, actual dimension losses were compared to the predicted dimension loss values from three subsequent mill studies.

3.4.3.5 Defect Loss Prediction Model for Single Size Parts

A defect loss prediction model was formulated using yield data. Defect loss is determined by cant grade, part dimensions, cant dimension, and ripsaw kerf. No defect loss is associated with dimension losses or salvage material.

A defect loss multivariable regression was performed to predict defect losses from the following independent variables: part length, cant length, part thickness, cant width, part width, and kerf. Cant thickness is not used in the prediction equation because it is a redundant variable. Cant thickness and part width are assumed interchangeable.

The independent variables were plotted against defect loss. Either no trend or linearity was exhibited in all plots, so linear regression analysis was performed. Figure 19 depicts a plot of part length versus defect loss for grade 1 cants.

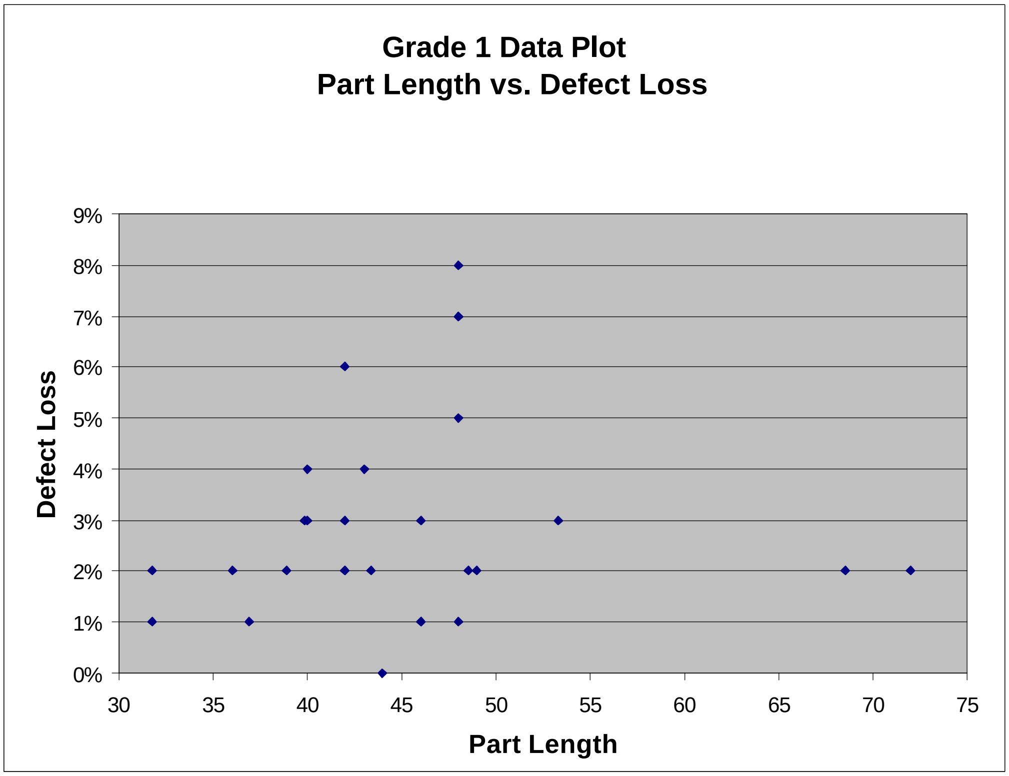


Figure 19. A Typical Plot of Defect Loss as a Function of Part Length for Grade 1 Cants

As seen in Figure 19, the part length plotted against defect loss exhibits no visible trend. No trend was visible in any plots of the independent variables versus defect loss. For simplicity, multivariable linear regression was used to determine the regression model for predicting defect loss. A residuals plot and "goodness-of-fit" test were performed on the regression model to determine its adequacy (Henkleman, 1998). Had the prediction model been determined inadequate, quadradic analysis would have been performed. The sample size of 28 mill studies and the relatively large number of model variables may provide for bias in the regression models. Therefore, an adjusted

R-square will be used to characterize the fit of the model to the original data. The linear model used for defect loss prediction follows:

$$\text{Predicted Defect Loss} = \ddot{Y} = \beta_1 \text{ Part length} + \beta_2 \text{ Cant length} + \beta_3 \text{ Part thickness} + \beta_4 \text{ Cant width} + \beta_5 \text{ Part width} + \beta_6 \text{ Kerf} \quad [9]$$

where:

β_1, β_2, β_3, β_4, β_5, and β_6, are the prediction coefficients for the independent variables.

The software package Statistical Analysis System (SAS) was used for regression analysis. The model coefficients were generated using a proc REG statement. Since all of the independent variables are nonzero with any production scenario, the prediction model was forced through its origin. The SAS model statement contained the /NOINT parameter which forces the regression fit through the origin.

Yield data was first converted to data suitable for the regression procedure. Only one cant and part size can be used from each study to make the prediction model. Instead of ignoring multiple part and cant sizes from the mill studies, one cant and part size was chosen from each study. All studies had one part and cant size, the target part size, that dominated the cutting bill. Regression input had to include only one cant and part size, so the target part size from each study was chosen to represent that study. While several mill studies had multiple cant and part sizes, the part volumes produced by the non-target sizes were not included in the regression data to reduce inaccuracy and skewing of the regression model. For example, Study Mill 10 produced stringers of lengths 36 and 40 inches. 40" stringers were the target size part, and included nearly 90 percent of the parts produced in this study. Regression data for this mill only included a part size of 40 inches.

Once all mill study data was changed to include one cant and part size per study, regression analysis was performed. The resulting defect loss prediction model was checked for accuracy using the models' adjusted R-square values, residuals plots, and t-tests comparing the predicted and actual defect losses.

The adjusted R-squared value is the proportion of the variability in the dependant variable that is accounted for by the independent variables. An adjusted R-squared value close to one indicates a proper fitting regression model. Typically, 0.7 or higher indicates that the regression model provides a proper fit. (Ott, 1992).

Residuals are the difference between actual values and predicted values. Plotting the residual against the predicted values should look like a random scattering of points if the data is well represented (Schlotzhauer, 1997). The model would then be acceptable according to residual analysis. Figure 20 is an example of both proper and improper fitting models plotted against their residuals.

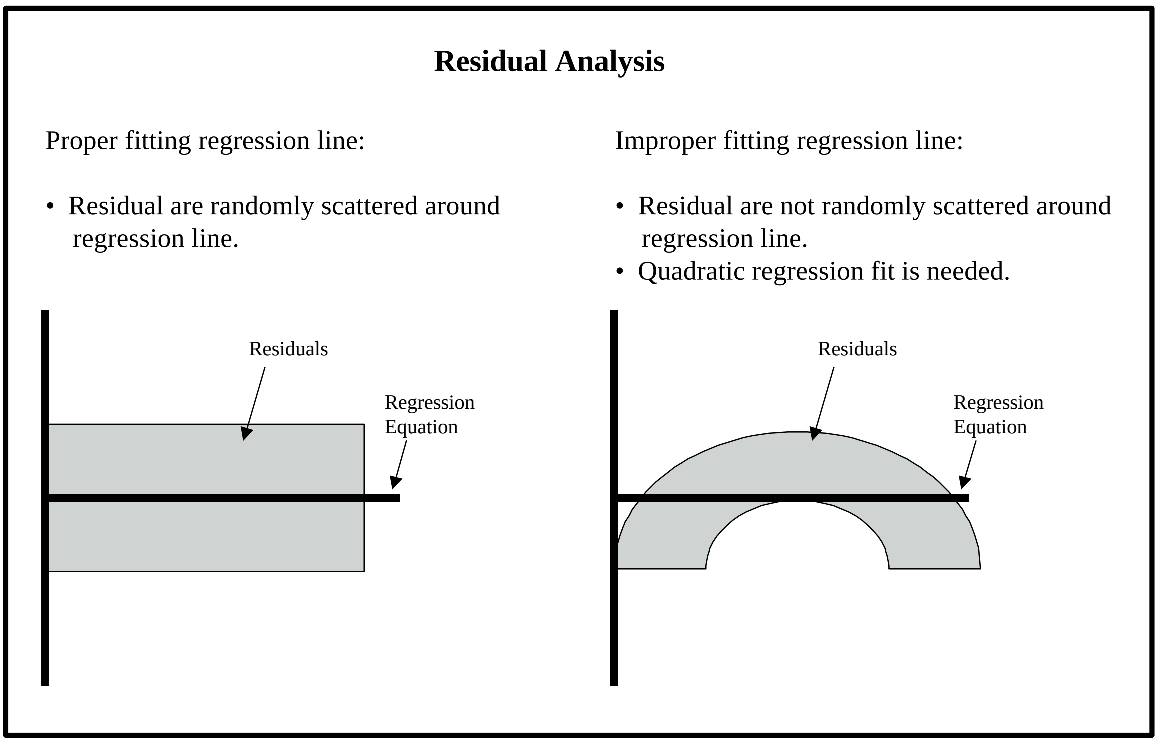


Figure 20. Example of Residual Plots used to Analyze the Fit of Regression Models to Original Data

3.4.3.6 Defect Loss Prediction Models for Multiple Size Parts

The defect loss prediction models from multiple size parts are the same prediction models used to estimate defect loss for single size parts. However, the variable names were changed to meet the input variables for multiple part sizes. Section 3.4.3.5 fully describes the defect loss prediction model and the statistical evaluation procedures for estimating its accuracy.

Defect loss must be determined for each part size when multiple part sizes are produced. Since part dimensions effect defect loss, defect loss for multiple part sizes is estimated for each part size rather the combination of all part sizes. Equation 10 is the linear model used for defect loss predictions.

$$\text{Defect Loss}_{(MSP)} = \ddot{Y} = \beta_1 \text{ Length of cant section A} + \beta_2 \text{ Cant length} + \beta_3 \text{ Part thickness T} + \beta_4 \text{ Cant width} + \beta_5 \text{ Part width} + \beta_6 \text{ Kerf} \quad [10]$$

where:

β_1, β_2, β_3, β_4, β_5, and β_6, are the prediction coefficients for the independent variables, A refers to lengths 1, 2, or 3, and T refers to thicknesses 1, 2, or 3.

3.4.4 Total Part Yield Prediction Equation

Total pallet part yield is calculated using Equation 11. The formula determines the yield of acceptable parts based on kerf, dimension, and defect loss predictions.

$$\text{Total part yield} = 1 - (\text{Kerf loss} + \text{Dimension loss} + \text{Defect loss}) \quad [11]$$

3.4.5 Part Cost Prediction Equations

The cost prediction algorithm can be used to determine the material cost associated with part production. The equation proportions yield loss material volume from the production scenarios based on the volume of each part. The proportioned yield loss volume is then added to the volume of each part to determine the total volume of material required to manufacture the part. The material is then costed based on the value of the cants. Salvage material costs are not allocated to part costs because salvage material is not lost during processing. Including the salvage material costs in part costing produces erroneously high cost predictions.

3.4.5.1 Part Costing Algorithms for Single Size Parts

To calculate part costs, yield loss material is proportioned according to part volume, then added to the volume of the part. To proportion yield loss material, the predicted total yield loss for the production scenario is multiplied by cant volume. This gives the volume of loss material per cant. Since defect loss is grade dependent, total yield loss must be calculated for each grade. The volume of yield loss per cant is then multiplied by the ratio of part volume to the total part volume. This weights the yield loss volume according to the part volume. The weighted volume is then added to the part volume and multiplied by the cant cost or cant purchase price. Equation 12 is the cost prediction equation for single size parts.

$$PC_{(SSP)} = \left[[(1 - TY) * CV] * \frac{PV}{TPV} + PV \right] * CC \qquad [12]$$

where:

TY = total yield

CV = CT * CW * CL

PV = PT * PW * PL

$$TPV = \left[\frac{CW + K}{PT + K} \right]^{Trunc} * PT * PW * \left[\frac{CL}{PL} \right]^{Trunc} * PL$$

CC = Cant cost per unit volume

A paired t-test at an alpha level of 0.05 was performed to test the null hypothesis that no difference exists between the predicted part costs between grades. A p-value of less than 0.05 results in the rejection of the null hypothesis and the conclusion that grade-related cant quality effects part costs.

To test the accuracy of the single size part cost prediction equation, predicted costs were compared with part prices from mills 2, 4, 7, 18, 27, 29. The part prices were quoted from the mills and include profit margins and processing and overhead costs. Since part prices are based on production runs including cant of all grades, an average part material cost was calculated according to the appropriate proportions of cant grades based on the mill study data.

The total part material costs (TPMC) were calculated by summing the product of cost per grade multiplied by the corresponding proportion of cants per grade from the study. Equation 13 is the total part material cost formula.

TPMC = (Grade 1 cost per cant * Proportion of grade 1 cants) +
(Grade 2 cost per cant * Proportion of grade 2 cants) +
(Grade 3 cost per cant * Proportion of grade 3 cants) [13]

Material costs account for about 75 percent of the costs associated with producing parts (Yaptenco, 1968). Since part selling prices typically include profit margins of 10 percent (Piland, 1998), part material costs should account for approximately 65 percent of the part-selling price. Actual part prices were compared with predicted part costs to verify the part cost model. The ratio of part costs to part prices (PC : PP) will be used to determine the relationship between predicted cost and actual price. While this method of evaluating accuracy in the part cost prediction is not precise, part manufacturers could not give accurate part cost values.

3.4.5.2 Part Costing Algorithms for Multiple Size Parts

To calculated part costs, yield loss material is proportioned according to part volume, then added to the volume of the part. The predicted total yield loss for the production scenario is first multiplied by cant volume. This gives the volume of loss material per cant. Since defect loss is grade dependent, total yield loss must be calculated for each grade. The volume of yield loss material per cant is proportioned by multiplying the yield loss volume per cant by the ratio of the volume of each part to the total volume of parts cut from the cant. The proportioned yield loss volume is then added to the part volume and multiplied by the cant cost or cant purchase price. Equation 14 is the part cost prediction equation for multiple size parts.

$$PC_{(MSP)} = \left[[(1 - TY) * CV] * \frac{PV}{TPV} + PV \right] * CC \qquad [14]$$

where:

TY = total yield

CV = CT * CW * CL

PV = PT * PW * PL

$$TPV = [(PT1 * \#PT1) + (PT2 * \#PT2) + (PT3 * \#PT3)] * CT * \left[(CSL1 * \#CS1) + (CSL2 * \#CS2) + (CSL3 * \#CS3) \right]$$

CC = Cant cost per unit volume

A paired t-test at an alpha level of 0.05 was performed to test the null hypothesis that no difference exists between the predicted part costs between grades. A p-value for the test of less than 0.05 results in the rejection of the null hypothesis. If significant difference exists between grades, then grade and cant quality effects part costs.

To test the accuracy of the cost prediction equation, predicted costs were compared with part prices for mills 1 through 5, 7, 17 through 21, and 27 through 31. The part prices include profit margins and processing and overhead costs. Since part prices are based on production runs including cant of all grades, the cost predictions were weighted according to the appropriate proportions of cant grades based on the mill study data.

The total part material costs (TPMC) were calculated by summing the product of cost per grade multiplied by the corresponding proportion of cants per grade from the study. Equation 15 is the total part material cost formula.

TPMC = (Grade 1 cost per cant * Proportion of grade 1 cants) +

(Grade 2 cost per cant * Proportion of grade 2 cants) +

(Grade 3 cost per cant * Proportion of grade 3 cants) [15]

To determine if the costing method is in the proper value range, the predicted part costs and actual part prices were compared. Part material costs should account for approximately 65 percent of the part-selling price. The ratio of part costs to part prices (PC : PP) will be used to determine the relationship between predicted cost and actual price. While this method of evaluating accuracy in the part cost prediction is not precise, part manufacturers could not give accurate part cost values.

3.5 Independent Prediction Analysis

Studies were conducted at mills 29, 30, and 31 subsequent to model development. Results from these studies were used to verify the prediction models by comparing study values to prediction model values. These mills were not included in the defect loss regression analysis and provide for independent verification of all prediction models. While the three-mill sample size is not sufficient to perform statistical analysis, observational evidence of model accuracy was possible.

During mill study 29, single size parts were produced, while mills 30 and 31 manufactured multiple size parts. The sample includes circle gang and multiple band rip saws. Prediction equations were tested by comparing actual verses predicted values for kerf, dimension, and defect losses and total yield. Predicted part costs were compared to part prices.

3.6 Analysis of the Methods Currently Used by the Pallet Industry to Determine Hardwood Cant Quality

As discussed in Section 2.3, the pallet industry typically evaluates cant quality based on the percentage of "bad" ends per cant bundle. If the percentage of bad ends exceeds a set quality criteria by the purchaser, the cants will be rejected. To assess the industry's technique for determining pallet quality, the percentage of bad ends per mill study was compared to the total defect loss for that mill. Defect loss provides a better representation of quality related yield loss than total yield. Total yield contains processing variability and is impacted by cutting bill parameters.

The number of bad cant ends was collected during 11 mill studies. The mill study numbers for cant data collection were 1, 4, 5, 7, 9, 11, 12, 13, 17, 24, and 26. Ends were considered "bad" if 10 percent of the cant end area was unsound. Data collection included the number of bad ends and the total number of ends per study. The percentage of bad ends per study was calculated as the ratio of bad ends to the total number of cant ends per study.

A Pearson Correlation Test was used to measure the strength of the relationship between the percentage of bad ends per study and the defect loss for the study. As the relationship between the tested variables strengthens, the correlation coefficient (r-value) approaches one. An r-value of 0.7 or higher indicates a strong relationship between variables (Schlotzhauer, 1997). This procedure also tests the hypothesis that the true population correlation is zero. A resulting p-value of less than 0.05 implies that a correlation between test variables exists. Correlation test results indicating a strong relationship between the percentage of bad ends and defect loss would imply that the industry's current method of evaluating cant quality is effective and that the percentage of bad ends could be used to determine cant quality and predict part yield.

The Pearson Correlation Analysis was performed using SAS for Windows version 6.12. The SAS procedure CORR was used for the analysis.

3.7 Evaluation of Hardwood Cant Grade Rules

Cant grade rules were evaluated by examining the defect losses associated with each grade. As cant quality declines from 1 to 3, defect loss for the corresponding grade should increase. Proper grade rules should provide statistically significant defect loss differences between grades. A Tukey Studentized Range Test was used to compare the defect losses for each grade. Alpha level of 0.01 was chosen to test evidence for a strong correlation between defect loss for each grade. Again, SAS with a general linear model procedure was used for the analysis.

Any material grading system should be easy to perform. Material grading must be quick and simple, yet accurate and effective. An acceptable grading system will produce quality separations between grades. Evaluation of grade rule application ease will be based on qualitative experience.

4 Results and Discussion

4.1 Mill Study Data

4.1.1 Overview

The data collected at each mill included ripsaw kerfs, number of cants per grade, cant volumes, part volume, salvage volumes. 2016 hardwood cants totaling of 47,258 board feet were graded during the studies. Parts produced and salvage totaled 36,462 and 1754 board feet, respectively. Average total yield was 78 percent for all mills studied, and grades 1, 2, and 3 provided 83, 77, and 47 percent average yields, respectively. Table 5 is the compilation of collection data for the 28 mill study sites.

Table 5. Data Collected During Pallet Part Yield Studies at Cooperating Pallet Mills

Mill	Kerf	Number of Cants				Cant Volume (bf)				Part Volume (bf)				Salvage (bf)				Pallet Part Yield			
#	(")	Grade 1	Grade 2	Grade 3	Total	Grade 1	Grade 2	Grade 3	Total	Grade 1	Grade 2	Grade 3	Total	Grade 1	Grade 2	Grade 3	Total	Grade 1	Grade 2	Grade 3	Total
1	0.135	86	0	0	86	3244	0	0	3244	2743	0	0	2743	0	0	0	0	85%	---	---	85%
2	0.133	33	14	2	49	693	294	42	1029	608	247	14	869	33	11	0	44	92%	87%	34%	88%
3	0.055	84	8	4	96	1960	196	98	2254	1375	136	40	1551	470	37	5	512	92%	86%	43%	89%
4	0.125	27	13	9	49	648	312	216	1176	468	193	36	697	7	27	40	73	73%	68%	20%	63%
5	0.175	29	33	34	96	614	730	770	2114	505	556	413	1474	0	0	0	0	82%	76%	54%	70%
6	0.040	46	12	5	63	2208	576	240	3024	1681	469	103	2253	396	63	0	459	93%	91%	43%	88%
7	0.050	58	16	22	96	928	256	352	1536	771	202	175	1148	0	0	0	0	83%	79%	50%	75%
8	0.125	39	10	9	58	501	128	116	744	370	86	65	521	0	6	5	11	74%	70%	59%	75%
9	0.155	50	17	10	77	1050	357	210	1617	798	258	110	1166	107	31	2	140	85%	79%	53%	79%
10	0.055	40	21	25	86	1479	551	656	2686	1300	447	328	2075	0	0	0	0	88%	81%	50%	77%
11	0.080	19	15	4	38	355	280	75	709	315	228	30	573	0	0	0	0	89%	81%	41%	81%
12	0.055	72	0	0	72	2112	0	0	2112	1695	0	0	1695	201	0	0	201	89%	---	---	89%
13	0.055	84	0	0	84	2352	0	0	2352	2185	0	0	2185	0	0	0	0	93%	---	---	93%
14	0.188	37	1	4	42	1036	28	112	1176	760	14	42	816	6	6	18	30	74%	64%	45%	71%
15	0.036	97	23	6	126	1789	422	110	2321	1614	340	37	1991	10	29	24	64	91%	87%	43%	88%
16	0.125	49	8	3	60	898	147	55	1100	694	111	24	829	13	0	0	13	78%	76%	43%	76%
17	0.125	90	39	11	140	1890	819	231	2940	1529	601	128	2258	0	0	0	0	81%	74%	55%	77%
18	0.068	51	27	7	85	1250	662	172	2083	1129	564	108	1801	0	0	0	0	90%	85%	63%	86%
19	0.125	22	7	2	31	352	112	32	496	243	75	12	339	63	17	0	80	84%	79%	38%	81%
20	0.125	20	12	10	42	405	243	203	851	298	154	87	539	0	0	0	0	74%	63%	43%	57%
21	0.125	46	9	2	57	690	135	45	870	541	97	22	660	0	0	0	0	78%	72%	49%	76%
22	0.055	50	9	13	72	719	129	187	1035	545	88	46	679	18	4	37	59	78%	70%	31%	69%
23	0.065	4	21	11	36	181	961	508	1650	134	680	297	1111	0	0	0	0	74%	71%	59%	67%
24	0.155	36	11	5	52	948	285	110	1343	739	217	63	1019	30	7	0	37	80%	78%	57%	78%
25	0.131	58	10	1	69	1218	210	21	1449	1074	170	11	1255	25	6	0	31	90%	83%	52%	84%
26	0.170	38	6	0	44	583	92	0	675	372	56	0	428	0	0	0	0	64%	61%	---	63%
27	0.135	47	23	14	84	1316	644	392	2352	1177	560	218	1955	0	0	0	0	89%	87%	56%	83%
28	0.100	97	23	6	126	1788	422	110	2320	1450	332	50	1832	0	0	0	0	82%	79%	45%	79%
Total =	---	1409	388	219	2016	33207	8991	5063	47258	27113	6881	2459	36462	1379	244	131	1754	---	---	---	---
Average =	0.106	50	14	8	72	1186	321	181	1688	968	246	88	1302	49	9	5	63	83%	77%	47%	78%
St Dev =	0.045	25	10	8	28	741	262	196	791	638	206	107	676	117	15	11	129	8%	8%	10%	9%
COV =	43%	50%	70%	103%	40%	63%	82%	108%	47%	66%	84%	122%	52%	237%	176%	237%	206%	9%	11%	21%	12%

4.1.2 Kerf and Kerf Loss Comparisons

Ripsaw kerfs ranged from 0.036 inches to 0.188 inches with the average being 0.109 inches. Ripsaw kerfs were compared between circle gang saws and multiple bandsaws. The average kerf of multiple bandsaws was 0.056 " with a coefficient of variations (COV) of 22 percent. The average saw kerf of circle gang saws was 0.138 inches with a coefficient of 16 percent. Thicker kerfs resulted in higher kerf losses and lower yields which creates higher part costs. The average kerf loss from multiple bandsaws and circle gang saws was 6 and 13 percent, respectively. This difference in kerf loss implies that a seven percent increase in yield can be attained through the use of thin kerf multiple band saws. Table 6 provides kerf and kerf loss information for both rip saw classifications.

Table 6. Comparison of Saw Kerf and Kerf Yield Losses for Pallet Mills Processing Hardwood Cants into Pallet Parts

Multiple Bandsaws			Circle Gang Saws		
Mill #	Kerf (inches)	Kerf Loss	Mill #	Kerf (inches)	Kerf Loss
3	0.055	9%	1	0.135	10%
6	0.040	4%	2	0.133	4%
7	0.050	7%	4	0.125	19%
10	0.055	3%	5	0.175	10%
11	0.080	10%	8	0.125	14%
12	0.055	9%	9	0.155	7%
13	0.055	6%	14	0.188	22%
15	0.036	4%	16	0.125	16%
18	0.068	8%	17	0.125	17%
22	0.055	4%	19	0.125	11%
23	0.065	3%	20	0.125	11%
Average =	0.056	6%	21	0.125	10%
St Dev =	0.012	3%	24	0.155	15%
COV =	22%	43%	25	0.131	7%
			26	0.170	23%
			27	0.135	7%
			28	0.100	10%
			Average =	0.138	13%
			St Dev =	0.023	5%
			COV =	16%	44%

The large variation in kerf loss to saw kerf can be attributed to differences in sawing patterns. Correlation analysis indicted that a significant correlation exists between kerf and kerf loss.

4.1.3 Cant Grade Distribution

The relative number of cants per grade indicates the quality distribution of cants used by the mills studied. Of the 2016 cants graded in the study, 1409 were grade 1, 388 were grade 2, and 219 were grade 3 cants. Table 7 contains the total percentage and number of cants in each grade.

Table 7. Quality Distribution of Hardwood Cants Used by the Study Mills

	Grade 1	Grade 2	Grade 3	Total
No. of cants	1409	388	219	2016
% of cants	70%	19%	11%	100%

The percentage of grade 1 cants used by the study mills indicates a high quality distribution of cants. However, data was insufficient to make regional cant quality comparisons. The data collection provided observational evidence that cant quality was dependent on local factors rather than regional trends. The cant quality of mills within the same general geographic locations varied widely. Cant quality problems are linked to characteristics of cant vendors or local competition from pulp and paper mills.

One yard operator commented that quality cants are available, cant prices had increased due to competition from pulp mills until it simply was not profitable to use them for making pallets. This mill was forced to purchase lower quality cants and produce their own cants to meet pallet part production requirements. Another pallet mill less than 40 miles away that paid approximately the same price for cants as the first mill was refusing to purchase cants because the yard inventory was too large. The company vice-president remarked that raw material was easier to find now than at any time in the last ten years. He added that his yard inventories during the winter had remained the highest since he had been in business (nearly 20 years). While these two mill are in the same geographic region, the availability of cants is drastically different. The difference is related to local competition, not local cant quality.

4.1.4 Data Yield Analysis

Cant, part, and salvage volumes and their totals are represented in the data collection for each grade at each mill. Due to the difference in grade distributions, a much larger volume of grade 1 cants were processed into parts during the study. Salvage values were also greatest for grade 1 cants. 33,207 bf of grade 1 cants were processed into 27,113 bf of parts and 1,379 bf of cant salvage material. The 8991 bf of grade 2 cants provided 6881 and 244 bf of parts and salvage, respectively. Grade 3 cant, part, and salvage volumes were 5063, 2459, and 131 bf, respectively.

From Table 5, cant grades 1, 2, and 3 yielded 83, 77, and 47 percent of their volume in quality parts, respectively. The average yield for all grades was 78 percent. The production of stringers resulted in a total usable part yield of 79 percent, while deckboards provided a 78 percent total yield. Therefore, no significant difference in total yields were provided between part types. Since yield is a function of processing technique, kerf, cant and part size, and cant quality, the relationship between grade effect and total yield is distorted. Section 4.7 contains comparisons between cant quality and yield through defect loss analysis.

4.1.5 Yield Loss Analysis

Yield data from each mill study was separated into three yield loss components; kerf loss, dimension loss, and defect loss. Defect loss was determined for each cant grade. Kerf and dimension losses are a function of the cutting bill, ripsaw blade orientation, equipment, and pallet part and cant geometry. Therefore, kerf and dimension losses were calculated for each mill study rather than each cant grade. Pallet part refers to both pallet stringers and deckboards. Total yield, defect loss, dimension loss, and kerf loss for each mill are reported in Table 8.

Table 8. Pallet Part Yield and Yield Losses from Cooperating Pallet Mills

Mill	Yield				Defect Loss				Dimen.	Kerf
#	Grade 1	Grade 2	Grade 3	Total	Grade 1	Grade 2	Grade 3	Total	Loss	Loss
1	85%	---	---	85%	0%	---	---	0%	7%	8%
2	92%	87%	34%	88%	2%	7%	61%	6%	2%	4%
3	92%	86%	43%	89%	1%	7%	50%	3%	0%	7%
4	73%	68%	20%	63%	0%	6%	53%	11%	8%	19%
5	82%	76%	54%	70%	3%	9%	32%	16%	5%	10%
6	93%	91%	43%	88%	2%	4%	52%	7%	1%	4%
7	83%	79%	50%	75%	1%	5%	34%	9%	9%	7%
8	74%	70%	59%	75%	1%	5%	16%	4%	12%	13%
9	85%	79%	53%	79%	4%	10%	36%	10%	4%	7%
10	88%	81%	50%	77%	3%	10%	41%	14%	6%	3%
11	89%	81%	41%	81%	1%	8%	49%	9%	0%	10%
12	89%	---	---	89%	2%	---	---	2%	0%	9%
13	93%	---	---	93%	2%	---	---	2%	0%	6%
14	74%	64%	45%	71%	1%	11%	30%	4%	3%	22%
15	91%	87%	43%	88%	3%	7%	51%	6%	3%	4%
16	78%	76%	43%	76%	3%	6%	39%	6%	2%	16%
17	81%	74%	55%	77%	2%	9%	28%	6%	0%	17%
18	90%	85%	63%	86%	2%	7%	29%	6%	0%	8%
19	84%	79%	38%	81%	3%	8%	50%	7%	1%	12%
20	74%	63%	43%	57%	3%	14%	34%	12%	12%	11%
21	78%	72%	49%	76%	2%	8%	31%	4%	8%	12%
22	78%	70%	31%	69%	1%	9%	48%	10%	17%	4%
23	74%	71%	59%	67%	8%	11%	24%	14%	15%	3%
24	80%	78%	57%	78%	5%	7%	28%	7%	0%	15%
25	90%	83%	52%	84%	2%	8%	39%	3%	2%	7%
26	64%	61%	---	63%	1%	4%	---	2%	12%	23%
27	89%	87%	56%	83%	0%	2%	34%	6%	4%	7%
28	82%	79%	45%	79%	4%	7%	40%	7%	4%	10%
Average =	83%	77%	47%	78%	2%	8%	39%	7%	5%	10%
St Dev =	8%	8%	10%	9%	2%	3%	11%	4%	5%	6%
COV =	9%	11%	21%	12%	76%	34%	28%	58%	102%	56%

As expected, defect loss is a function of grade. Defect losses were 2, 8, and 39 percent for cant grades 1, 2, and 3, respectively. A Tukey Studentized Range Test indicates defect losses were significantly different between all grades.

The variation of defect loss within cant grade was different for each grade. For grades 1, 2, and 3, the standard deviation of defect loss was 2, 3, and 11 percent , respectively. As cant grade decreased, defect loss and defect loss variability increased.

The average kerf loss was 10 percent with 6 percent standard deviation and a COV of 56 percent. The large standard deviation in kerf loss is the result of variation in sawing patterns and ripsaw kerfs. The production of stringers results in much less kerf loss than producing thinner deckboards. Also, as discussed in section 4.1.2, circle gang saws and multiple band saws represents different saw kerf.

The average dimension loss was 5 percent for the 28 study mills. The standard deviation and COV for dimension loss were 6 and 102 percent, respectively. Different saw patterns and salvage decisions resulted in large variations in dimension loss. Mills producing multiple size parts had dimension losses nearly 2 percent lower than mill producing only single size parts. Mills salvaging short cant sections had dimension losses 0.8 percent lower than mills that did not keep salvage material.

4.1.6 Defect Loss Prediction Equations

Defect loss (DefL) multivariable linear regressions were performed on the mill study data to predict defect loss from the following independent variables: part length, cant length, part thickness, cant width, part width, and kerf. Defect loss from the mill study data was the dependant variable. To account for grade effects on defect loss, a prediction model was determined for each grade.

Defect losses for each were plotted and examined for outliers. Outliers are data points that are extreme to the entire data set and provide residuals greater than three units (Schlotzhauer, 1997). Outliers were removed from the data set. The preliminary models were plotted against their residuals. The residual plots were checked for model accuracy.

Models may not be applicable when processing pallet parts from hardwood cants outside the parameters of the research data. For example, part length data ranged from 31.75 to 72 inches. Prediction models may not be accurate for processing parts of length less than 31.75 inches and greater than 72 inches. Data ranges are included in Table 9.

Table 9. Data Ranges for the Application of Prediction Models for Producing Pallet Parts from Hardwood Cants

Mill	Cant			Part			Kerf
Number	Thickness	Width	Length	Thickness	Width	Length	(")
1	3.500	8.000	196.000	1.250	3.500	46.000	0.135
2	3.500	6.000	144.000	1.875	3.500	48.000	0.133
3	3.500	6.000	168.000	0.500	3.500	68.500	0.055
4	4.000	6.000	144.000	0.438	4.000	72.000	0.125
5	3.750	6.667	144.000	1.188	3.750	53.333	0.175
6	6.000	8.000	144.000	0.625	6.000	38.875	0.040
7	6.000	4.000	96.000	0.500	6.000	46.000	0.050
8	3.500	5.500	96.000	0.625	3.500	48.500	0.125
9	3.500	6.000	144.000	1.313	3.500	43.000	0.155
10	3.500	6.000	180.000	1.375	3.500	36.000	0.055
11	4.000	7.000	96.000	0.625	4.000	48.000	0.080
12	3.500	5.500	196.000	0.563	3.500	43.375	0.055
13	3.500	6.000	196.000	0.750	3.500	42.000	0.055
14	4.000	6.000	168.000	0.563	4.000	42.000	0.188
15	5.500	4.000	120.000	0.750	5.500	39.875	0.036
16	4.000	5.500	120.000	0.563	4.000	40.000	0.125
17	3.500	6.000	144.000	0.563	3.500	36.000	0.125
18	3.500	6.000	168.000	0.625	3.500	42.000	0.068
19	4.000	6.000	96.000	0.750	4.000	31.750	0.125
20	4.500	6.000	108.000	0.750	4.500	31.750	0.125
21	3.000	6.000	120.000	0.750	3.000	36.875	0.125
22	3.750	5.750	96.000	1.000	3.750	44.000	0.055
23	7.250	7.500	120.000	1.438	3.500	48.000	0.065
24	5.500	6.180	96.000	0.750	5.500	49.000	0.155
25	3.500	6.000	144.000	1.375	3.500	48.000	0.131
26	4.000	5.750	96.000	0.438	4.000	46.000	0.170
27	3.500	6.000	196.000	1.375	3.500	48.000	0.135
28	5.500	4.000	120.000	0.750	5.500	40.000	0.100
Range (lo) =	3	4	96	0.438	3	31.75	0.036
Range (high) =	7.25	8	196	1.875	6	72	0.188
Average =	4.170	5.977	137.714	0.859	4.036	44.887	0.106
St Dev =	1.034	0.954	34.980	0.381	0.846	8.932	0.045
COV =	25%	16%	25%	44%	21%	20%	43%

4.1.6.1 Grade 1 Defect Loss Prediction Equation

A visual inspection of grade 1 defect loss versus mill study number provides evidence of a probable outlier. Figure 21 is a plot of grade 1 defect loss versus part length.

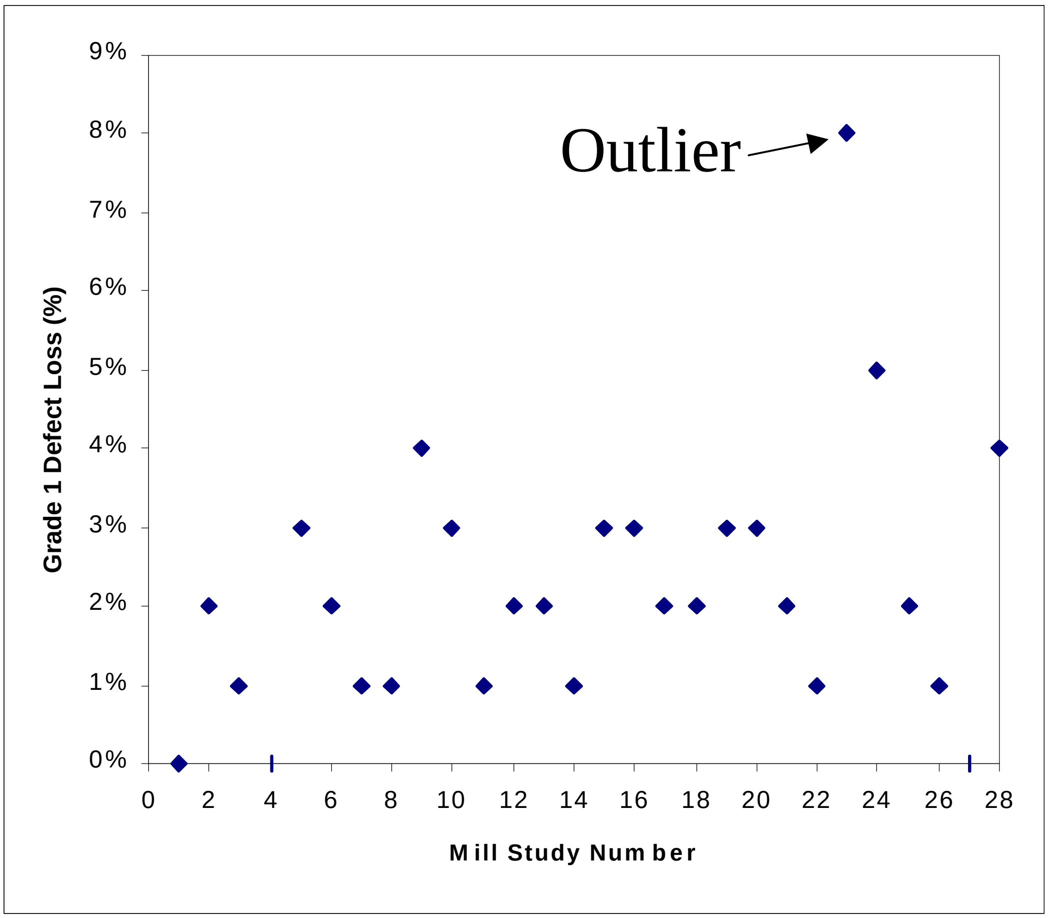


Figure 21. Plot of Grade 1 Defect Losses from Producing Pallet Parts from Hardwood Cants

A studentized residual outlier test was performed to determine if the probable outlier was significant. The results of the studentized residual outlier test are in Table 10.

Table 10. Preliminary Defect Loss Model Outlier Test Analysis

Mill Number	Actual Defect Loss	Predicted Defect Loss	Prediction Std Error	Residual	Residual Std Error	Student Residual	Signifigance Level	Cook's D
1	0%	2%	0.01	-0.02	0.01	-0.18	***	0.10
2	2%	2%	0.01	0.00	0.01	-0.52	*	0.02
3	1%	0%	0.01	0.01	0.01	1.10	**	0.12
4	0%	1%	0.01	-0.01	0.01	-0.06	*	0.04
5	3%	2%	0.00	0.01	0.01	0.86	*	0.02
6	2%	3%	0.01	-0.01	0.01	-0.94	*	0.11
7	1%	3%	0.01	-0.02	0.01	-1.93	***	0.27
8	1%	1%	0.00	0.00	0.01	-0.34		0.00
9	4%	2%	0.00	0.02	0.01	1.51	***	0.05
10	3%	2%	0.01	0.01	0.01	0.90	*	0.04
11	1%	1%	0.01	0.00	0.01	-0.31		0.01
12	2%	1%	0.01	0.01	0.01	0.82	*	0.03
13	2%	1%	0.01	0.01	0.01	0.64	*	0.02
14	1%	2%	0.01	-0.01	0.01	-1.42	**	0.15
15	3%	3%	0.01	0.00	0.01	0.13		0.00
16	3%	2%	0.00	0.01	0.01	0.84	*	0.01
17	2%	2%	0.00	0.00	0.01	0.17		0.00
18	2%	1%	0.00	0.01	0.01	0.65	*	0.01
19	3%	2%	0.00	0.01	0.01	0.49		0.01
20	3%	3%	0.00	0.00	0.01			0.00
21	2%	2%	0.00	0.00	0.01	0.39		0.00
22	1%	2%	0.01	-0.01	0.01	-0.56	*	0.01
23	8%	8%	0.01	0.00	---	>3	***********	Sig. Outlier
24	5%	3%	0.01	0.02	0.01	1.87	***	0.11
25	2%	2%	0.00	0.00	0.01	-0.04		0.00
26	1%	2%	0.01	-0.01	0.01	-0.89	*	0.03
27	0%	2%	0.01	-0.02	0.01	-2.01	****	0.14
28	4%	3%	0.01	0.01	0.01	0.73	*	0.03

The studentized residual was calculated by dividing the residual value by its standard error. Studentized residual values greater than three indicate significant outliers. As indicated by the studentized residual test, yield data from mill number 23 was a defect loss outlier. The grade 1 defect loss for the mill was 8 percent. The high defect loss can be attributed to the large cant cross sections and unusual sawing pattern used in mill study 23. Figure 14 depicts the sawing pattern and cant dimensions for mill 23.

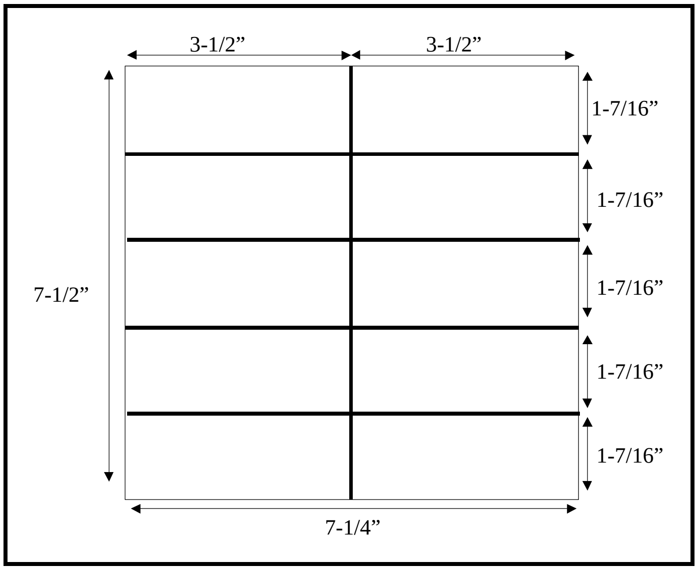


Figure 22. Ripsaw Sawing Pattern from Processing Hardwood Cants into Pallet Parts for Mill 23

Data for mill study 23 was removed from the prediction model data and another multiple variable linear regression was performed. Equation 16 is the grade 1 defect loss prediction model.

$$DefL_{(Grade\ 1)} = -0.000409\ PL + 0.000007802\ CL + 0.008375\ PT - 0.001014\ CW + 0.007197\ PW + 0.063545\ K \qquad [16]$$

The adjusted R-square value is 0.7518. A visual inspection of the residual analysis indicated an accurate model fit. Figure 23 is the plot of residual fitted to the prediction model.

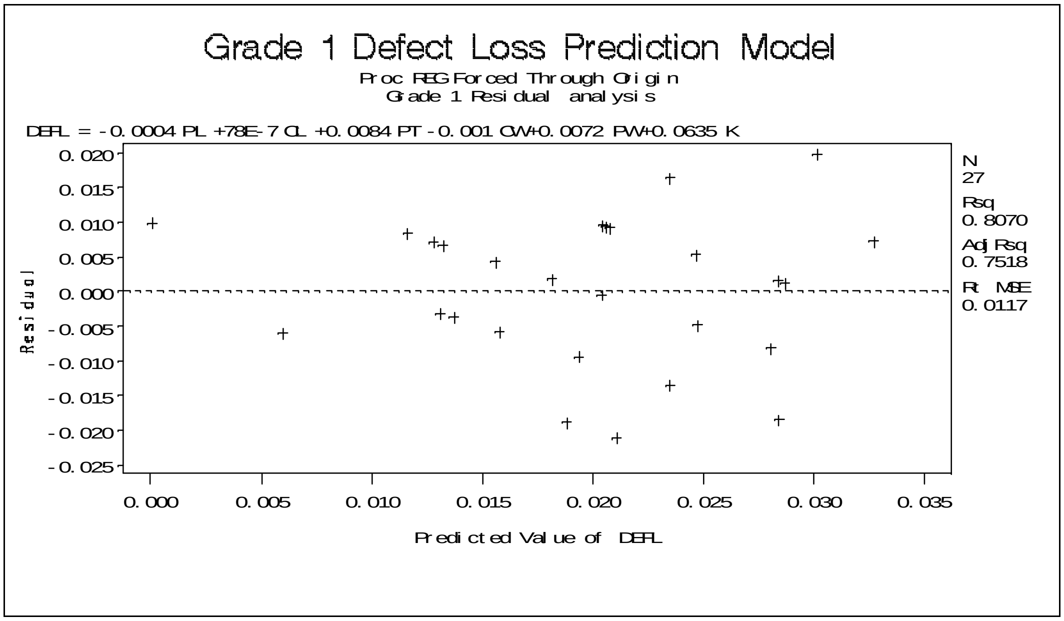


Figure 23. Residual Plot of Grade 1 Defect Loss Model for Processing Hardwood Cants into Pallet Parts

To further test the accuracy of the grade 1 defect loss prediction model, the actual and predicted defect loss values were compared in a two-sample t-test. As expected, the predicted and actual dimension losses were not significantly different at an alpha level of 0.01. Table 11 provides the actual and predicted values.

Table 11. Actual and Predicted Defect Losses from Pallet Mills Processing Grade 1 Hardwood Cants into Pallet Parts

Mill Number	Actual Defect Loss	Predicted Defect Loss
1	0%	2%
2	2%	2%
3	1%	0%
4	0%	1%
5	3%	2%
6	2%	3%
7	1%	3%
8	1%	1%
9	4%	2%
10	3%	2%
11	1%	1%
12	2%	1%
13	2%	1%
14	1%	2%
15	3%	3%
16	3%	2%
17	2%	2%
18	2%	1%
19	3%	2%
20	3%	3%
21	2%	2%
22	1%	2%
23	8%	8%
24	5%	3%
25	2%	2%
26	1%	2%
27	0%	2%
28	4%	3%
Average =	2%	2%
St Dev =	2%	1%
COV =	76%	62%
p-value =	0.961	

The average actual and predicted defect losses are both 2 percent with standard deviations of 2 and 1 percent, respectively. The COV varied between actual and predicted values at 76 and 62 percent, respectively. Differences in COV values may be due to computer rounding and prediction errors. The similar values in average and standard deviation are evidence that the prediction model is accurate. The t-test p-value of 0.961 also indicates that the prediction model accurately estimates defect loss. No statistically significant difference exists between the predicted and actual defect losses.

4.1.6.2 Grade 2 Defect Loss Prediction Equation

The grade 2 defect loss prediction equation was determined by a multivariable linear regression of the 28 mill studies. Defect loss was the dependant variable predicted from part length, cant length, part thickness, cant width, part width, and kerf. Again, model adjusted R-square value, residual analysis, and statistical comparison of actual and predicted defect loss determines adequacy of the model fit. Equation 17 is the grade 2 defect loss prediction model.

$$Defl_{(Grade\ 2)} = -0.000475\ PL + 0.000019253\ CL + 0.013680\ PT + 0.009731\ CW - 0.003521\ PW + 0.092093\ K \quad [17]$$

A residual analysis plot was performed to check the accuracy and fit of the prediction model. Figure 24 is the residual plot for the grade 2 defect loss prediction model.

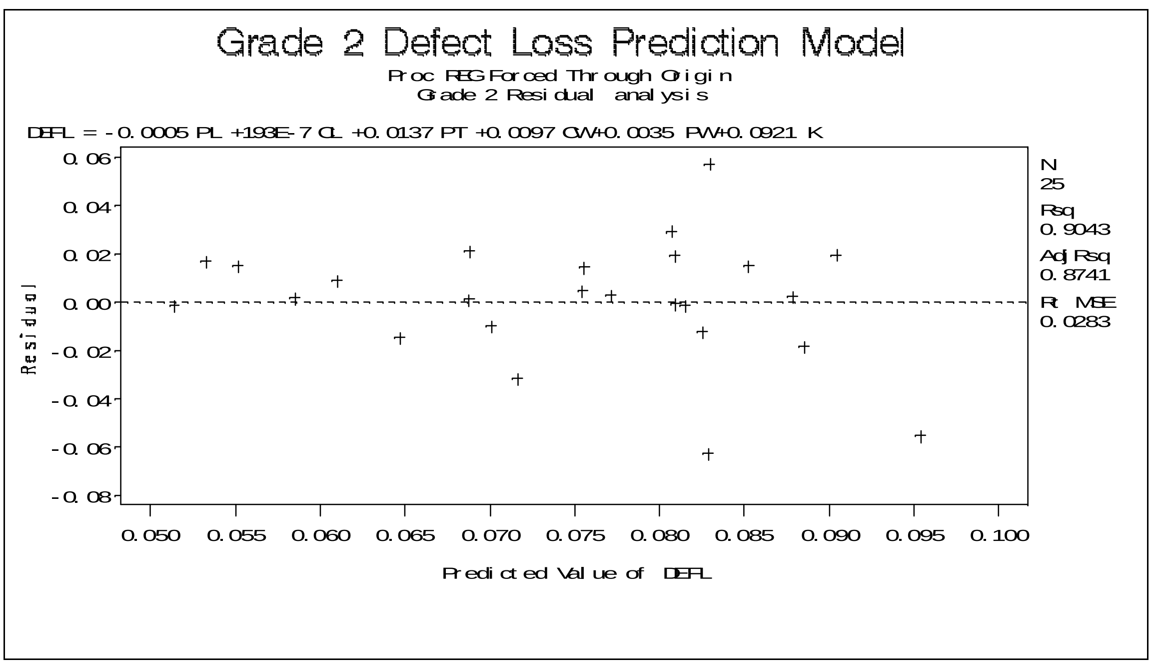


Figure 24. Residual Plot of Grade 2 Defect Loss Model for Processing Hardwood Cants into Pallet Parts

A visual inspection of the residual plot indicated an accurate regression line fit with no outliers. The adjusted R-square value of 0.8741 indicates accurate prediction values. To further substantiate the adequacy of the regression fit, the predicted defect loss values were compared to the actual values. Table 13 contains the actual and predicted defect losses.

Table 12. Actual and Predicted Defect Losses for Pallet Mills Processing Grade 2 Hardwood Cants into Pallet Parts

Mill Number	Actual Defect Loss	Predicted Defect Loss
2	7%	9%
3	7%	5%
4	6%	6%
5	9%	9%
6	4%	10%
7	5%	5%
8	5%	6%
9	10%	9%
10	10%	8%
11	8%	8%
14	11%	8%
15	7%	6%
16	6%	7%
17	9%	8%
18	7%	7%
19	8%	8%
20	14%	8%
21	8%	8%
22	9%	7%
23	11%	9%
24	7%	8%
25	8%	8%
26	4%	7%
27	2%	8%
28	7%	6%
Average =	8%	7%
St Dev =	3%	1%
COV =	34%	16%
p-value =	0.898	

The average actual and predicted defect losses are 8 and 7 percent with standard deviations of 3 and 1 percent, respectively. The COV varied between actual and predicted values from 34 and 16 percent, respectively. Differences in

COV values may be due to computer rounding and prediction errors. The similar average values are evidence that the prediction model is accurate. The lower standard deviation in the prediction equation indicates less variation in the model. Lower prediction model variation is expected as Y-axis variation is minimized by the regression procedure. The t-test p-value of 0.898 also indicates that the prediction model accurately estimates defect loss. No significant difference exists between the predicted and actual defect losses.

4.1.6.3 Grade 3 Defect Loss Prediction Equation

The grade 3 defect loss prediction equation was determined by a multivariable linear regression of the 28 mill studies. Defect loss was the dependant variable predicted from part length, cant length, part thickness, cant width, part width, and kerf. Again, model adjusted R-square value, residual analysis, and statistical comparison of actual and predicted defect loss determine adequacy of the model fit. Equation 18 is the grade 3 defect loss prediction equation.

$$DefL_{(Grade\ 3)} = 0.003042\ PL + 0.000318\ CL + 0.072404\ PT + 0.009136\ CW + 0.039298\ PW - 0.673188\ K \qquad [18]$$

The residual analysis plot was performed to check the accuracy and fit of the prediction model. Figure 25 is the residual plot for the grade 3 defect loss prediction model.

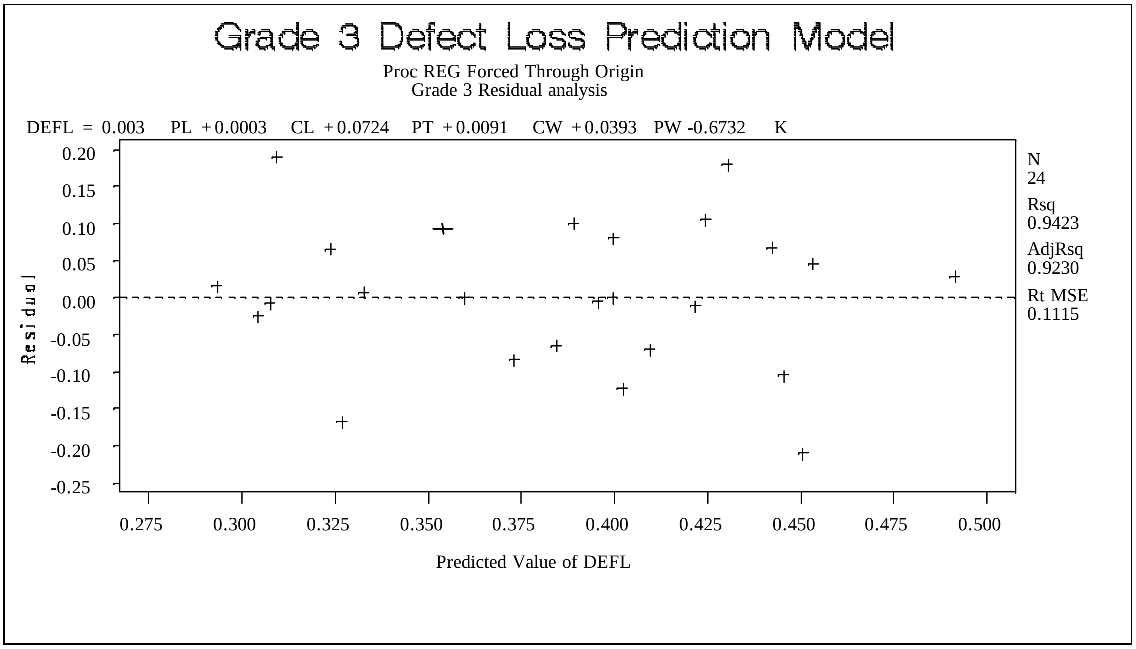


Figure 25. Residual Analysis for Grade 3 Defect Loss Model for Processing Hardwood Cants into Pallet Parts

A visual inspection of the residual plot indicated an accurate regression fit with no outliers. The adjusted R-square value of the model is 0.923 which indicates excellent model predictions. To further substantiate the adequacy of the regression fit, the predicted defect loss values were compared to the actual values. Table 13 contains the actual and predicted defect losses.

Table 13. Actual and Predicted Defect Losses for Pallet Mills Processing Grade 3 Hardwood Cants into Pallet Parts

Mill Number	Actual Defect Loss	Predicted Defect Loss
2	61%	43%
3	50%	45%
4	53%	42%
5	32%	38%
6	52%	49%
7	34%	45%
8	16%	33%
9	36%	36%
10	41%	42%
11	49%	39%
14	30%	31%
15	51%	44%
16	39%	32%
17	28%	30%
18	29%	37%
19	50%	31%
20	34%	33%
21	31%	29%
22	48%	40%
23	24%	45%
24	28%	40%
25	39%	40%
27	34%	41%
28	40%	40%
Average =	39%	39%
St Dev =	11%	6%
COV =	28%	14%
p-value =	0.984	

The average actual and predicted defect losses were identical with standard deviations of 11 and 6 percent, respectively. The similar average values provided evidence that the prediction model is accurate. However, comparisons between actual and predicted grade 3 defect loss values from individual mills indicate inaccurate predictions. These inaccuracies resulted from the large quality variation exhibited by grade three cants. The lower standard deviation value in the prediction equation indicates less variation in the model. Lower prediction model variation is expected as Y-axis variation is minimized by the regression procedure. Minimizing Y-axis variation also causes the correlation between predicted and actual defect loss values to increased as cant grades decreased. The t-test p-value of 0.984 also indicates that the prediction model accurately estimates defect loss. No significant difference exists between the predicted and actual defect losses.

All defect loss prediction equations accurately predict defect loss for their corresponding grade as a function of part thickness, width, and length, cant width and length, and kerf.

4.2 Total Part Yield

The yield loss prediction equations were used to determine total yield from the total part yield equation (see equation 11, page 52). Predicting total dimension loss for single or multiple size parts requires the appropriate kerf and dimension loss equations. Defect loss is not dependent on single or multiple size parts.

4.2.1 Total Yield Calculations for Single Size Parts

To assess the accuracy of the total yield prediction equation for single size parts, the actual total yield from each mill study that included single size part production was compared to the predicted total yield.

Cutting bill requirements for single size part yield calculations should include no cant salvage material. Salvage material is considered dimension loss by the single size part prediction equations. Table 14 contains the actual and predicted total pallet part yield values for mills producing single part sizes.

Table 14. Actual and Predicted Total Yield of Usable Pallet Parts from Mills Processing Hardwood Cants into Single Size Pallet Parts

Mill Number	Grade 1		Grade 2		Grade 3	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
2	92%	92%	87%	85%	34%	51%
4	73%	74%	68%	69%	20%	33%
7	83%	81%	79%	79%	50%	39%
14	74%	73%	64%	67%	45%	44%
15	91%	90%	87%	87%	43%	49%
18	90%	83%	85%	77%	63%	47%
20	74%	74%	63%	69%	43%	44%
21	78%	78%	72%	72%	49%	51%
22	78%	78%	70%	73%	31%	40%
25	90%	89%	83%	83%	52%	51%
27	89%	88%	87%	82%	56%	49%
Average =	83%	82%	77%	77%	44%	45%
St Dev =	8%	7%	10%	7%	12%	6%
COV =	9%	9%	13%	9%	28%	13%
p-value =	0.732		0.960		0.931	

The difference between predicted and actual pallet part yield was less than one percent, and the variation between predicted and actual values was similar. Errors in individual mill predictions for grade 3 cants were due to large variation in grade 3 cant quality. To further assess the relationship between actual and predicted values, two-sample t-tests were performed for each grade at an alpha level of 0.01. As seen in Table 14 the p-values from the t-tests provide evidence that no significant difference exists between the actual and predicted total yields. The conclusion was made that the total yield prediction equation for single part sizes was accurate.

4.2.2 Total Yield Prediction Equations For Multiple Size Parts

To determine the accuracy of the total yield prediction equation for multiple part sizes, the actual total yield from each mill study was compared to the predicted total yield. Table 15 contains the actual and predicted total yield for mills producing multiple size parts.

Table 15. Actual and Predicted Yield from Pallet Mills Processing Hardwood Cants into Multiple Size Pallet Parts

Mill Number	Grade 1		Grade 2		Grade 3	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	85%	83%	---	---	---	---
2	92%	92%	87%	85%	34%	45%
3	92%	93%	86%	88%	43%	46%
4	73%	72%	68%	67%	20%	31%
5	82%	83%	76%	76%	54%	45%
6	93%	92%	91%	85%	43%	42%
7	83%	81%	79%	79%	50%	41%
8	74%	74%	70%	69%	59%	41%
9	85%	87%	79%	80%	53%	52%
10	88%	89%	81%	83%	50%	45%
11	89%	89%	81%	83%	41%	45%
12	89%	90%	---	---	---	---
13	93%	93%	---	---	---	---
14	74%	73%	64%	67%	45%	51%
15	91%	90%	87%	87%	43%	50%
16	78%	80%	76%	75%	43%	51%
17	81%	81%	74%	75%	55%	54%
18	90%	91%	85%	85%	63%	55%
19	84%	85%	79%	79%	38%	54%
20	74%	74%	63%	69%	43%	43%
21	78%	78%	72%	72%	49%	49%
22	78%	77%	70%	72%	31%	32%
23	74%	74%	71%	73%	---	---
24	80%	82%	78%	77%	59%	58%
25	90%	89%	83%	83%	57%	45%
26	64%	63%	61%	58%	52%	48%
27	89%	87%	87%	81%	56%	49%
28	82%	83%	79%	80%	45%	50%
Average =	83%	83%	77%	77%	47%	47%
St Dev =	8%	8%	8%	7%	10%	7%
COV =	9%	9%	11%	10%	21%	14%
p-value =	1.000		0.999		0.940	

The difference between actual and predicted total average pallet part yield was less than one percent. Again, individual grade 3 defect loss prediction resulted from large grade 3 cant quality variations. Predicted and actual variation was similar. To further assess the relationship between actual and predicted values, two-sample t-tests were performed for each grade at an alpha level of 0.01. As seen in Table 15, the t-test p-values provide evidence that no significant difference exists between the actual and predicted total yields. P-values were 1.000, 0.999, and 0.940 for grade 1, 2, and 3, respectively. The conclusion was made that the total yield prediction equation for multiple size parts is accurate.

4.3 Part Costing Algorithms

Total yield predictions were used to develop part-costing algorithms. The algorithms predict the material cost associated with producing a part based on raw material cost and processing parameters, including part and cant dimensions, cutting bill requirements, yield, and kerf. The part cost predictions only provide material cost and do not include processing costs. The predictions should only be used to cost pallet parts.

Again, single and multiple size parts were predicted with different equations to maintain simplicity for single sized part production. The costing algorithms require the same basic input variables as the defect loss prediction equations. However, raw material cost or purchase price and pallet cant grade distributions must also be included in part costing.

4.3.1 Part Costing Algorithm for Single Size Parts

The cost prediction algorithm for single size parts determines the material costs associated with the production of a single part. The equation allocates the volume of the yield loss material to the volume of each part. This yield loss allocation distributed yield losses based on part volume. The part material cost is determined based on the purchase price of the cants. Salvage material is not included in cost calculations.

To calculated part costs, cant yield loss material is proportioned according to part volume. The volume of yield loss material is allocated to the part by multiplying the predicted total yield loss in percent for the production scenario by the cant volume. This gives the volume of yield loss material per cant. Since defect loss is grade dependent, total yield loss must be calculated for each grade. The volume of yield loss material per cant is then multiplied by the ratio of part volume to the total part volume. This allocates yield loss volume according to the part volume. The allocated yield loss volume is then added to the part volume and multiplied by the cant cost or cant purchase price. Equation 12 is the part cost prediction equation for single size parts (see page 53):

Table 16 contains the part dimensions and predicted prices for the mills that produced single size parts during the study. Cant costs were assumed to be $280 per Mbf.

Table 16. Predicted Part Costs for Single Size Parts from the Cut-up Operations of Hardwood Pallet Mills

Mill	Part			Predicted Part Cost		
Number	Thickness	Width	Length	Grade 1	Grade 2	Grade 3
2	1.88	3.50	48.00	$0.66	$0.70	$1.04
4	0.44	4.00	72.00	$0.34	$0.35	$0.51
7	0.50	6.00	46.00	$0.32	$0.34	$0.43
14	0.56	4.00	42.00	$0.25	$0.27	$0.32
15	0.75	5.50	39.88	$0.35	$0.36	$0.51
18	0.63	3.50	42.00	$0.20	$0.21	$0.26
20	0.75	4.50	31.75	$0.28	$0.31	$0.36
21	0.75	3.00	36.88	$0.21	$0.22	$0.26
22	1.00	3.75	44.00	$0.41	$0.44	$0.60
25	1.38	3.50	48.00	$0.55	$0.56	$0.66
27	1.38	3.50	48.00	$0.63	$0.64	$0.70
			Average =	$0.38	$0.40	$0.51
			St Dev =	$0.16	$0.17	$0.23
			COV =	43%	42%	45%
			p-value =	0.001		

Part cost averaged $0.38, $0.40, and $0.51 for grades 1, 2, and 3, respectively. The cost difference between grades is related to the higher defect loss from lower grade cants. The difference is small between grade 1 and 2, but large between grades 2 and 3. As cant grade decreases, the defect loss associated with lower grade cants requires more initial volume of cant material to produce equivalent part volumes. Therefore, it is more costly to produce pallet parts from low-grade poor quality cants than from high-grade cants.

The relatively high standard deviation and COV values resulted from large in-grade cant quality variation. Standard deviations of $0.16 and $0.17 and COV values of 0.430 and 0.415, respectively for grade 1 and 2 were similar. However, as expected, grade 3 produced more variation with standard deviation and COV values of $0.23 and 0.448, respectively.

Paired t-tests at an alpha level of 0.05 were conducted that compared each grades' part material costs to the remaining two grades. The t-tests provided evidence that the part material costs between grades were statistically different with p-values of 0.001. The differences in grade related part cost values show the importance of producing parts from quality material. For example, mill 2 produced stringers with material costs of \$0.66, \$0.71, and \$0.97 from cants of grades 1, 2, and 3, respectively. While part costs were similar for grades 1 and 2, part costs increased nearly 47 percent from grade 1 to 3. Cant quality significantly effects part costs.

To test the accuracy of the cost prediction equation, the predicted part material costs were compared with part prices from five of the study mills. The part prices include profit margins and processing and overhead costs. Since part prices are based on production runs including cants of all grades, the total part material costs (TPMC) were determined by multiplying the material costs per grade by the cant grade distributions from the corresponding mill study data (see equation 13, page 55).

When comparing the total part material costs to part prices, the part material costs should be approximately 65 percent of the selling price of the part. While this method of evaluating accuracy for the part cost prediction equation is not precise, pallet manufacturers could not give accurate part cost values. The part prices are the selling prices of the parts quoted from their corresponding mill. A comparison of the predicted part costs and actual part prices indicated that the predicted part material costs are in the proper value range. The predicted part material costs are compared to part prices for their corresponding mills in Table 17.

Table 17. Actual Part Prices and Predicted Part Costs for Single Size Pallet Parts Sawn from Hardwood Cants

Mill	Part			Part Price	Part Cost
Number	Thickness	Width	Length	($ per part)	($ per part)
2	1.88	3.50	48.00	$0.94	$0.69
4	0.44	4.00	72.00	$0.44	$0.37
7	0.50	6.00	46.00	$0.55	$0.35
18	0.63	3.50	42.00	$0.36	$0.21
27	1.38	3.50	48.00	$0.95	$0.65
			Average =	$0.65	$0.45
			St Dev =	$0.28	$0.21
			COV =	43%	46%
			PC : PP =	0.70	

As seen in the ratio of part costs to part prices (PC : PP), part prices are about 30 percent higher than the predicted part costs. The average part price was $0.65, while the average part material cost was $0.45 per part. The difference between predicted part material cost and part price indicates that profit margins and overhead and production costs account for an average of about $0.20 per pallet part for mills included in the comparison. The comparisons between part material costs and actual part prices indicate that the part cost prediction algorithm is accurate.

4.3.2 Part Costing Algorithm for Multiple Size Parts

The cost prediction algorithm for multiple size parts determines the material cost associated with the production of a single part. The equation allocates the volume of the yield loss material to the volume of each part. This yield loss allocation distributed yield losses based on part volume. The part material cost is determined based on the purchase price of the cants. While salvage material is not directly included in cost calculations, multiple size part dimension loss does account for salvage material. Salvage material is not costed to part material costs for multiple size part predictions.

To calculated part costs, cant yield loss material is proportioned according to part volume. Parts with larger volumes are allocated a higher percentage of the cant yield loss material. The volume of yield loss material is allocated to the part by multiplying the predicted total yield loss in percent for the production scenario by the cant volume. This gives the volume of yield loss material per cant. Since defect loss is grade dependent, total yield loss must be calculated for each grade. The volume of yield loss material per cant is then multiplied by the ratio of part volume to the total part volume. This allocates yield loss volume according to the part volume. The allocated yield loss volume is then added to the part volume and multiplied by the cant cost or cant purchase price. Equation 14 is the part cost prediction equation for multiple size parts (see page 56).

Table 18 contains the part dimensions and predicted prices for the mills that produced multiple size parts during the study. Cant costs were assumed to be $280 per Mbf.

Table 18. Predicted Pallet Part Costs for Multiple Size Parts from the Cut-up Operations of Hardwood Pallet Mills

Mill	Part			Predicted Part Cost		
Number	Thickness	Width	Length	Grade 1	Grade 2	Grade 3
1	1.500	3.500	46.000	$0.55	---	---
2	1.875	3.500	48.000	$0.66	$0.70	$1.04
3	0.500	3.500	68.500	$0.26	$0.28	$0.41
4	0.438	4.000	72.000	$0.34	$0.35	$0.51
5	1.188	3.750	53.333	$0.56	$0.57	$0.71
6	0.625	6.000	38.875	$0.31	$0.32	$0.50
7	0.500	6.000	46.000	$0.32	$0.34	$0.43
8	0.625	3.500	48.500	$0.28	$0.29	$0.32
9	1.313	3.500	43.000	$0.46	$0.49	$0.61
10	1.375	3.500	36.000	$0.38	$0.41	$0.52
16	0.563	4.000	40.000	$0.22	$0.23	$0.30
17	0.563	3.500	36.000	$0.17	$0.18	$0.21
18	0.625	3.500	42.000	$0.20	$0.21	$0.25
19	0.750	4.000	31.750	$0.22	$0.23	$0.32
20	0.750	4.500	31.750	$0.28	$0.31	$0.36
21	0.750	3.000	36.875	$0.21	$0.22	$0.26
22	1.000	3.750	44.000	$0.41	$0.44	$0.60
23	1.438	3.500	48.000	$0.75	$0.78	---
24	0.750	5.500	49.000	$0.49	$0.50	$0.59
25	1.375	3.500	48.000	$0.50	$0.53	$0.68
26	0.438	4.000	46.000	$0.24	$0.25	---
27	1.375	3.500	48.000	$0.50	$0.51	$0.67
28	0.750	5.500	40.000	$0.39	$0.40	$0.53
			Average =	$0.38	$0.39	$0.49
			St Dev =	$0.16	$0.16	$0.20
			COV =	42%	42%	41%
			p-value =	0.001		

As seen in Table 18, the average part costs are $0.38, $0.39, and $0.49 for grades 1, 2, and 3, respectively. The cost difference between grades is related to the higher defect loss from lower grade cants. Little difference in part costs exist between grades 1 and 2. However, a change in cant grade from 2 to 3 results in much higher part costs. As cant grade decreases, more initial volume of cant material is required to produce equivalent part volumes. Again, evidence indicates that it is more costly to produce pallet parts from low-grade, poor-quality cants than from high-grade cants.

The standard deviation and COV values show the quality variation between grades. Standard deviation of $0.16 and COV values of 42 percent, for grades 1 and 2, respectively were virtually identical. Grade 3 produced a higher standard deviation of $0.20 and a lower COV of 41 percent.

Paired t-tests at an alpha level of 0.05 were conducted that compared each grades' part material costs to the remaining two grades. The t-tests provided evidence that the part material costs between grades were statistically different with a p-value of 0.001. The part cost values provide additional evidence of the importance of producing parts for quality material. For example, mill 25 produced stringers with material costs of $0.50, $0.53, and $0.68 from cants of grades 1, 2, and 3, respectively. Material cost for the stringers increased 36 percent from grade 1 to 3. Again, evidence indicated that cant quality directly effects part costs.

To test the accuracy of the cost prediction equation, the predicted part material costs were compared with part prices from thirteen study mills. The part prices include profit margins and processing and overhead costs. Since part prices are based on production runs including cants of all grades, the total part material costs (TPMC) were determined by multiplying the material costs per grade by corresponding proportion of cants per grade from the mill study data. Equation 15 is the total part material cost prediction equation (see page 57).

For example, mill 2 produced stringers of with cost $0.66, $0.71, and $0.97 from cants of grades 1, 2, and 3, respectively. The mill study grade proportions for grades 1, 2, and 3 were 67, 29, and 4 percent, respectively. The total part material cost based on the relative volume of grade 1, 2, and 3 cants for mill 2 is $0.69 per part.

When comparing the total part material costs to part prices, the part material costs should be approximately 65 percent of the selling price of the part. While this method of evaluating accuracy for the part cost prediction equation is not precise, part manufacturers could not give accurate part cost values. The part prices are the selling prices of the parts quoted from their corresponding mill. A comparison of the predicted part costs and actual part prices indicated that the predicted part material costs are in the proper value range. The predicted part material costs are compared to part prices for their corresponding mills in Table 19.

Table 19. Actual Part Prices and Predicted Part Costs for Multiple Size Pallet Parts Sawn from Hardwood Cants

Mill Number	Part			Part Price ($ per part)	Part Cost ($ per part)
	Thickness	Width	Length		
1	1.500	3.500	46.000	$0.83	$0.55
2	1.875	3.500	48.000	$0.94	$0.69
3	0.500	3.500	68.500	$0.55	$0.27
4	0.438	4.000	72.000	$0.44	$0.37
5	1.188	3.750	53.333	$0.94	$0.62
7	0.500	6.000	46.000	$0.39	$0.36
17	0.563	3.500	36.000	$0.23	$0.18
18	0.625	3.500	42.000	$0.36	$0.23
19	0.750	4.000	31.750	$0.34	$0.23
20	0.750	4.500	31.750	$0.44	$0.31
21	0.750	3.000	36.875	$0.30	$0.21
27	1.375	3.500	48.000	$0.83	$0.53
28	0.750	5.500	40.000	$0.55	$0.40
			Average =	$0.55	$0.38
			St Dev =	$0.25	$0.17
			COV =	45%	44%
			PC : PP =	0.69	

As seen in the ratio of part costs to part prices (PC : PP), part prices are about 31 percent higher than the predicted part costs. Part prices average $0.55 per part, while part cost were $0.38 per part. The difference between predicted part material cost and part price indicates that profit margins and overhead and production costs account for an average of about $0.17 per pallet part for mills included in the comparison. The comparisons between part cost and prices indicate an accurate part cost prediction algorithm. Error in the cost predictions may result from improper part pricing and/or cost predictions.

4.4 Model Verfification

Subsequent to the development of the yield and costing models, three additional mill studies were performed. Cant grade and raw material, part, and processing characteristics were inputted into the prediction models. Prediction equations were verified by comparing actual verses predicted values for kerf, dimension, and defect losses and total yield. Predicted part material costs were compared to the selling prices of the parts as quoted from their corresponding mill.

Mill 29 cut single size parts, and mills 30 and 31 produced multiple size parts. While the three-mill sample size is not sufficient to perform statistical analysis, observational evidence of model accuracy was provided.

4.4.1 Model Verifications for Single Size Parts

Predicted values for kerf, dimension, and defect loss, and total yield were compared to their corresponding actual values obtained from direct measurements. Table 20 contains actual and predicted yield analysis values for mill 29.

Table 20. Actual and Predicted Pallet Part Yield from Cutting Hardwood Cants into Single Size Pallet Parts

----- Mill 29 -----		
Cant Dimension	4" X 6" X 12'	
Part Dimensions	1-3/4" X 4" X 46"	
Kerf	0.180"	
	Actual	Predicted
Kerf Loss	6%	6%
Dimension Loss	10%	10%
Grade 1 Defect Loss	2%	3%
Grade 2 Defect Loss	9%	9%
Grade 3 Defect Loss	36%	40%
Total Defect Loss	7%	9%
Total Yield	77%	75%

Analysis of actual versus predicted values indicates that the prediction equations seem to be effective. Kerf and dimension losses are 6 and 10 precent, respectively for actual and predicted values. Grade 1 and 2 defect loss predictions seem to be accurate as actual and predicted values differ one percent or less. The predicted defect loss for grade 3 was 43 percent, while the actual grade 3 defect loss was 36 percent. This is probably due to the high quality variation exhibited by the grade 3 cants. Total defect losses were determined by weighting the defect loss per grade by the relative proportional cant volume per grade. Total defect losses were 7 and 9 percent for actual and predicted values, respectively. The two-percent difference in the total actual versus predicted defect losses reflects the relatively higher percentage of grade 1 cants in the mill 29 study. The resulting total yield prediction is 75 percent, while the actual total yield is 77 percent. The two-percent difference between actual and predicted total yield is small. The single size part yield prediction equations accurately predict kerf, dimension, and defect loss and total yield.

The single size part-costing algorithm was applied to the predicted yield values and predicted part material costs were generated. These part material costs were then compared to the actual part-selling price used by mill 29. Table 21 displays the predicted part material cost and actual part price for mill 29.

Table 21. Predicted Cost and Actual Price for Single Size Pallet Parts Produced from Hardwood Pallet Cants

Part Dimensions	Predicted Part Cost	Actual Part Price
1-3/4" X 4" X 46"	$0.81	$1.08
PC:PP =	0.75	

The predicted part cost for mill 29 is $0.81, while the actual part price at which the mill sells the part is $1.08. The ratio of part cost to part price of 0.75 reflects a 25 percent difference in cost versus price. A comparison of the predicted part costs and actual part prices indicated that the predicted part material costs are in the approximate value range. Error may be due to improper part prices, cant pricing, and/or cost predictions.

4.4.2 Verification of Multiple Size Part Yield Models

Multiple size part predicted values for kerf, dimension, and defect losses and total yield were compared to their corresponding actual values obtained from direct measurements. Table 22 contains actual and predicted yield analysis values for the predominant pallet part size produced for mill studies 29 through 31.

Table 22. Actual and Predicted Pallet Part Yield and Material Costs from Cutting Hardwood Cants into Multiple Size Pallet Parts

Mill Number	Mill 29		Mill 30		Mill 31	
Cant Dimension	4" X 6" X 12'		4" X 6" X 8'		4" X 6" 12'	
Part Dimensions	1-3/4" X 4" X 46"		1-¼" X 4" X 44"		1/2" X 4" X 40"	
Kerf	0.180"		0.135"		0.055"	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Kerf Loss	6%	6%	6%	6%	8%	8%
Dimension Loss	10%	10%	17%	17%	17%	17%
Grade 1 Defect Loss	2%	3%	2%	2%	2%	2%
Grade 2 Defect Loss	9%	9%	8%	8%	8%	7%
Grade 3 Defect Loss	36%	40%	46%	38%	35%	38%
Total Defect Loss	7%	9%	9%	8%	7%	7%
Total Yield	77%	75%	68%	69%	68%	68%

Predicted kerf and dimension loss values were identical to the actual values for all three mills. The kerf and dimension loss prediction equations for multiple size parts appear to be accurate. Predicted defect loss values for grades 1 and 2 differ from actual defect loss values by one percent or less. The error in the prediction values is possibly due to the high quality variability in grade 3 cants. The unsound material by volume in grade 3 cants can be 30 percent or greater. Grade 3 defect loss predictions differ from the actual values by 7, -4, and 4 percent for mills 29 through 31, respectively. Despite the error in grade 3 defect loss predictions, total defect loss and total yield predictions are accurate. The multiple size part yield prediction equations effectively predict kerf, dimension, and defect losses and total yield.

The part costing algorithm was then applied to the predicted yield values and predicted part material costs were generated. These part material costs were then compared to the actual selling price used by the mills. Table 23 contains the predicted part material cost and actual part price.

Table 23. Predicted Cost and Actual Price for Multiple Size Pallet Parts Produced from Hardwood Pallet Cants

Mill Number	Part Dimensions	Part Cost	Part Price	PC:PP
29	1-3/4" X 4" X 46"	$0.81	$1.08	0.75
30	1-¼" X 4" X 44"	$0.60	$0.55	1.21
31	1/2" X 4" X 40"	$0.22	$0.33	0.67

The predicted part cost for mills 29 through 31 are $0.81, $0.60, and $0.22, respectively. The respective actual part prices are $1.08, $0.55, and $0.33. The ratio of part cost to part price for mills 29 and 31 are 0.75 and 0.67, respectively. The model seems to be in the correct cost range for mills 29 and 31.

The ratio of cost to price for mill 30 was 1.21. The predicted part cost is larger than the quoted price. The mill quoted a selling price of $0.33 per board foot which only slightly higher than the raw material purchase price. Therefore, it must be concluded that the mill is selling the part at a loss.

4.5 Cant End Analysis

To evaluate one of the industry's current techniques for determining pallet quality, the percentage of bad ends per mill study was compared to the total defect loss for that mill study. Cant end data was collected at 11 of the 28 mills studied. Ends were considered "bad" if 10 percent of the cant end area was unsound. The percentage of bad ends per study was calculated as the ratio of bad ends to the total number of cant ends per study. Cant end data is in Table 24.

A Pearson Correlation Test was used to measure the strength of the relationship between the percentage of bad ends per study and the corresponding defect losses. As the relationship between the tested variables strengthens, the correlation coefficient (r-value) approaches one. An r-value of 0.7 or higher implies a strong relationship between variables (Schlotzhauer, 1997). The r-value of 0.597 implies a weak correlation between the percentage of bad ends and defect loss.

Table 24. Comparisons of End Quality for Hardwood Cants versus Defect Loss from Cutting the Cants into Pallet Parts

Mill Number	Number of Bad Ends per Study	Number of Ends per Study	Percentage of Bad Ends	Defect Loss
1	6	172	3%	0%
4	18	98	18%	11%
5	29	192	15%	16%
7	28	192	15%	9%
9	16	154	10%	10%
11	14	76	18%	9%
12	2	144	1%	2%
13	7	168	4%	2%
17	27	280	10%	6%
24	25	104	24%	7%
26	17	88	19%	5%
		Average =	13%	7%
		St Dev =	7%	5%
		COV =	59%	67%
		r-value =	0.597	
		p-value =	0.053	

The p-value tests the hypothesis that the true population correlation is zero. The p-value of 0.053 again indicates a weak correlation between the percentage of bad ends and defect losses. The results of the Pearson Correlation Tests imply that the industry's method of counting the bad ends of cant to determine cant quality is not effective and is not related to the yield of usable pallet parts.

4.6 Evaluation of Hardwood Cant Grading Rules

The rules of any grading system should be easy to use. Material grading must be quick and simple, yet accurate and effective. An acceptable grading system will produce quality separations between grades. Evaluation of grade rule application ease will be based on qualitative experience and quantitative analysis.

Cant grade rules were evaluated by examining the defect losses associated with each grade. Total yield was not used for grade rule evaluation because total yield is dependent on processing technique. As cant grade declines from 1 to 3, defect loss for the corresponding grade should increase. Table 25 includes defect losses for each cant grade for the 28 mills studied.

Table 25. Grade Related Defect Losses From Cutting Hardwood Cants into Pallet Parts

Mill #	Defect Loss			
	Grade 1	Grade 2	Grade 3	Average
1	0%	---	---	0%
2	2%	7%	61%	6%
3	1%	7%	50%	3%
4	0%	6%	53%	11%
5	3%	9%	32%	16%
6	2%	4%	52%	7%
7	1%	5%	34%	9%
8	1%	5%	16%	4%
9	4%	10%	36%	10%
10	3%	10%	41%	14%
11	1%	8%	49%	9%
12	2%	---	---	2%
13	2%	---	---	2%
14	1%	11%	30%	4%
15	3%	7%	51%	6%
16	3%	6%	39%	6%
17	2%	9%	28%	6%
18	2%	7%	29%	6%
19	3%	8%	50%	7%
20	3%	14%	34%	12%
21	2%	8%	31%	4%
22	1%	9%	48%	10%
23	8%	11%	24%	14%
24	5%	7%	28%	7%
25	2%	8%	39%	3%
26	1%	4%	---	2%
27	0%	2%	34%	6%
28	4%	7%	40%	7%
Average =	2%	8%	39%	7%
St Dev =	2%	3%	11%	4%
COV =	76%	34%	28%	58%

As expected, defect loss increased with a worsening in cant. The average defect losses for grades 1, 2, and 3 were 2, 8, and 39 percent, respectively. Defect losses were expected to be consistent with the percentage of unsound material by grade according to the proposed hardwood cant grading rules. The low defect losses for grades 1 and 2 were probably due to several factors. High-quality cants with low volumes of unsound material may have caused a skewing of the grade 1 defect losses. The low proportions of unsound material also impact grade 2 defect losses. Cants containing wane (usually from small diameter logs) could be initially classified by unsound volume as a grade 1 cant. The strict “10 percent unsound” face grading criteria resulted in a final grade of grade 2 due to the wane limitation in the cant grading rules. The resulting defect losses were lower than the expected 15 to 30 percent. Also, defect losses were calculated as a function of dimension and kerf losses. Cant material removed as dimension and kerf losses (including end-trim allowances) contained defects. By removing these defects prior to calculating defect losses, defect losses for grade 2 cants were lower then the expected 15 to 30 percent.

The relatively large defect loss associated with grade three is due to the larger cant quality variation within this grade. This is also evident with a comparison of standard deviation between grades. Standard deviations increased from 2 and 3, percent to 11 percent as cant grade worsened from 1 to 3.

Proper grade rules should provide significantly different defect losses between grades. A Tukey Studentized Range Test was used to test for significant differences in defect losses between each grade. An alpha level of 0.05 was chosen to test evidence for correlation between defect loss for each grade. SAS with a general linear model procedure was used for the analysis. Figure 26 is the SAS output from the tukey test for differences between grade related defect losses.

Tukey Studentized Range Test
For Differnces Between Grade Related Defect Losses
General Linear Models Procedure

Tukey's Studentized Range (HSD) Test for variable: DEFL

Alpha= 0.05 Confidence= 0.95 df= 74 MSE= 0.001945
Critical Value of Studentized Range= 3.382

Comparisons significant at the 0.05 level are indicated by '***'.

GRADE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
3 - 2	0.28133	0.31147	0.34161	***
3 - 1	0.33590	0.36524	0.39458	***
2 - 3	-0.34161	-0.31147	-0.28133	***
2 - 1	0.02475	0.05377	0.08279	***
1 - 3	-0.39458	-0.36524	-0.33590	***
1 - 2	-0.08279	-0.05377	-0.02475	***

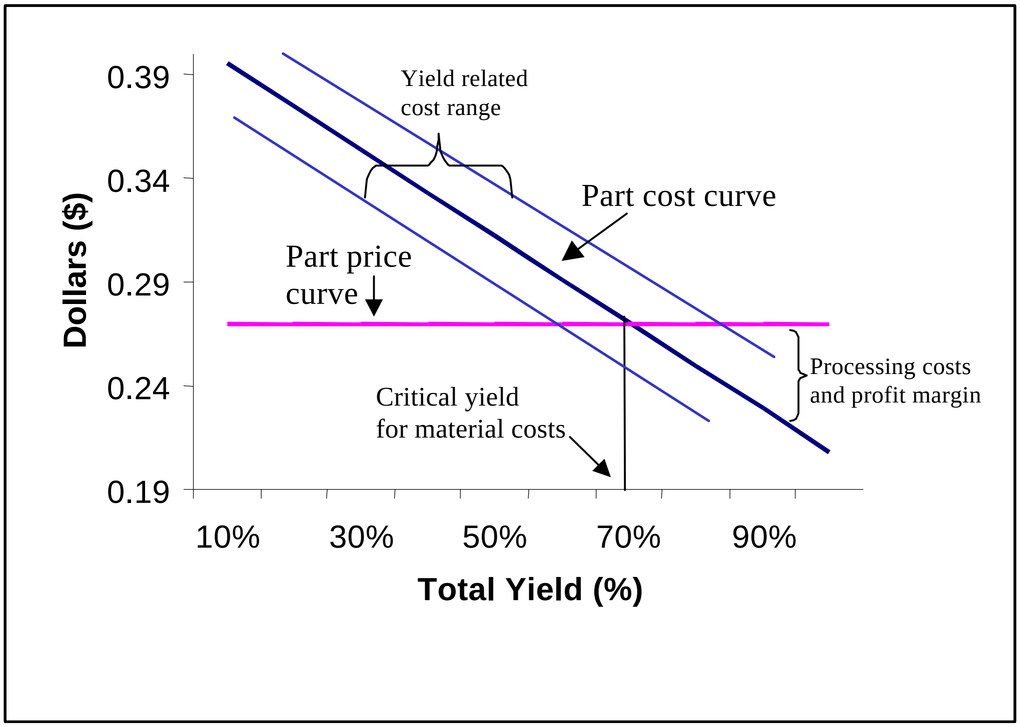
Figure 26. Tukey Studentized Range Test Analysis of Pallet Part Defect Yield Losses between Grades of Hardwood Cants

The defect losses for grades 1, 2, and 3 were tested for similarity. Each defect loss was compared against the defect loss for the other two grades. Grade related defect losses that were significantly different were indicted by the symbols "***". According to the Tukey test output in Figure 26, the defect losses between each grade were significantly different. The different quality divisions between cant grades indicate that the grade rules are effective.

The cant grade rules are easy to apply. The only defects are unsound wood, so determining which features of the cants are defects is simple. Determining the magnitude of internal defects may be subjective, but is often evident through examination of both ends and all four sides. The grading process is quick because the grade rules divided into two processes. Determining the total volume of unsound material often allows the grader the ability to forgo further grading of the sides and ends. The grade rules seem to be quick, effective, and easy to apply.

Handling of the cants to examine both ends and all four sides is often difficult. Depending upon cant size and moisture content, two people were required to grade and restack the cants. Cant grading in production settings would be more difficult than lumber grading, but green chain conveyor systems would allow cant handling by one person. While, the cant grade rules are much easier to apply than lumber grades, physically grading cants is more difficult.

To further simplify the grade rules, a minimum grade rule based on unsound volume could be used. A single grade based on one set of minimum quality criteria would reduce grading time and expenses. Since part material costs are based on total yield, determining the lowest cant quality that allows adequate coverage of production costs is mill specific and dependant on mill design, equipment type, processing procedures, and cutting bill parameters. Figure 27 is an example of the interaction between part material costs, part selling price, and material yield.



- Pallet part price is based on Pallet Profile (July 3, 1998) price listing for a 5/8" X 4" X 40" hardwood pallet part
- Part costs were estimates assuming a 4" X 6" X 12' pallet cant price of $300 per Mbf

Figure 27. Pallet Part Material Costs, Selling Price, and Critical Yield Value for a 5/8" X 4" X 40" Pallet Part Cut From a 4" X 6" X 12' Hardwood Cant

From Figure 27, the critical yield value is approximately 73 percent. Assuming part and cant prices remain constant, the mill would have to achieve a total usable part yield of 73 percent to cover part material costs. To cover production and overhead costs and generate profit, the mill must achieve a yield of more than 73 percent. Since this critical yield value is only true for this processing scenario, determining a minimum cant grade rule that assures coverage of production costs is not possible.

Covering alternative cant costs is another basis for assigning minimum cant grade rules. Alternative cant costs would include selling cants for flooring stock or wood chips. Assuming cants could be sold for approximately the same price as #3A hardwood lumber, cant manufacturers would have little incentive to sell most hardwood cants to pallet manufacturers. For example, #3A, 4/4 red oak lumber prices are approximately $430 per Mbf (Hardwood Market Report, 1999). Cant prices are considerably less at $280 Mbf. No cant yield would justify selling flooring stock at cant prices. Wood chips interact with cant prices in an opposite manner. Currently, wood chips are selling for $18 to $34 per ton in the South East and are worth approximately $52 to $92 per Mbf, respectively (TimberMart South, 1999). Ignoring processing costs, part yields in the range of 19 percent (18/52) to 36 percent (34/92) would be required to justify selling pallet cants as wood chips.

Alternative cant costs cannot be used to establish a minimum cant grade rule. However, a grade rule can be established based on the relationship of pallet part price to cant price and average yield losses that ensures coverage of cant costs. However, the grade rules would only cover cant costs for that specific processing and cost scenario.

The average selling price for pallet parts in the Mid-Atlantic US is $494 per Mbf based on a 5/8” X 3-1/2” X 40” pallet deckboard (Pallet Profile, 1999). Assuming a 10 percent profit margin and 10 processing costs (Ray Piland, 1998) have been added to the part price, the estimated material price for the part is $395 per Mbf. Cant prices are $280 per Mbf (Hardwood Market Report, 1999). The break-even material yield for pallet manufacturers assuring coverage of material costs is 71 percent (280/395)). A sound cant volume of approximately 70 percent would assure defect losses less than the break-even yield for the provided production scenario.

In the proposed hardwood cant grade rules all grades provided statistically significant differences in grade related defect losses. However, grades 1 and 2 provided average defect losses of 2 and 8 percent, respectively. Grade 3 produced a much larger average defect loss of 38 percent. This large difference in grade related defect loses between grades 2 and 3 provided a practical separation for determining cant quality. It is recommended that the proposed grade rules be simplified into a single minimum grade rule similar to the proposed grade 2 rules. The face grading criteria seemed to place high quality cants into lower grades. Specifically, grade 2 cants produced lower than expected defect losses. The 10 percent unsound face grading criteria seemed to be strict. Therefore, a single cant grade rule based entirely on a maximum allowable 30 percent unsound volume is recommended.

Defect loss prediction models are grade specific. By simplifying the cant grade rules to a 30 percent allowable unsound cant volume, a defect loss prediction algorithm for the minimum cant grade rules can be established using data from this research. Appendix C contains a defect loss prediction model for the recommended minimum cant grade rules.

The minimum cant grade rules create opportunities for pallet and cant manufacturers to benefit. Quality cants could be sold at a premium price. Cant sections containing volumetric defect greater than 30 percent could be trimmed from the cant and sold as pulp chips. The remaining short quality cant sections could also be sold at a premium price. Pallet manufacturers would only purchase cants with guaranteed defect losses of less than 30 percent.

4.7 Development of the Pallet Material Yielding System

Pallet part yield and cost prediction equations were combined in an Excel worksheet program called the Pallet Part Yield System (PPYS). PPYS predicts yield and material costs for pallet parts produced from hardwood cants.

PPYS allows pallet manufacturers to accurately predict material yield and part costs. Pallet manufacturers can then use the predicted yields and costs to attain better value from their raw materials and more accurately price their pallets. The program does not consider manufacturing costs. A PPYS user guide is provided in Appendix A.

5 Summary, Conclusions, and Recommendations for Future Research

5.1 Summary

Thirty-one yield studies were conducted throughout the Eastern United States at pallet mills producing pallet parts from hardwood cants. Hardwood pallet cants were graded, and usable pallet part yields and yield losses were determined for each cant grade.

Yield losses were separated into three components: kerf loss, dimension loss, and defect loss. Kerf and dimension losses are a function of raw material and part geometry and were calculated without regard to cant quality. Defect loss is a function of cant quality and was determined for each cant grade.

Mathematical models were developed to predict each yield loss component as a function of cant dimensions, grade, and orientation, cutting bill parameters, pallet part dimensions, and kerf. Dimension and kerf losses were predicted geometrically. Regression analysis was used to predict defect loss. The models were combined to predict the total yield of usable pallet parts and pallet part material costs as a function of cant price and part yield.

The effectiveness of the proposed cant grading rules was determined by grading cants and analyzing the cant grade distributions and corresponding pallet part yields. The grade rules resulted in statistically different pallet part yields between grades. However, a more practical single cant grade based on the minimum quality for the proposed grade 2 rules is recommended.

5.2 Conclusions

Conclusions may not be applicable when processing pallet parts from hardwood cants outside the parameters of the research data. Data ranges are included in Table 26.

Table 26. Data Ranges for the Application of Research Conclusion for Producing Pallet Parts from Hardwood Cants

	Cant			Part			Kerf
	Thickness	Width	Length	Thickness	Width	Length	(")
Range (lo) =	3	4	96	0.438	3	31.75	0.036
Range (high) =	7.25	8	196	1.875	6	72	0.188

Yield models based on raw material geometry and grade, processing equipment, and pallet part geometry accurately predict the yield of usable pallet parts cut from hardwood cants. Other conclusions inferred from the research are as follows:

- Cant quality significantly effects pallet part costs.
- Cants grades 1, 2, and 3 resulted in average pallet part yields of 83, 77, and 47 percent, respectively.
- The pallet industry is using a high percentage of premium quality hardwood cants. 70 percent of the cants randomly selected for the research were grade 1 hardwood cants.
- The pallet industries current method of counting the number of “bad” ends per cant bundle is not reliable for predicting cant quality.
- The proposed hardwood cant grade resulted in defect losses of 2, 8, and 39 percent for grades 1, 2, and 3, respectively.
- The average kerf loss is the largest yield loss component at 10 percent and is followed by defect and dimension losses at 7 and 5 percent, respectively.

- Pallet part yields are seven-percent higher when thin-kerf band saws are used instead of circle gang ripsaws.
- Cost models based on pallet part yield and cant costs and quality distributions accurately predict the material costs of producing pallet parts from hardwood cants.
- Cutting multiple size parts result in a two-percent higher yield compared to single size part production.
- Salvaging short material increased part yield nearly 1 percent.

5.3 Recommendations for Future Research

The models may not be applicable when processing pallet parts from hardwood cants outside the parameters of the research data. Yield algorithms must be developed for all production ranges and pallet part raw materials. While this research produced yielding algorithms to predict the yields of usable pallet parts from hardwood cants, other pallet raw materials are not considered. The provided yield algorithms cannot predict material yields from hardwood lumber or softwood lumber and cants. Since yield algorithms are based on studies conducted in the Eastern United States, the prediction algorithms are not appropriate for use outside this geographical area.

Algorithms must be developed to optimize part production as a function of cutting bill parameters. Pallet part costs would decrease through the optimization of processing techniques.

Cant quality distributions must be further examined. To determine the necessity and impact of hardwood cant grading rules, studies on cant quality distribution from sawmills must be conducted. Additionally, studies should be conducted to determine the impacts of local and regional influences on cant quality and supply.

A hardwood cant grading system should be adopted by the pallet and sawmill industries. A single, minimum, hardwood cant grade would be both practical and effective. Due to large differences in defect losses between grades 2 and 3 and because the costs of pallet parts from grade 3 cants will exceed the value in most markets, the grade rules should be simplified into a maximum allowable 30 percent unsound volume. Grade application would be based general visual observations of total unsound cant volume.

The proposed face grades based on counting the number of sound faces were not effective and appeared to provide inappropriately low defect losses for grade one and two cants. Alternative definitions for allowable face grades should be studied due to the precedent of face grading for separating lumber by quality.

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7 Appendix A

Pallet Material Yield System User Guide

Pallet Part Yield System

Introduction

Pallet Part Yield System (PPYS) is an Excel based program that predicts yield and material costs for pallet parts produced from hardwood cants. The program uses input variables relating to cant and part dimensions, cutting bill parameters, kerf, and cant quality and cost. All calculations are based on actual dimensions.

PPYS allows pallet manufacturers to accurately predict material yield and part costs. Pallet manufacturers can then use the predicted yields and costs to attain better value from their raw materials and more accurately price their pallets. The program does not consider manufacturing costs and should not be used for direct part pricing.

Hardware and Software Requirements

PPYS is a worksheet program for Microsoft Excel©97. An IBM compatible computing system with Excel©97 (or later version) is required.

PPYS Installation

PPYS is open as an Excel worksheet. From the excel file menu, select open. Highlight PPYS and open file.

Using PPYS

Selecting the Single Size Part or Multiple Size Part Worksheet

PPYS contains two worksheets that are used for different processing scenarios: Single Size Part and Multiple Size Part Worksheets. The Single Size Part Worksheet only predicts material yields and costs for production scenarios that involve processing one part size. The entire production scenario must contain one cant and part size. The Single Size Part Worksheet requires simpler input than the Multiple Size Part Worksheet. The Multiple Size Part Worksheet allows for up to nine sizes of parts to be produced during one production scenario.

Production input

PPYS computes part yields and material costs from production input supplied by the user. The program uses input variables relating to actual cant and part dimensions, cutting bill parameters, kerf, and cant quality and cost. Single and multiple part production scenarios require different inputs.

Production input for single part size production scenarios consists of 11 variables:

- Cant thickness (in)
- Cant width (in)
- Cant length (in)
- Part thickness (in)
- Part width (in)
- Part length (in)
- Kerf (in)
- % grade 1 cants
- % grade 2 cants
- % grade 3 cants
- Cant cost ($ per Mbf)

Multiple size part prediction equations require 18 input variables:

- cant thickness, width, and length
- length of cant sections 1, 2, and 3
- number of cant sections 1, 2, and 3 to be cut from each cant
- part width, length, and thickness 1, 2, and 3
- number of part thickness 1, 2, and 3 to be cut from each quality cant section
- salvage lengths 1 and 2
- kerf
- % grade 1 cants
- % grade 2 cants
- % grade 3 cants

Pallet Part Yield Output and Prediction Equations

Program output consists of two categories: pallet part material yield and cost. Part material yield outputs includes kerf loss, dimension loss, defect loss (grade 1, 2, and 3), and total yield (grade 1, 2, and 3). Kerf and dimension losses are estimated geometrically. Defect loss is predicted using a regression model based on actual mill study data. Total yield is then determined as a function of kerf, dimension, and defect losses.

Kerf loss is estimated as the proportion of ripsaw kerf volume to cant volume. The kerf loss prediction equation determines the number of rip saw lines in the transverse cant face or cross-section. The equation also estimates the total length of parts cut from the cant to determine the length of the saw lines. Kerf volume is then determined and related to cant volume. Equation 1 is the kerf loss prediction equation for single size parts.

$$\text{Predicted kerf loss} = \left(\left[\left(\left[(\text{Cant width} + \text{Kerf}) / (\text{Part thickness} + \text{Kerf}) \right]^{\text{Truncated}} - 1 \right) * \text{Kerf} \right] * \text{Cant thickness} * \left(\left[(\text{Cant length} / \text{Part length})^{\text{Truncated}} \right] * \text{Part length} \right) \right] / 144) / \left[\text{Cant thickness} * \text{Cant width} * \text{Cant length} / 144 \right] \quad 1$$

Equation 2 is the kerf loss prediction equation for multiple size parts.

$$\text{Kerf loss} = (((((\text{Number of part thickness 1} + \text{Number of part thickness 2} + \text{Number of part thickness 3}) - 1) * \text{Kerf}) * \text{Cant thickness} * ((\text{Number of cant section 1} * \text{Length of cant section 1}) + (\text{Number of cant section 2} * \text{Length of cant section 2}) + (\text{Number of cant section 3} * \text{Length of cant section 3}))) / 144) / (\text{Cant thickness} * \text{Cant width} * \text{Cant length} / 144) \quad 2$$

Dimension loss is calculated assuming dimension loss material has not been defected and contains no rip saw kerf. Dimension loss material includes the cant volume not contained in the produced parts, salvage, and ripsaw kerf volumes. This material may be used for salvage or discarded if its dimensions are unacceptable. Dimension loss is the ratio of cant volume not processed into parts, kerf, and salvage material to the total volume of the cant. Equation 3 is the dimension loss prediction equation for single size parts.

Dimension loss = [[([((Cant width + Kerf) / (Part thickness + Kerf)) [((Cant width + Kerf) / (Part thickness + Kerf))$^{\text{Truncated}}$]] * Part thickness * Part width * [((Cant length / Part length)$^{\text{Truncated}}$) * Part length]) / 144] + [(((Cant length / Part length) – [(Cant length / Part length)$^{\text{Truncated}}$]) * Part length * Cant thickness * Cant width) / 144]] / [Cant width * Cant thickness * Cant length / 144] (3)

Equation 4 is the dimension loss prediction equation for multiple size parts.

Dimension loss = 1 – (((((((Number of part thickness 1 * Part thickness 1) + (Number of part thickness 2 * Part thickness 2) + (Number of part thickness 3 * Part thickness 3)) + (((Number of part thickness 1 + Number of part thickness 2 + Number of part thickness 3) – 1) * Kerf)) * Cant thickness * ((Cant section 1 length * Number of cant section 1) + (Cant section 2 length * Number of cant section 2) + (Cant section 3 length * Number of cant section 3))) / 144) + ((Salvage 1 length * Number of salvage length 1) + (Salvage 2 length * Number of salvage length 2)) * Cant thickness * Cant width / 144)) / (Cant thickness * Cant width * Cant length / 144)) (4)

Defect loss is a function of cant quality, part dimensions, cant dimension, and ripsaw kerf. Cant quality is determined by the cant grade distributions (input variables are % grade 1, 2, and 3) and are based on the proposed grading rules for hardwood pallet cants. Defect loss is determined for each grade. Equations 5, 6, and 7 are defect loss prediction equations for grades 1, 2, and 3, respectively.

$$\text{Grade 1 Defect Loss} = -0.000409 \text{ Part length} + 0.000007802 \text{ Cant length} + 0.008375 \text{ Part thickness} - 0.001014 \text{ Cant width} + 0.007197 \text{ Part width} + 0.063545 \text{ Kerf} \quad (5)$$

$$\text{Grade 2 defect loss} = -0.000475 \text{ Part length} + 0.000019253 \text{ Cant length} + 0.013680 \text{ Part thickness} + 0.009731 \text{ Cant width} - 0.003512 \text{ Part width} + 0.092093 \text{ Kerf} \quad (6)$$

$$\text{Grade 3 Defect loss} = 0.003042 \text{ Part length} + 0.000318 \text{ Cant length} + 0.072404 \text{ Part thickness} + 0.009136 \text{ Cant width} + 0.039298 \text{ Part width} - 0.673188 \text{ Kerf} \quad (7)$$

Part yield is a function of kerf, dimension, and defect losses and is determined for each cant grade**.** Total part yield is the overall yield of usable material. Equation 8 is the part yield prediction equation.

$$\text{Part yield} = 1 - (\text{Kerf loss} + \text{Dimension loss} + \text{Defect loss}) \quad (8)$$

Predicted part material costs are calculated as a function of part yield. The predicted part yield losses for the production scenario are first multiplied by cant volume. This gives the volume of loss material per cant. The volume of yield loss material per cant is proportioned by multiplying the yield loss volume per cant by the ratio of the volume of each part to the total volume of parts cut from the cant. The proportioned yield loss volume is then added to the part volume and multiplied by the cant cost or cant purchase price. Part material costs are determined for each grade and for the overall production scenario. Equation 9 is the material cost prediction equation for single size parts.

$$\text{Cost per part} = ((((\text{Part thickness} * \text{Part width} * \text{Part length}) / ((((\text{Cant length} / \text{Part length})^{\text{Truncated}}) * \text{Part length}) * ((((\text{Cant width} + \text{Kerf}) / (\text{Part thickness} + \text{Kerf})^{\text{Truncated}}))* \text{Part thickness}) * \text{Part width})) * ((\text{Cant thickness} * \text{Cant width} * \text{Cant length} / 144)) * (\text{Kerf loss} + \text{Dimension loss} + \text{Defect Loss}))) + (\text{Part thickness} * \text{Part width} * \text{Part length} / 144)) * (\$ / \text{bf}) \quad (9)$$

Equation 10 is the material cost prediction equation for multiple size parts.

Cost per part = ((((Part thickness A * Part width A * Part length A / 144)
/ (((Part thickness 1 * Number of part thickness 1) *
(((Part thickness 2 * Number of part thickness 2) *
(((Part thickness 3 * Number of part thickness 3)) *
Part width * ((Cant salvage length 1 * Number of cant
salvage length 1) + (Cant salvage length 2 * Number
of cant salvage length 2) + (Cant salvage length 3 *
Number of cant salvage length 3)) / 144)) * (Cant
thickness * Cant width * Cant length / 144) * (Kerf loss
+ Dimension Loss + Defect Loss)) + (Part thickness *
Part length * Part width / 144)) * ($ / bf) 10

8 Appendix B

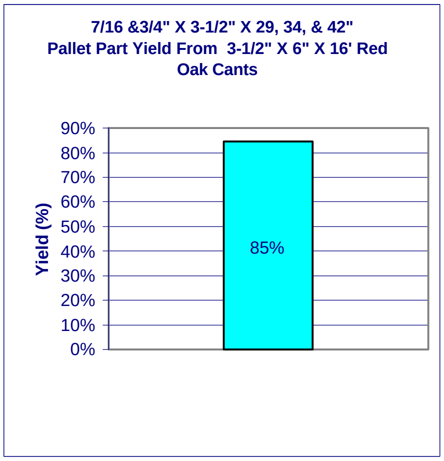
Mill Study Data

Mill Numer 1
8/10/98

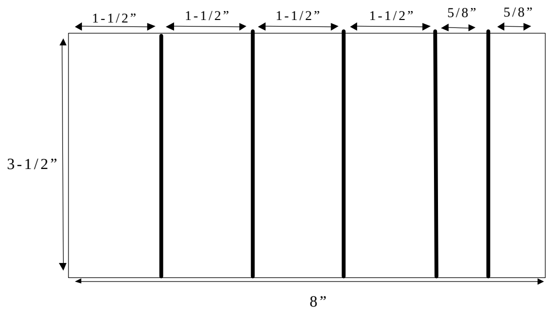
I. Equipment:
Circle Gang
Kerf: 0.135"

II. Raw Material:
Cant Size: 3-1/2" X 8" X 16'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringers and Deckboards
Size: Stringers: 1-1/4" X 3-1/2" X 46"
Deckboards 5/8" X 3-1/2" X 46"



IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Part Volume (bdft)	Salvage (bdft)	Yield
1	86	3244	2743	0	85%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	7%	0%	8%

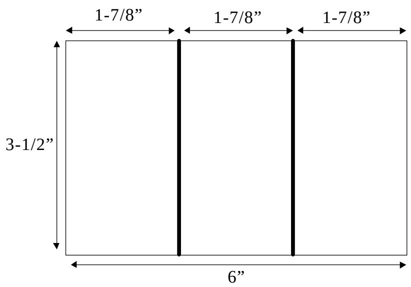
Mill Number 2
3/12/98

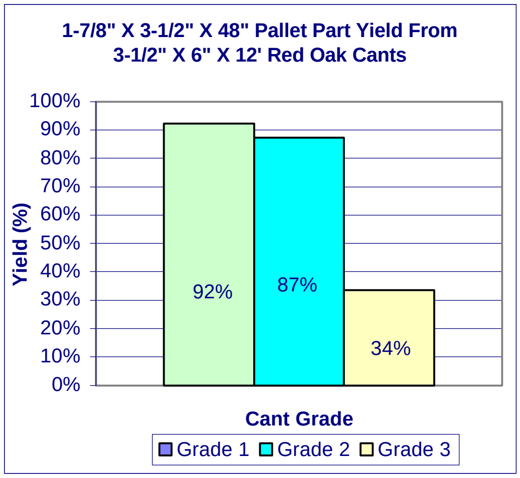
I. Equipment:
Circle Gang
Kerf : 0.133"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 12'
Species: Red Oak

III. Parts Produced:
Type: Stringers
Size: 1-7/8" x 3-1/2" x 48"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stinger Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	33	693	608	33	92%
2	14	294	247	11	87%
3	2	42	14	0	34%
Total =	49	1029	869	44	88%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	2%	2%	4%
2	2%	7%	4%
3	2%	61%	4%
Total Loss =	2%	6%	4%

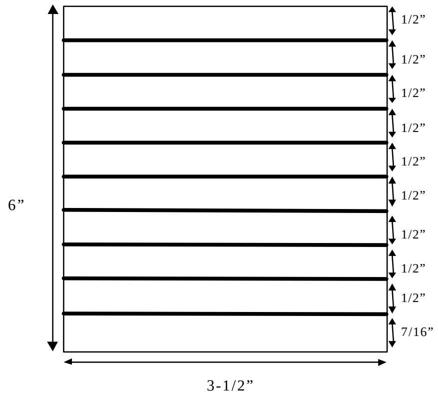
Mill Study 3
5/20/98

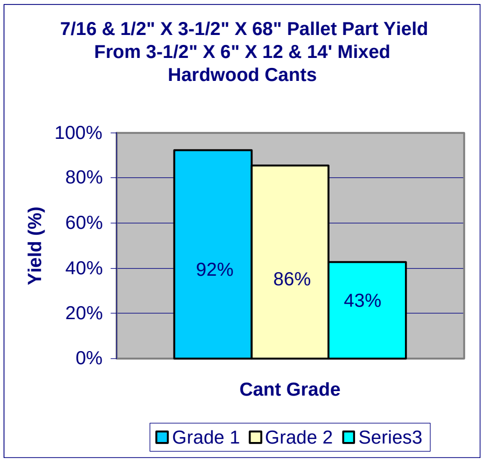
I. Equipment:
Multi-head Bandsaw
Kerf: 0.055"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 12 &14'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 1/2" X 3-1/2" X 68-1/2"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	84	1960	1375	470	92%
2	8	196	136	37	86%
3	4	98	40	5	43%
Total =	96	2254	1551	512	89%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	1%	7%
2	0%	7%	7%
3	0%	50%	7%
Total Loss =	0%	3%	7%

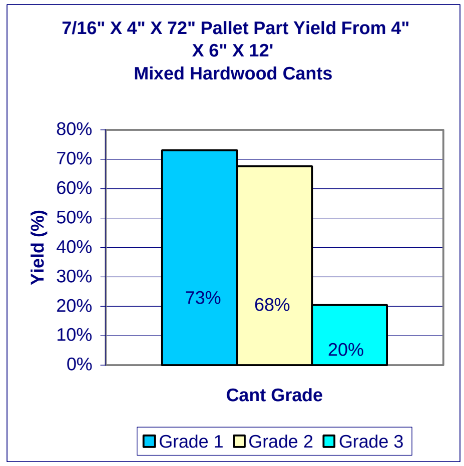
Note: Dimension and kerf loss calculation based on 14' cant lengths

Mill Number 4
7/23/98

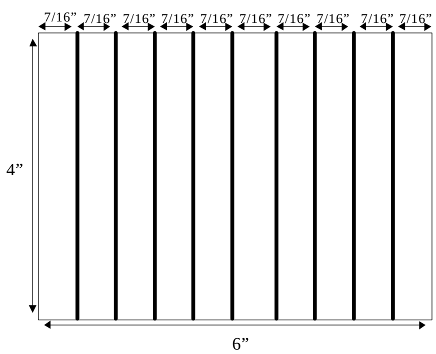
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 4" X 6" X 12'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 7/16" X 4" X 72"



IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	27	648	468	7	73%
2	13	312	193	27	68%
3	9	216	36	40	20%
Total =	49	1176	697	73	63%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	8%	0%	19%
2	8%	6%	19%
3	8%	53%	19%
Total Loss =	8%	11%	19%

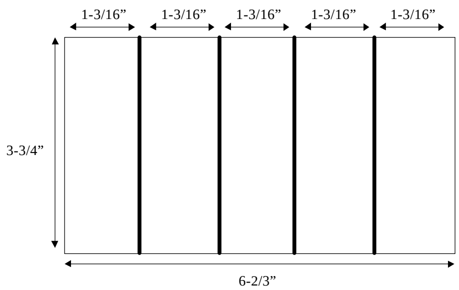
Mill Number 5
7/22/98

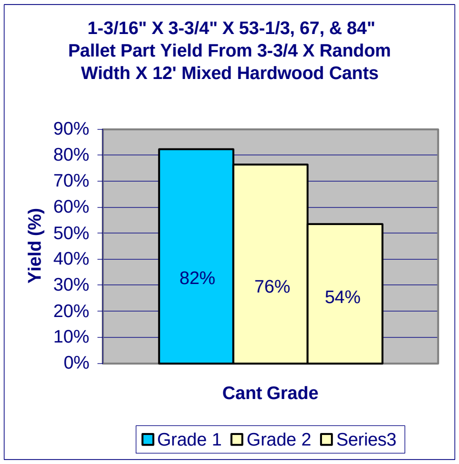
I. Equipment:
Circle Gang
Kerf: 0.175"

II. Raw Material:
Cant Size: 3-3/4 X Random Width X 12'
Species: Mixed Hardwoods

III. Parts Produced:
Type: Stingers
Size: 1-3/16" X 3-3/4" X 53-1/3, 67, & 84"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	29	614	505	0	82%
2	33	730	556	0	76%
3	34	770	413	0	54%
Total =	96	2114	1474	0	70%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	5%	3%	10%
2	5%	9%	10%
3	5%	32%	10%
Total Loss =	5%	16%	10%

Note: Average cant width was assumed to be 6-2/3" for dimension and kerf loss calculations.

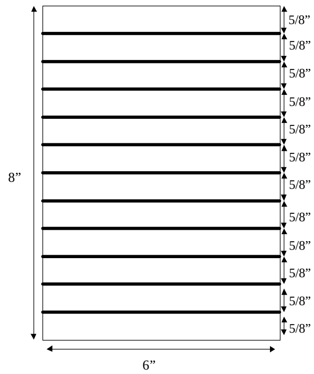
Mill Number 6
7/14/97

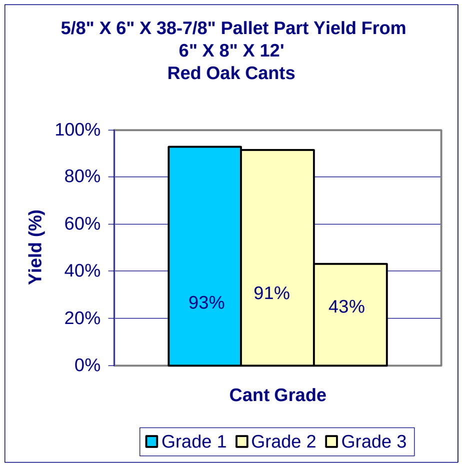
I. Equipment:
Multi-head Bandsaw
Kerf: 0.040"

II. Raw Material:
Cant Size: 6" X 8" X 12'
Species: Red Oak

III. Parts Produced:
Type: Deckboards
Size: 5/8" X 6" X 38-7/8"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	46	2208	1681	396	93%
2	12	576	469	63	91%
3	5	240	103	0	43%
Total =	63	3024	2253	459	88%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	1%	2%	4%
2	1%	4%	4%
3	1%	52%	4%
Total Loss =	1%	7%	4%

Note: Salvage length 27" was included in cutting bill.

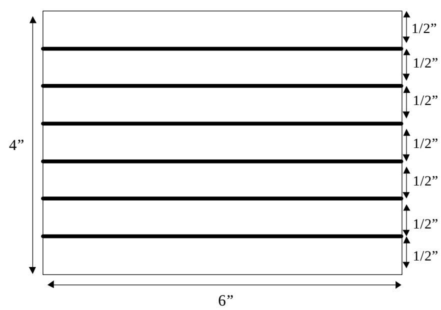
Mill Number 7
5/21/98

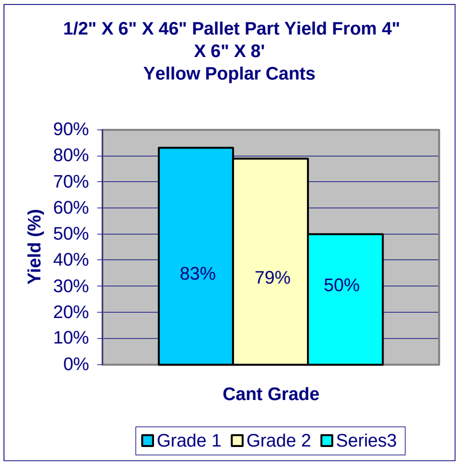
I. Equipment:
Multi-head Bandsaw
Kerf: 0.050"

II. Raw Material:
Cant Size: 4" X 6" X 8'
Species: Yellow Poplar

III. Parts Produced:
Type: Deckboards
Size: 1/2" X 6" X 46"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	58	928	771	0	83%
2	16	256	202	0	79%
3	22	352	175	0	50%
Total =	96	1536	1148	0	75%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	9%	1%	7%
2	9%	5%	7%
3	9%	34%	7%
Total Loss =	9%	9%	7%

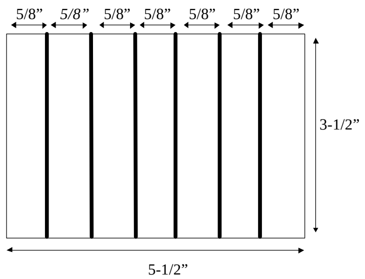
Mill Number 8
2/19/98

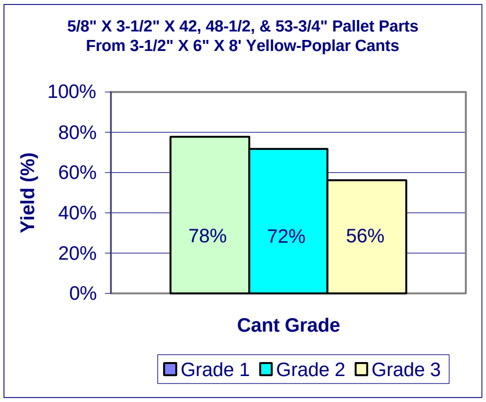
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 3-1/2" X 5.5" X 8'
Species: Yellow Poplar

III. Parts Produced:
Type: Deckboards
Size: 5/8" X 3-1/2" X 42, 48-1/2, & 53-3/4"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	39	501	370	0	74%
2	10	128	86	6	70%
3	9	116	65	5	59%
Total =	58	744	521	11	71%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	12%	1%	13%
2	12%	5%	13%
3	12%	16%	13%
Total Loss =	12%	4%	13%

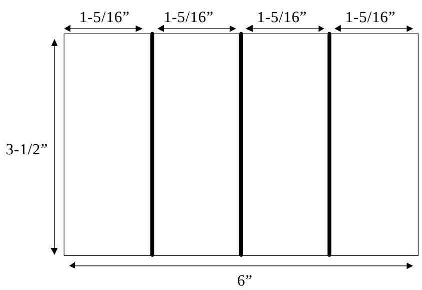
Mill Number 9
7/21/98

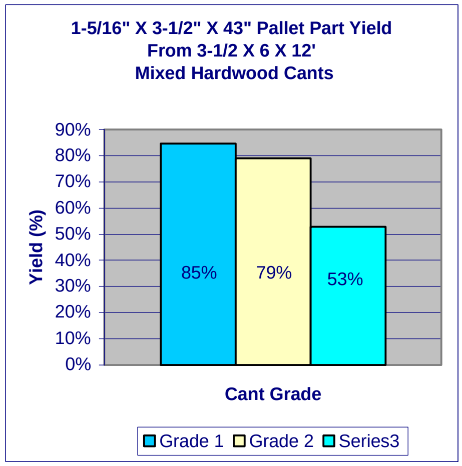
I. Equipment:
Circle Gang
Kerf: 0.155"

II. Raw Material:
Cant Size: 3-1/2 X 6 X 12'
Species: Mixed Hardwoods

III. Parts Produced:
Type: Stingers
Size: 1-5/16" X 3-1/2" X 43"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	50	1050	798	107	85%
2	17	357	258	31	79%
3	10	210	110	2	53%
Total =	77	1617	1166	140	79%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	4%	4%	7%
2	4%	10%	7%
3	4%	36%	7%
Total Loss =	4%	10%	7%

Note: Length related dimension loss was assumed to be zero due to 15" cant salvage lengths.

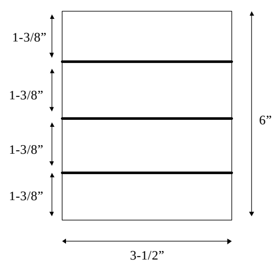
Mill Number 10
8/11/97

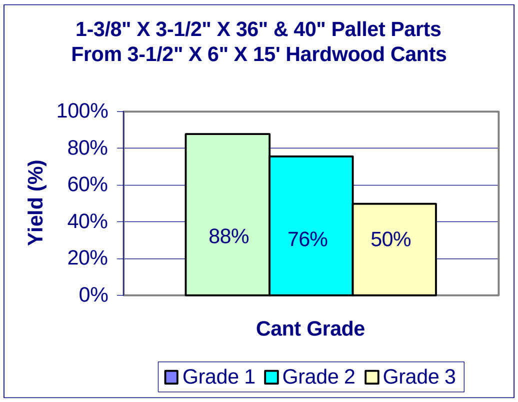
I. Equipment:
Cirlce Gang
Kerf: .055"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 15'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringers
Size: 1-3/8" X 3-1/2" X 36 & 40"

IV. Sawing Pattern



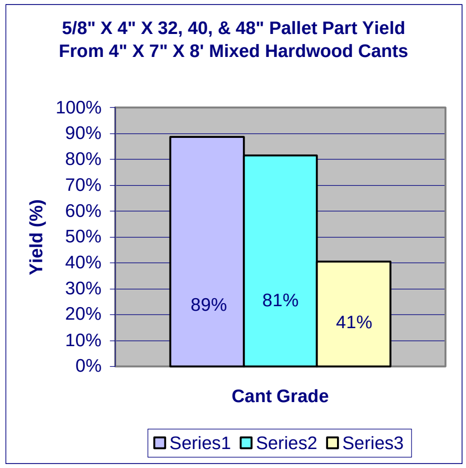


V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	40	1479	1300	0	88%
2	21	551	447	0	81%
3	25	656	328	0	50%
Total =	86	2686	2075	0	77%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	6%	3%	3%
2	6%	10%	3%
3	6%	41%	3%
Total Loss =	6%	14%	3%

Mill Number 11
8/9/98

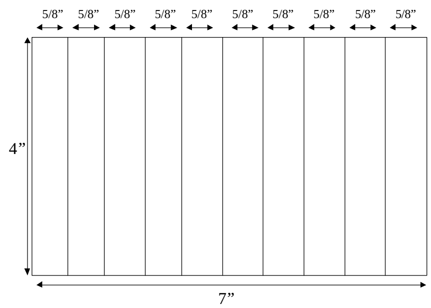


I. Equipment:
Multi-head Band Saws
Kerf: 0.080"

II. Raw Material:
Cant Size: 4" X 7" X 8'
Species: Mixed Hardwoods

III. Parts Produced:
Type: Deckboard
Size: 5/8" X 4" X 32, 40, & 48"

IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Deckboard Volume (bdft)	Salvage (bdft)	Yield
1	19	355	315	0	89%
2	15	280	228	0	81%
3	4	75	30	0	41%
Total =	38	709	573	0	81%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	1%	10%
2	0%	8%	10%
3	0%	49%	10%
Total Loss =	0%	9%	10%

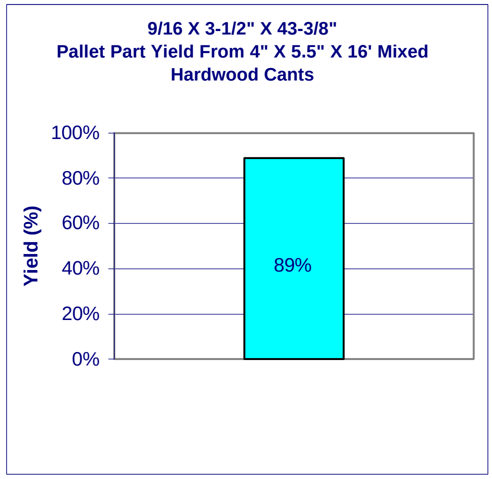
Note: Best possible dimension yields were assumed. This may be reflected in high grade loss values.

Mill Number 12
8/12/98

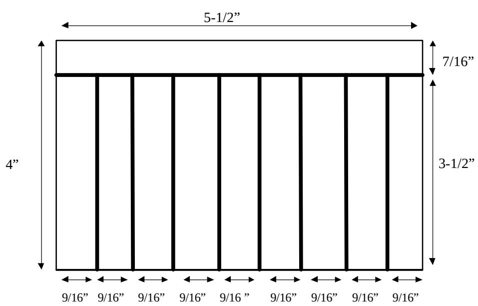
I. Equipment:
Multi-head Band Saw
Kerf: 0.055"

II. Raw Material:
Cant Size: 4" X 5.5" X 16'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 9/16 X 3-1/2" X 43-3/8"



IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Deckboard Volume (bdft)	Salvage (bdft)	Yield
1	72	2112	1695	201	89%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	2%	9%

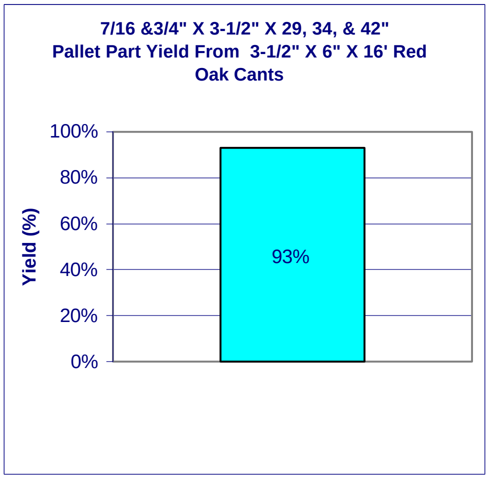
Note: Cant salvage length of 22-1/2" provided no length related dimension loss.

Mill Number 13
8/10/98

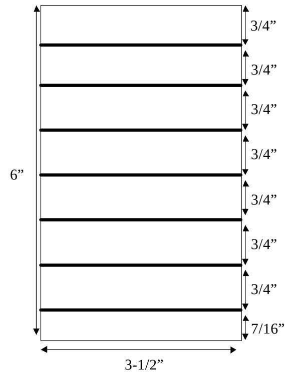
I. Equipment:
Circle Gang
Kerf: 0.055"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 16'
Species: Red Oak

III. Parts Produced:
Type: Deckboards
Size: 7/16 & 3/4" X 3-1/2" X 29, 34, & 42"



IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Deckboard Volume (bdft)	Salvage (bdft)	Yield
1	84	2352	2185	0	93%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	2%	6%

Note: 7/16" deckboards were only sawn on cants with widths equal 6.0175" or greater.

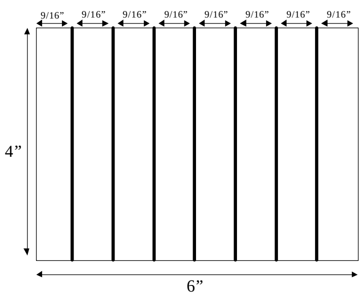
Mill Number 14
2/24/98

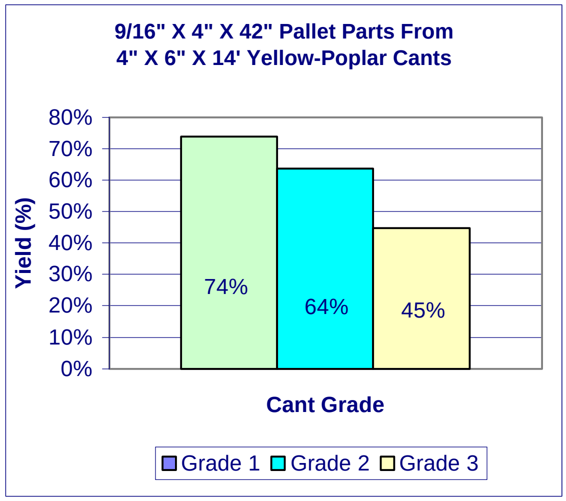
I. Equipment:
Gang Band
Kerf : 0.1875"

II. Raw Material:
Cant Size: 4" X 6" X 14'
Species: Yellow-Poplar

III. Parts Produced:
Type: Deckboards
Size: 9/16" X 4" X 42"

IV. Sawing Pattern



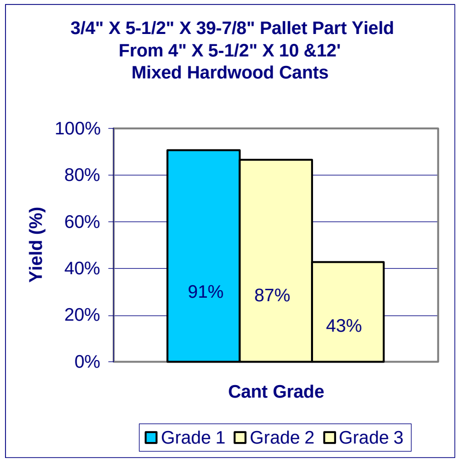


V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	37	1036	760	6	74%
2	1	28	14	6	64%
3	4	112	42	18	45%
Total =	42	1176	816	30	71%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	3%	1%	22%
2	3%	11%	22%
3	3%	30%	22%
Total Loss =	3%	4%	22%

Mill Number 15
3/13/97

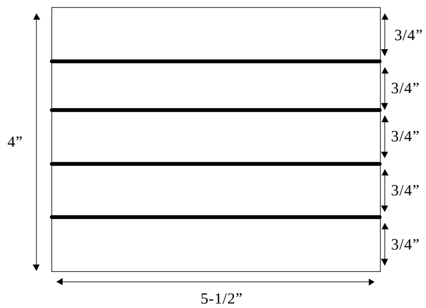


I. Equipment:
Multi-head Bandsaw
Kerf: 0.036"

II. Raw Material:
Cant Size: 4" X 5-1/2" X 10 & 12'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 3/4" X 5-1/2" X 39-7/8"

IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis

Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	97	1789	1614	10	91%
2	23	422	340	29	87%
3	6	110	37	24	43%
Total =	126	2321	1991	64	88%

Table 4. Yield Loss Analysis

Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	3%	3%	4%
2	3%	7%	4%
3	3%	51%	4%
Total Loss =	3%	6%	4%

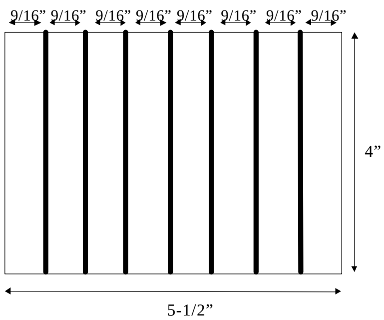
Mill Number 16
1/7/98

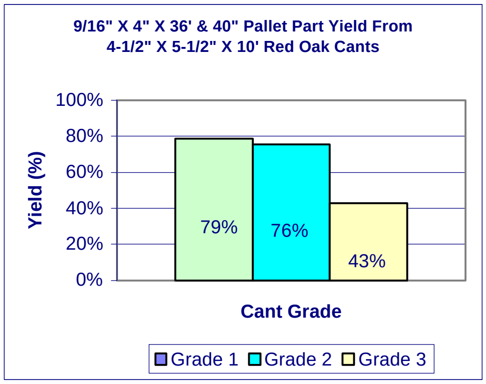
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 4" X 5-1/2" X 10'
Species: Red Oak

III. Parts Produced:
Type: Stringers
Size: 9/16" X 4" X 36"
9/16" X 4" X 40"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	49	898	694	13	78%
2	8	147	111	0	76%
3	3	55	24	0	43%
Total =	60	1100	829	13	76%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	2%	3%	16%
2	2%	6%	16%
3	2%	39%	16%
Total Loss =	2%	6%	16%

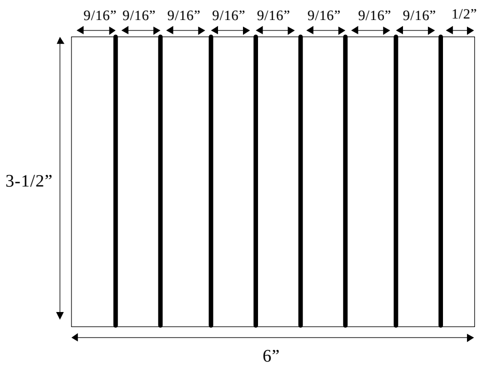
Mill Number 17
7/21/97

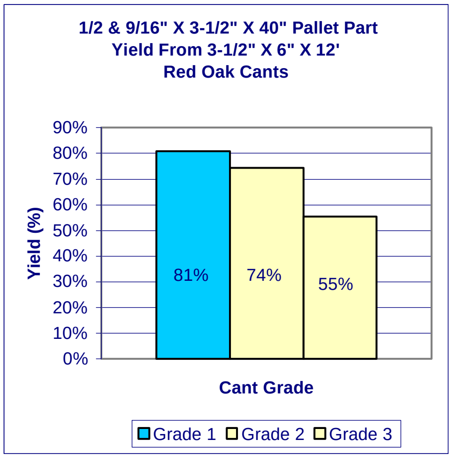
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 12'
Species: Red Oak

III. Parts Produced:
Type: Deckboards
Size: 1/2 & 9/16" X 3-1/2" X 36"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	90	1890	1529	0	81%
2	39	819	610	0	74%
3	11	231	128	0	55%
Total =	140	2940	2267	0	77%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	2%	17%
2	0%	9%	17%
3	0%	28%	17%
Total Loss =	0%	6%	17%

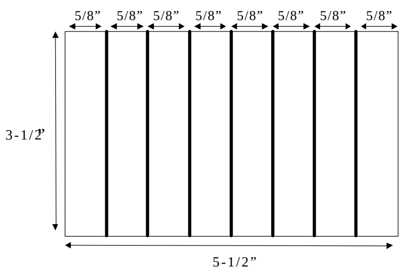
Mill Number 18
5/21/97

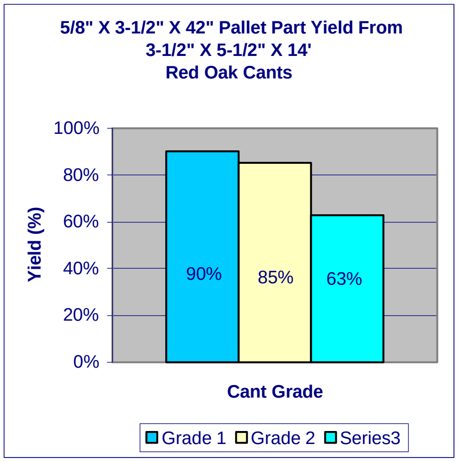
I. Equipment:
Circle Gang
Kerf: .068"

II. Raw Material:
Cant Size: 3-1/2" X 5-1/2" X 14'
Species: Red Oak

III. Parts Produced:
Type: Deckboards
Size: 5/8" X 3-1/2" X 42"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	51	1250	1129	0	90%
2	27	662	564	0	85%
3	7	172	108	0	63%
Total =	85	2083	1801	0	86%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	2%	8%
2	0%	7%	8%
3	0%	29%	8%
Total Loss =	0%	6%	8%

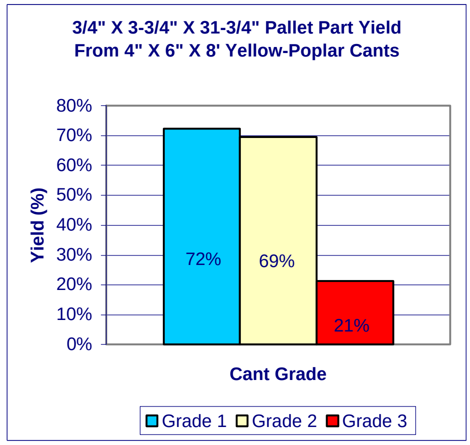
Mill Number 19
7/23/97

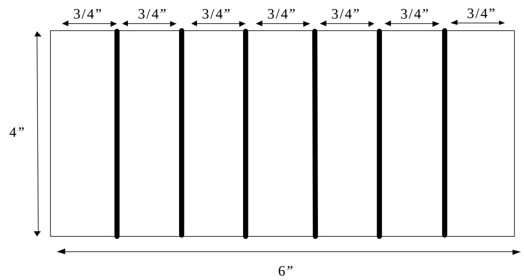
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 4" X 6" X 8'
Species: Poplar

III. Parts Produced:
Type: Deckboard
Size: 3/4" X 3-3/4" X 31-3/4"

IV. Sawing Pattern



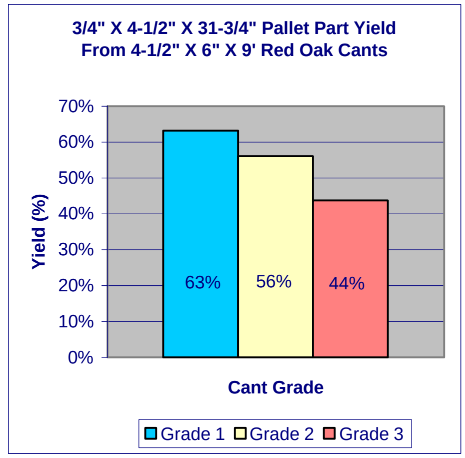


V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	22	352	243	63	84%
2	7	112	75	17	79%
3	2	32	12	0	38%
Total =	31	496	339	80	81%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	1%	3%	12%
2	1%	8%	12%
3	1%	50%	12%
Total Loss =	1%	7%	12%

Mill Number 20
7/23/97

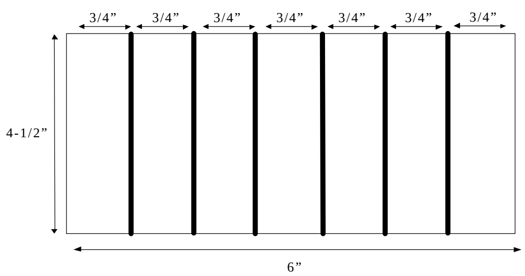


I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 4-1/2" X 6" X 9'
Species: Red Oak

III. Parts Produced:
Type: Deckboard
Size: 3/4" X 4-1/2" X 31-3/4"

IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	20	405	298	0	74%
2	12	243	154	0	63%
3	10	203	87	0	43%
Total =	42	851	539	0	63%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	12%	3%	11%
2	12%	14%	11%
3	12%	34%	11%
Total Loss =	12%	12%	11%

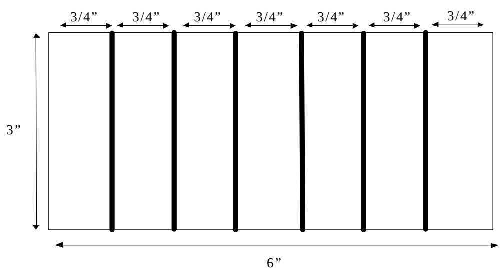
Mill Number 21
7/23/97

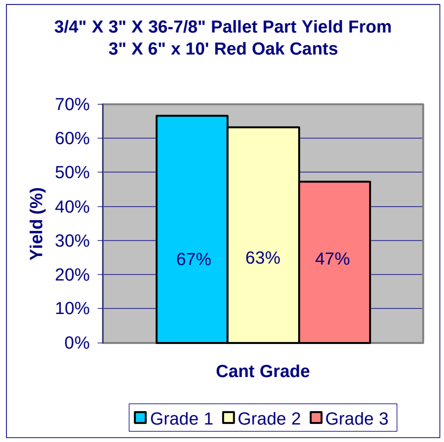
I. Equipment:
Circle Gang
Kerf: 0.125"

II. Raw Material:
Cant Size: 3" X 6" X 10'
Species: Red Oak

III. Parts Produced:
Type: Deckboard
Size: 3/4" X 3" X 36-7/8"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	46	690	541	0	78%
2	9	135	97	0	72%
3	2	45	22	0	49%
Total =	57	870	660	0	76%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	8%	2%	12%
2	8%	8%	12%
3	8%	31%	12%
Total Loss =	8%	4%	12%

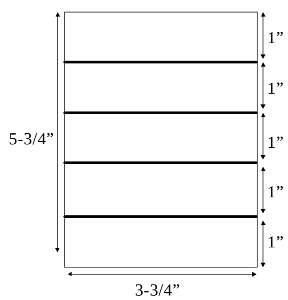
Mill Number 22
3/13/98

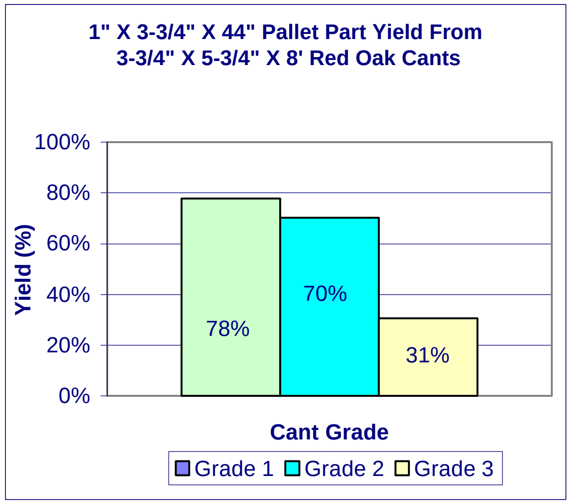
I. Equipment:
Gang Band
Kerf : 0.055"

II. Raw Material:
Cant Size: 3-3/4" X 5-3/4" X 8'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 1" x 3-3/4" x 44"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	50	719	545	18	78%
2	9	129	88	4	70%
3	13	187	46	37	31%
Total =	72	1035	679	59	70%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	17%	1%	4%
2	17%	9%	4%
3	17%	48%	4%
Total Loss =	17%	10%	4%

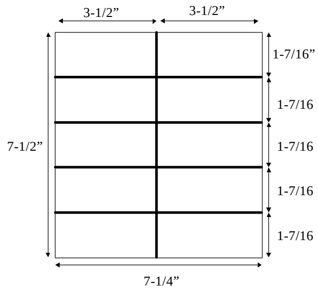
Mill Number 23
5/23/98

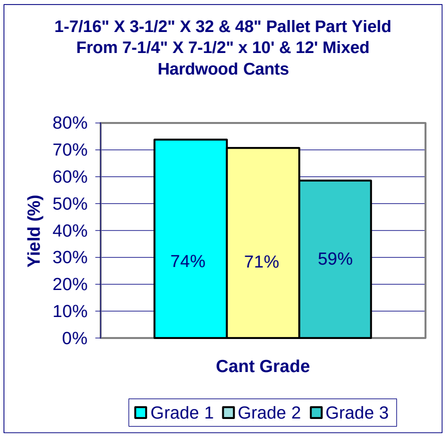
I. Equipment:
Gang Band
Kerf: 0.065"

II. Raw Material:
Cant Size: 7-1/4" X 7-1/2" X 10' & 12'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringer
Size: 1-7/16" X 3-1/2" X 32" & 48"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	4	181	134	0	74%
2	21	961	680	0	71%
3	11	508	297	0	59%
Total =	36	1649	1111	0	67%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	15%	8%	3%
2	15%	11%	3%
3	15%	23%	3%
Total Loss =	15%	14%	3%

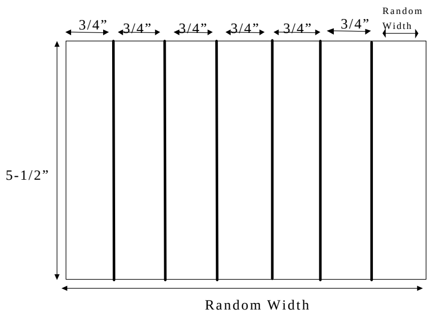
Mill Number 24
7/13/98

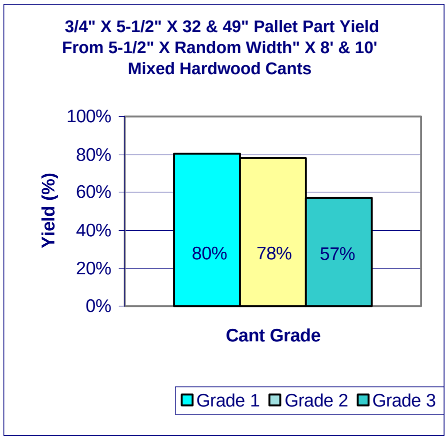
I. Equipment:
Circle Gang
Kerf: 0.155"

II. Raw Material:
Cant Size: 5-1/2" Random Width" X 8' & 10'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 3/4" X 5-1/2" X 32 & 49"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Deckboard Volume (bdft)	Salvage (bdft)	Yield
1	36	948	739	30	80%
2	11	285	217	7	78%
3	5	110	63	0	57%
Total =	52	1344	1019	37	78%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	0%	5%	15%
2	0%	7%	15%
3	0%	28%	15%
Total Loss =	0%	7%	15%

- Dimension loss of 3% was assumed from resiudual volume due to random cant width.
- Trim loss of 0% was assumed because manufacturer requires 8" trim allowance in cants (actual 8' cant length = 104").
- Kerf loss based on approximate average cant width (6.2").

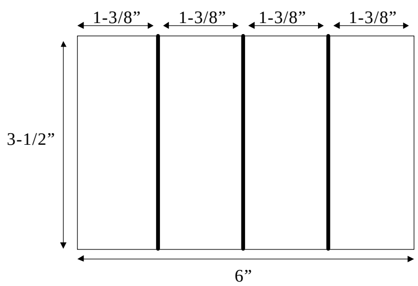
Mill Number 25
3/12/98

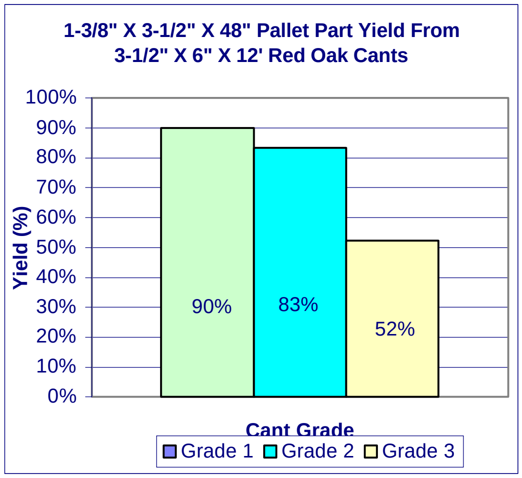
I. Equipment:
Pendu Saw System: Circle Gang
Kerf : 0.131"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 12'
Species: Red Oak

III. Parts Produced:
Type: Stringers
Size: 1-3/8" x 3-1/2" x 48"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis

Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Stringer Volume (bdft)	Salvage (bdft)	Yield
1	58	1218	1074	25	90%
2	10	210	170	6	83%
3	1	21	11	0	52%
Total =	69	1449	1255	31	89%

Table 2. Yield Loss Analysis

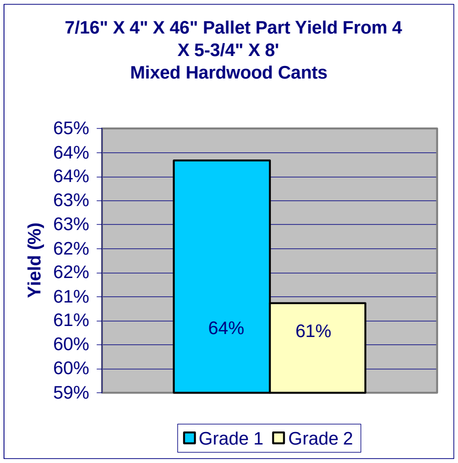
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	2%	2%	7%
2	2%	8%	7%
3	2%	39%	7%
Total Loss =	2%	3%	7%

Mill Number 26
7/22/98

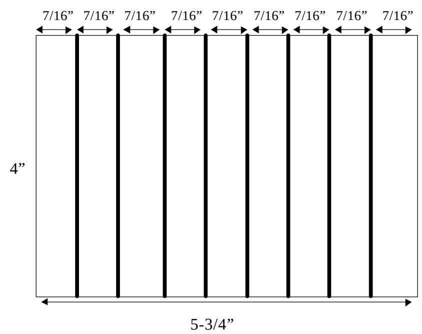
I. Equipment:
Circle Gang
Kerf: 0.170"

II. Raw Material:
Cant Size: 4 X 5-3/4" X 8'
Species: Mixed Hardwoods

III. Parts Produced:
Type: Deckboards
Size: 7/16" X 4" X 46"



IV. Sawing Pattern

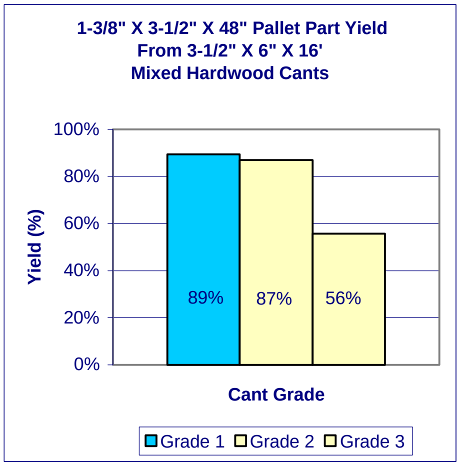


V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	38	583	372	0	64%
2	6	92	56	0	61%
Total =	44	675	428	0	63%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	12%	1%	23%
2	12%	4%	23%
Total Loss =	12%	2%	23%

Mill Number 27
5/25/97

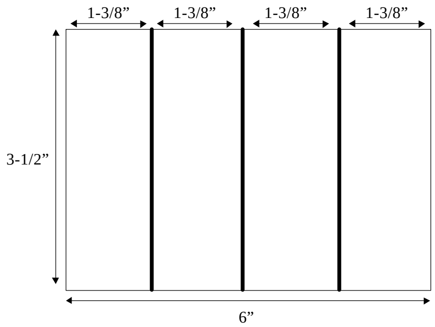


I. Equipment:
Circle Gang
Kerf: 0.135"

II. Raw Material:
Cant Size: 3-1/2" X 6" X 16'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringers
Size: 1-3/8" X 3-1/2" X 48"

IV. Sawing Pattern



V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	47	1316	1177	0	89%
2	23	644	560	0	87%
3	14	392	218	0	56%
Total =	84	2352	1955	0	83%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	4%	0%	7%
2	4%	2%	7%
3	4%	34%	7%
Total Loss =	4%	6%	7%

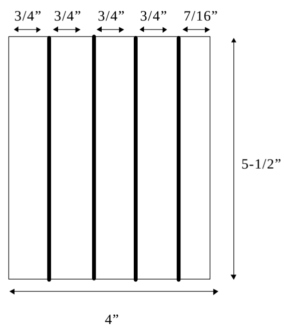
Mill Number 28
7/18/97

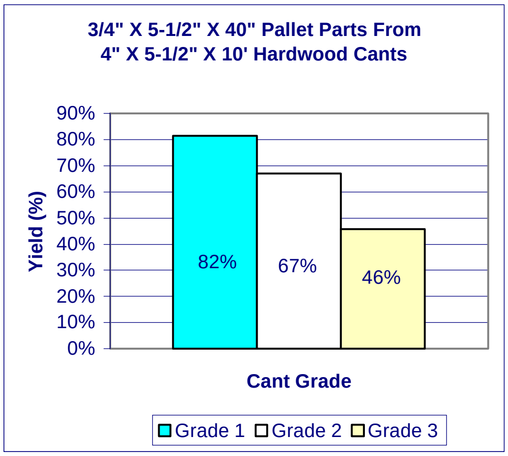
I. Equipment:
Rip Saw: Circle Gang
Kerf: 0.100"

II. Raw Material:
Cant Size: 4" X 5-1/2" X 10'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 3/4" X 5-1/2" X 40"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Deckboard Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	97	1778	1450	0	82%
2	23	422	332	0	79%
3	6	110	50	0	45%
Total =	126	2310	1832	0	79%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	4%	4%	10%
2	4%	7%	10%
3	4%	40%	10%
Total Loss =	4%	7%	10%

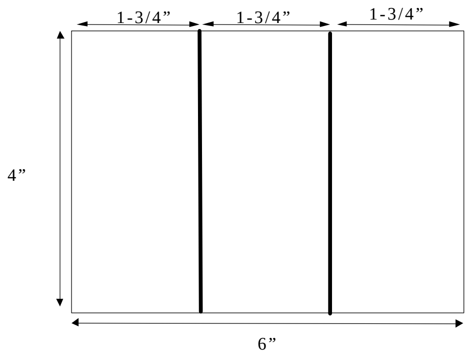
Mill Number 29
12/17/97

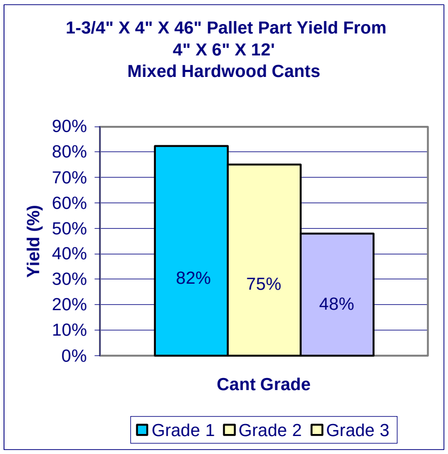
I. Equipment:
Circle Gang
Kerf: 0.180"

II. Raw Material:
Cant Size: 4" X 6" X 12'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringers
Size: 1-3/4" X 4" X 46"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	39	930	758	9	82%
2	3	72	54	0	75%
3	7	168	81	0	48%
Total =	49	1170	893	9	77%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	10%	2%	6%
2	10%	9%	6%
3	10%	36%	6%
Total =	10%	7%	6%

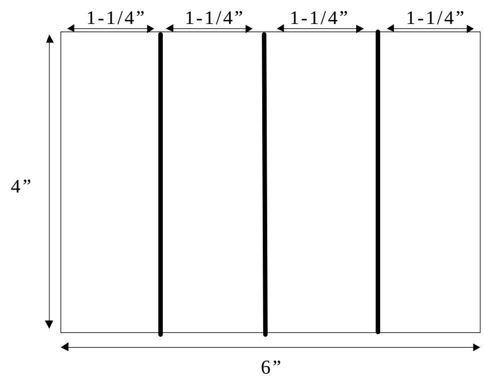
Mill Number 30
12/17/97

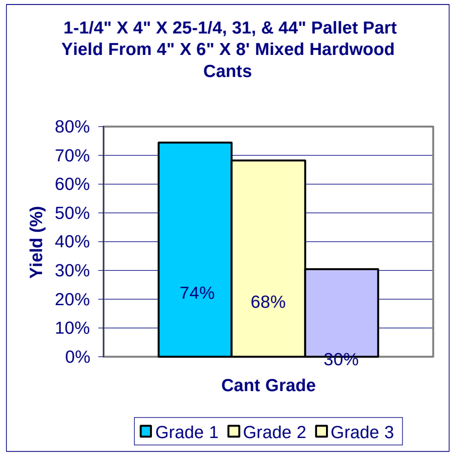
I. Equipment:
Circle Gang
Kerf: 0.135"

II. Raw Material:
Cant Size: 4" X 6" X 8'
Species: Mixed Hardwood

III. Parts Produced:
Type: Stringers
Size: 1-1/4" X 4" X 25-1/4, 31, & 44"

IV. Sawing Pattern





V. Yield Results

Table 3. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume	Stringer Volume	Salvage	Yield
		(bdft)	(bdft)	(bdft)	
1	63	1008	750	0	74%
2	17	272	186	0	68%
3	11	176	54	0	30%
Total =	91	1456	990	0	68%

Table 4. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	17%	2%	6%
2	17%	8%	6%
3	17%	46%	6%
Total =	17%	9%	6%

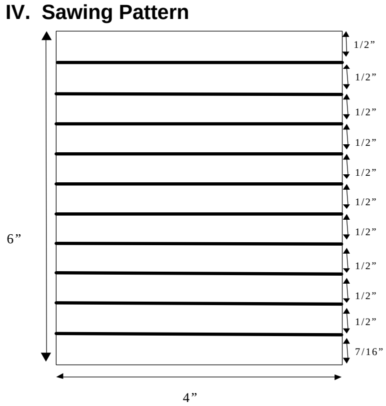
Mill Number 31
7/18/97

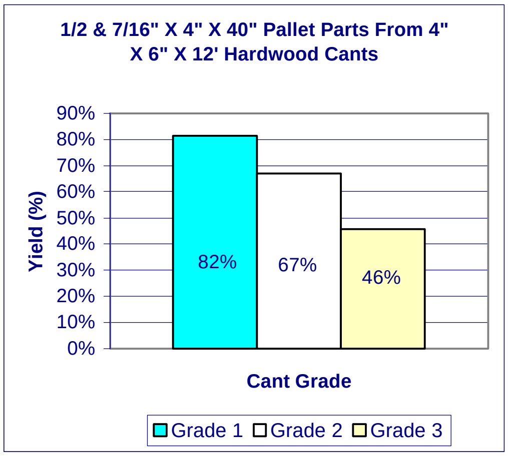
I. Equipment:
Rip Saw: Multiple Band
Kerf: 0.055"

II. Raw Material:
Cant Size: 4" X 6" X 12'
Species: Mixed Hardwood

III. Parts Produced:
Type: Deckboards
Size: 1/2 & 7/16" X 4" X 40"

IV. Sawing Pattern





V. Yield Results

Table 1. Yield Analysis					
Pallet Cant Grade	Number of Cants	Cant Volume (bdft)	Deckboard Volume (bdft)	Salvage (bdft)	Yield
1	55	1320	964	0	73%
2	17	408	276	0	68%
3	9	216	88	0	41%
Total =	81	1944	1328	0	68%

Table 2. Yield Loss Analysis			
Pallet Cant Grade	Dimension Loss	Grade Loss	Kerf Loss
1	17%	2%	8%
2	17%	8%	8%
3	17%	35%	8%
Total Loss =	17%	7%	8%

9 Appendix C

Defect Loss Prediction Model
for the Recommended Minimum Cant Grade Rules

The defect loss prediction model for the recommended minimum cant grade rules was determined by a multivariable linear regression of 27 mill studies. Mill study 23 was not used in the analysis due to its unusual sawing pattern. Average defect losses for cant grades 1 and 2 were calculated from each mill. Defect loss was the dependent variable predicted from part length, cant length, part thickness, cant width, part width, and kerf. Again, model adjusted R-square value, residual analysis, and statistical comparison of actual and predicted defect loss determines adequacy of the model fit. Equation 1 is the defect loss prediction model for the recommended minimum cant grade rules.

$$DefL_{(Grades\ 1\ \&\ 2)} = -0.000422\ PL - 0.000107\ CL + 0.011994\ PT + 0.002724\ CW + 0.007183\ PW + 0.08658\ K \qquad [1]$$

A residual analysis plot was performed to check the accuracy and fit of the prediction model. Figure 1 is the residual plot from the defect loss prediction model for the recommended minimum cant grade rules.

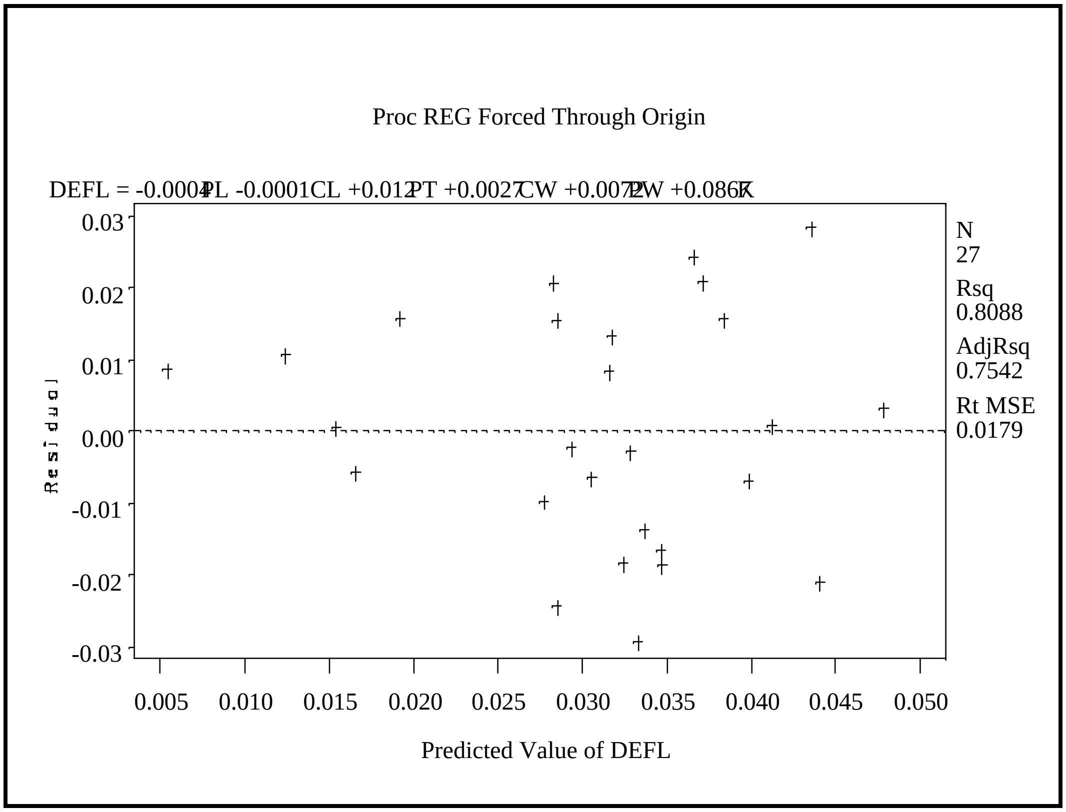


Figure 1. Residual Plot of Defect Loss Model for the Recommended Minimum Hardwood Cant Grade Rules.

A visual inspection of the residual plot indicated an accurate regression line fit with no outliers. The adjusted R-square value of 0.7542 indicates accurate prediction values. To further substantiate the adequacy of the regression fit, the predicted defect loss values were compared to the actual values. Table 1 contains the actual and predicted defect losses.

Table 1. Actual and Predicted Defect Losses from Pallet Mills Processing Hardwood Cants into Pallet Parts

Mill Number	Actual Defect Loss	Predicted Defect Loss
1	0%	3%
2	3%	4%
3	1%	1%
4	2%	2%
5	6%	4%
6	2%	4%
7	2%	3%
8	2%	3%
9	6%	4%
10	5%	3%
11	5%	3%
12	2%	1%
13	1%	2%
14	1%	3%
15	3%	3%
16	4%	3%
17	4%	3%
18	4%	2%
19	4%	4%
20	7%	4%
21	3%	3%
22	2%	3%
24	5%	5%
25	2%	3%
26	2%	3%
27	0%	3%
28	5%	4%
Average =	3%	3%
St Dev =	2%	1%
COV =	58%	32%
p-value =	0.926	

The average actual and predicted defect losses were 3 percent with standard deviations of 2 and 1 percent, respectively. The COV varied between actual and predicted values from 58 and 32 percent, respectively. Differences in COV values may be due to computer rounding and prediction errors. The similar average values are evidence that the prediction model is accurate. The lower standard deviation in the prediction equation indicates less variation in the model. Lower prediction model variation is expected as Y-axis variation is minimized by the regression procedure. The t-test p-value of 0.926 also indicates that the prediction model accurately estimates defect loss. No significant difference exists between the predicted and actual defect losses.

Comparing the actual and predicted defect losses from three subsequent mill studies further substantiated the accuracy of the defect loss prediction model for the recommended minimum cant grade rules. These comparisons are seen in Table 2.

Table 2. Actual and Predicted Pallet Part Defect Losses from Hardwood Pallet Mill Studies Subsequent to Model Development

Mill Number	Mill 29		Mill 30		Mill 31	
Cant Dimension	4" X 6" X 12'		4" X 6" X 8'		4" X 6" 12'	
Part Dimensions	1-3/4" X 4" X 46"		1-¼" X 4" X 44"		1/2" X 4" X 40"	
Kerf	0.180"		0.135"		0.055"	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Defect Loss =	2%	4%	4%	4%	3%	3%

Predicted defect losses were identical to actual values for mills 30 and 31. Despite the two-percent error in predicting defect loss for mill 29, the defect loss prediction model for the recommended minimum cant grade rules is accurate.

10 Vita

Hal Lee Mitchell, son of Fred and Eloise Mitchell, was born in Lynchburg, Virginia on June 13, 1974. He graduated from Appomattox County High School in 1992.

After starting a small sawmill operation with his father, he entered Virginia Polytechnic Institute and State University in 1992. He graduated with a Forest Products Marketing and Management degree in 1996. He then returned to Virginia Tech to complete a Maters degree. In 1999, he graduated with a Wood Science & Forest Products Masters degree in the production management option.