A Preliminary Examination of Factors Affecting Manufacture of Value Added Products From Recycled Pallet Parts

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Abstract

Pallets are the single largest consumer of hardwood lumber in the United States. While the pallet industry has effectively adopted widespread pallet recycling, many pallets still go into landfills with little or no value gained from their material. Recovered pallet lumber has been proposed as a potential source of material for value added wood products. This study sought preliminary data on issues pertinent to the development of pallet parts as a source of raw material for value added products, with a focus on oak strip flooring. Issues examined included pallet disassembly efficiency, characteristics of recovered boards, and yield of blanks compatible with commercial flooring production.

Disassembly of pallets was affected by pallet design. Overall 81% of the deckboards from all pallet designs were recovered, along with 70% of stringers. Oak boards useable in strip flooring represented 21% of the recovered boards studied. Proper board stacking was found to maintain a uniform (MC) which would reduce drying defects and complications. The manufactured blank dimensions would allow production of some of the thinner strip flooring commercially available. National Oak Flooring Manufacturers Association Pre-finished Oak Strip Flooring Grading Rules found almost 80% of the blanks made Prime and Standard Grades.

Wide spread adoption of flooring production from recovered pallet would

increase the value of recovered pallets, presumably justifying an increased rate and expanded scope of pallet recovery. Economics favoring such valued added recovery would create recovery-related jobs, decrease pallets going into landfills, and ease the demand on timber resources.

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Chapter 1

Introduction

Pallets are the largest single consumer of hardwood lumber in the United States. In 1997 pallets consumed 4.5 Billion Board Feet (BBF). This consumption is 50% greater than that of the second largest hardwood user, the furniture industry, which consumed 3.0 BBF in 1997 (Hansen and West 1998). Consumption of hardwood by pallets had decreased 2% since 1991. This decrease is attributed to increased recycling within the pallet industry (Hansen and West 1998).

The pallet industry actively and increasingly recovers and recycles pallets at the end of their service lives in an effort to reuse the valuable hardwood they contain. This serves to combat the rising price of low grade lumber and rising cost of disposal while addressing customer concerns about waste management and environmental impact. The pallet industry recycled 171 million pallets in 1995 (Araman 1997a). These pallets represented approximately 2.6 BBF of lumber. This recycling activity creates jobs in the form of recovery/repair/recycling (RRR) operations, decreases the volume of pallets going into landfills, and eases the demand that new pallet manufacture places on timber resources. RRR is necessary due to a combination of forces including increases in low-grade material prices and waste disposal costs, low cost of entry into recycling, and increasing prominence of environmental concerns regarding resource use and waste disposal.

Recovery takes place after the end of a pallet's service life, when the pallet is removed from the waste stream. Recycling implies using a post service life pallet, or its parts, for a new use, typically new pallets. Reuse is often married with the term repair, meaning pallets that are still sound can be sorted and reused, and those needing repair receive it. Pallets with limited damage can be repaired with new or recovered pallet parts, and then reused.

Despite recent RRR efforts, there is still a huge volume of pallet material that is not recovered by the industry. In 1998 over 180 million pallets entered municipal solid waste (MSW) and construction and demolition landfills (C&D) (Corr and Bush 2000). Only 34 million pallets were recovered, and most of these were ground for no or low value uses, typically mulch or boiler fuel. The recovered pallets represented approximately 512 million board feet (MMBF) of lumber, with the addition of the 2 BBF worth of lumber that was landfilled, there were over 2.6 BBF of lumber passing into landfills in 1998. Pallets are not the only form of wood material entering landfills. In 1998, pallets represented only 20% of the 34 million tons of wood waste at municipal solid waste landfills and only 7.5% of the 16 million tons of wood waste at construction and demolition landfills (Corr and Bush 2000). The pallets going into landfills represent a tremendous potential source of lumber.

Deckboards from recovered pallets have been explored as a source of lumber for value added products. Hardwood flooring is one such product that is especially compatible with pallet parts in terms of lumber grade and part dimensions. It has been established that commercial flooring lines can use recovered pallet material as feedstock (Araman 2000). While pallet recycling is well established in the industry; increased recycling, including the diversion of high quality parts for value added products, would have many potential benefits. The resultant increased pallet recovery would have multiple effects. It would help ease the demand for low-grade lumber by both the pallet industry and value added sectors of the wood products industry, lowering prices and conserving timber resources. This increased pallet RRR would decrease the amount of pallets directed to landfills. Also, increased pallet recovery from landfills could decrease barriers to greater recovery of more of the types of wood waste directed into landfills.

Activities related to and resulting from the recycling of recovered pallet parts for flooring products would serve to extend the hardwood lumber resource, and increase its long-term value. Creating a new market for recovered pallet material would instigate increased recovery and economic growth. It is important to note that the production of value added products from recovered pallet material would likely increase the price demanded by pallet depositors changing the economics of the pallet RRR industry.

The wood flooring industry has experienced a long trend of annual market growth, the rate of which has increased in recent years. However, flooring manufacturers have suffered from raw material price increases as furniture and cabinet manufacturers have turned to low-grade lumber that traditionally fed the flooring and pallet industry. Unfortunately for the flooring industry, where raw material represents over half the cost of wood flooring production, the cost of low-grade lumber is increasing (Tucker 1999a).

In assessing the potential of reusing pallet material for flooring products, all aspects of pallet reuse and compatibility issues need to be examined. One potential problem is the thickness of traditional flooring versus the thickness of pallet material. The traditional industry standard for a flooring product thickness is ¾”, while an average 40” × 48” pallet deckboard is approximately 5/8” thick, with 1 ½” thick stringers

(Mitchell 1998, Araman 1998). Traditional wood flooring is ¾" thick, but improvements in manufacturing and finishes has allowed the development of thinner flooring products, including ½", 3/8" and even 5/16" thicknesses.

Araman and Winn (1997) estimated the value of 3 ½" wide deckboards. Based on clear 3/8" strip flooring, individual deckboards would be worth $0.53 unfinished and $0.92 for finished flooring at the flooring producer level. This estimate is favorable compared to $0.20 per board as a replacement/repair deckboard and $0.01 to $0.02 per board when ground for fuel.

A spreadsheet program, PROACT, (Pallet Recovery Opportunity Analysis Computer Tool) has been developed to allow for the assessment of profitability of potential pallet RRR operations. Based on previously proposed PROACT projections (Araman et al 1998, 1999), the economics appear favorable for a pallet RRR operation to recover material for value added products, in addition to pallet related activities. However, these studies did not have the true potential yield and part characterization data. Measured part yields will enable PROACT to make more accurate economic projections on the profit potential of a proposed pallet recycler and allow estimates to be made on the cost of the material to a flooring manufacturer.

This study serves as a preliminary investigation into many of the practical issues that need to be resolved before commercial use of recovered pallet material can be seriously considered. Issues explored include projected part recovery percentages, the physical characteristics of the recovered parts, and the potential yields of flooring material from high value pallet parts.

Problem Statement and Justification

Pallet recycling is widespread and growing in the pallet industry. Over 100 million pallets go into landfills annually (Corr and Bush 2000). This large number of pallets represent a tremendous source of solid wood raw material and biomass. Researchers at the USDA Forest Service Southern Research Station have successfully conducted trials to convert recycled pallet deckboards into usable flooring products on commercial production lines (Araman 2000). The biggest question surrounding the process involves the ability to operate economically in an industrial setting. What kind of yields and material quality can be expected? What are the costs of recycled pallet boards? Would it be profitable for a pallet RRR operation to add labor and equipment necessary to allow the sorting and sale of boards that can be used for value added products?

Previously no study identified the percentages of useable parts that can be recovered from disassembled pallets. Also, there had been no attempt to characterize the species distribution of deckboards recovered from disassembled pallets. What percentage of boards are suitable for value added products? What percentage yield could be recovered from converting these boards into a form suitable for sale to the value added wood products industry? This study provided the preliminary data on these topics. As a result of answering these questions:

- Data and observations can be used by industrial operations for comparison and possible adoption of higher value part selection;
- Industry can use the research methods to test their own operations;

- PROACT software can be increased in accuracy by having estimated part yields from disassemblers and the yield of boards that could be selected for sale as material for value added products.

Economics drive most industrial decisions. If the yields and subsequently, the economics, appear favorable perhaps pallet material can be even more widely recovered for both pallet RRR and for high value boards directed into the value added industry. This activity and the resultant increased pallet recovery would have multiple effects. It would help the demand for low-grade lumber by both the pallet industry and value added sectors of the wood products industry, lowering prices and conserving timber resources. This increased pallet RRR would also decrease the amount of pallets directed into landfills.

Study Perspective

Figure 1 shows the movement taken by low grade lumber into pallet production and through service. Also shown are the multiple possibilities after service. The focus of this study is what occurs at the "Post Service" point in Figure 1. The courses leading to RRR, back into the pallet industry, and into landfills are the current reality. This study is exploring the course that leads to "high value part recovery." The broken lines from "landfill wood recovery" to "pallet" and "high value part recovery" are idealized scenarios, that would become reality only through adoption of wide spread adoption of the principles of this study, widespread recovery of pallet parts for high value uses.

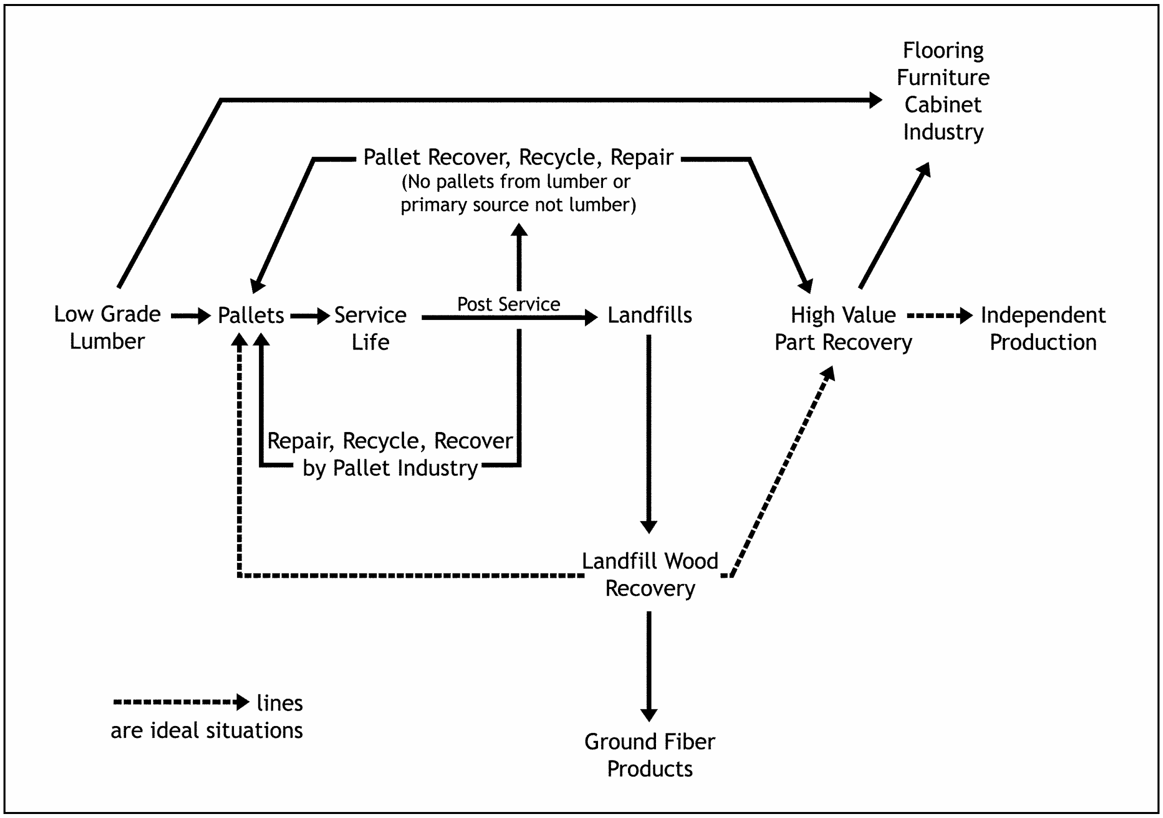

Figure 1: Part flow through pallet and value added products, including idealized part movement

The data collection and discussion of this study focus on the Pallet "Recover, Recycle, Repair" (RRR) point in Figure 1. It is important to note that these pallets and their parts are presumably of the same types, species mix, and conditions as those passing into the "Landfills" (Figure 1). The pallet and parts passing into RRR are being used in a manner that increases economic value, conserves timber, decreases landfilling, and lowers raw material costs for the pallet industry. The potential exists for RRR operations to sort out parts with potential for use in value added products, while maintaining current pallet RRR activities using material of lower potential for value added products.

Landfills represent an enormous source of additional pallets and parts that could be diverted into pallet RRR and value added products, either through landfill based recovery or through increased diversion of pallets into RRR. Additionally, landfills receive large volumes of wood material other than pallets, which potentially could also be recovered and recycled for pallet material and value added products. Currently most pallets and wood recovered at landfills are ground for low or no value products, typically mulch, landfill cover, or boiler fuel. This study will serve as a basis for future work to thoroughly examine landfills

This study developed a better idea of the feasibility of high value part recovery from pallet RRR and landfills. Future research based on these results, will help to answer questions pertinent to any manufacturing activity, including the characteristics of the pallet material, the yield and availability of pallet material, and the expected yield of products from pallet material. Understanding these issues will allow companies to address the economic questions surrounding high value part recovery. Only when the economics are understood can this resource be utilized most effectively. This study sought to answer some of the questions that will help the RRR industry better understand the potential of high value part recovery

Research Objectives

1) Identify the percentage of structurally sound pallet parts, stringers, and deckboards at the disassembler stage of a RRR operation.
2) Characterize the deckboards recovered by a RRR operation. Features observed will be species percentage divided into softwood, non-oak hardwood, and oak, approximate size, and percentage of oak deckboards sufficiently free of defects for use in value added products and the moisture content of these deckboards.

3) Identify the percentage board foot yield from converting useable oak deckboards into standard, flooring-size blanks.

Limitations and Assumptions

The greatest limitation of this study was the lack of time and labor available for extensive data collection. Only one data collection trip was made to each of the four RRR mills. The volume of data recorded at the disassembler and the number of boards evaluated for part characterization, were not necessarily assumed to be representative of the vast number and variety of pallets recovered. However, this data was assumed to provide a better idea of the state of the post service pallet resource than had been previously documented. The data collected was also assumed to be sufficient to identify problems and issues that must be addressed for a more thorough and wide reaching investigation to be conducted. The lack of previously published studies required this one to develop the majority of the techniques used for data collections, material treatment and handling, and data analysis.

There was one major assumption made by this study. Nail holes were included as an allowable defect, in addition to the defects allowed by the National Oak Flooring Manufacturers Association's Prefinished Oak Flooring Grading Rules (2000b). These rules were used to grade the blanks produced by the study. While oak flooring was not considered the only potential use for pallet material, the blanks produced by this study were made to be compatible with strip flooring production.

Thesis Organization

Following this introductory chapter, Chapter 2 contains a review of the literature pertinent to this study. Topics discussed include the state of pallet recycling and the potential resource post-service pallets represent. The lack of value added pallet recovery is addressed, along with projections of the economic potential of pallet part recovery. Hardwood flooring is covered, including the growing flooring market, pressure on traditional flooring raw material, and the compatibility of pallet parts with flooring products. Potential marketing tools for flooring products produced form recycled pallet parts are addressed.

Chapter 3 covers the methods used to carry out the study objectives. Methods relating to each objective are reviewed, including the motivation behind them, how the data was collected and analyzed.

Chapter 4 displays and discusses the results of the research. Results and related discussion for each objective is organized and explained. Conclusions based on this data are established.

Finally, Chapter 5 provides a summary of the study and lists the significant conclusions and contributions of the study. Chapter 5 ends with a recommendation for future research.

Chapter 2

Literature Review

Pallet Recovery/Repair/Recycling (RRR)

Large Scale Recycling: The Pallet Industry

USDA Forest Service statistics reported there are around 1.9 billion pallets in the U.S. Approximately 400 million new pallets are currently produced annually, and about 175 million are repaired or recycled. Annually, some 100 million pallets are estimated to be abandoned, lost, burned, or taken from the country (USDA Forest Service 2000).

Pallets consumed 4.5 BBF (Billion Board Feet) of hardwood lumber in 1997. This volume represented between 34% and 38% of the total hardwood consumption in the U.S., making pallets the single largest domestic user of hardwood lumber (Hansen and West 1998, Bush and Araman 1998a). Hardwood consumption for pallets was 50% greater than the second largest hardwood consumer, furniture (Hansen and West 1998).

Surprisingly the amount of hardwood lumber used in pallets has decreased by 2% since 1991, when 4.6 BBF of hardwood was used in pallets. This decrease was due to the continuous and growing emphasis on recycling in the pallet industry. Currently, as many as 20% of new pallets are remanufactured (Hansen and West 1998). New wood use in pallets declined from 87% in 1992 to 70% in 1995 (Bush and Araman 1997). The prospect for further increases in recycling levels and subsequent decreases in new timber use seem assured.

Pallets are excellent candidates for recycling. They have short service lives and tend to accumulate in large quantities in central locations, such as shipping locations, retail centers, or large manufacturers, facilitating ease of consolidation and collection. They are easily disassembled due to their simple designs and standardized part sizes (Bush and Araman 1997).

Increased pallet recycling is a standard practice within the pallet industry. Among the forces driving recycling are increases in both low grade material prices and waste disposal costs, the low cost of entry into recycling, and increasing prominence of environmental concerns regarding both resource use and waste disposal. In 1995 alone, pallet RRR firms recovered 171 million pallets (Araman 1997a). Assuming an average pallet weight of approximately 55 lbs., and an average of 15 BF of lumber per pallet (Mitchell 1998), the 171 million pallets recovered in 1997 represent approximately 4.7 million tons, or 2.6 BBF of lumber recovered. This recovery represented an increase of 160% from 1992 (Bush and Araman 1997). Among the pallet wood recovered, 87% was used again in pallets, allowing approximately 1/3 of all pallets sold in 1995 to contain recovered material (Bush and Araman 1998b). Pallet industry recycling is only expected to increase in both volume and efficiency.

The National Wooden Pallet and Container Association (NWPCA 2000) reported a number of benefits from their Pallet and Container Retrieval and Recovery System. Pallet users receive used pallets from third party providers who track, retrieve, sort, repair (if necessary), and return pallets to the user. These networks are in place, and can be implemented on size levels from a municipality up to a national or even global level.

The top three reported benefits of member companies, in order of decreasing value are: lower cost, eliminating disposal issues, and customers demand.

A Vast Resource: Municipal Solid Waste and Construction and Demolition Landfills

Municipal Solid Waste (MSW) and Construction and Demolition (C&D) landfills represent a potentially vast source of post service life pallets. While some of these facilities currently recover pallets, there could be far greater recovery for more valuable uses. There exists precedent for a system where pallets could be widely recovered in a situation that saves the depositor money, in the form of reduced or eliminated tipping fees (tipping fees are paid by the depositor at a landfill), and makes the receiver money, in the form of RRR pallet sales and pallet parts sold for value added products.

In 1998 approximately 84% of MSW landfills accepted pallets, receiving over 4,000 tons of pallets per landfill. Only around 33% of MSW landfills recycled pallets, processing an average of about 2,561 tons of pallets each. This represents a total influx of over 3.8 million tons of wood pallet waste or approximately 138 million pallets. At a 33% recycling rate, only 607,000 tons or 22.1 million pallets were recovered. Pallets only represented around 20% of the 33.9 million tons of wood waste received for MSW landfilling, and only around 2% of the 239 million tons of all waste received. Most MSW facilities with wood recovery yards charge a lower tipping fee for sorted loads of pallets, or pallets and lumber waste. Overall MSW charged $29.33 at non-recycling facilities versus $23.44 at facilities equipped for recycling (Corr and Bush 2000).

Slightly more than 71% of C&D landfills accepted pallets, receiving an average of 1,061 tons each. About 27% of C&D landfills recycled pallets, processing about 1,245 tons each. This recycling activity amounts to approximately 1.2 million tons or 42.4

million pallets total, with only 331 thousand tons or 12.04 million pallets recovered. Approximately 25%-30% of the pallets reaching C&D landfills were recovered. Pallets represented only about 3% of the 40.3 million tons of all waste, and just 7.5% of the 15.5 million tons of the wood waste received at C&D facilities. C&D tipping fees are handled differently than at MSW landfills. C&D landfills with recycling capability will have their landfill separate from their recycling area. Trucks going to the landfill are charged around $22.66, while trucks going to the recycling facility, with their load sorted into all wood or all pallets, are charged an average of $18.64 (Corr and Bush 2000).

Wood material collected in the form of pallets at both MSW and C&D landfills represents a tremendous volume of raw material. Table 1 illustrates how much pallet material goes into landfills. Assuming approximately 15 BF per pallet, MSW facilities recovered around 331.1 MMBF, with an additional 1.7 BBF going into landfills. C&D landfills recycled 181 MMBF, with around 455 MMBF being landfilled. This yields a total of 512.1 MMBF recovered, with an additional 2.155 BBF going into the ground, in 1998 alone.

Table 1: MSW and C&C Pallet Recovery in 1998

	% Receiving pallets	% Recovering pallets	Tipping Fee: recovering /non recovering	Total tons pallets received (millions)	Total No. pallets received (millions)	Total tons pallets recovery (millions)	Total No. pallets recovered (millions)	BF recovered (assumes avg. 15 BF/pallet) (millions)	Total BF landfilled (billions)
MSW	84%	33%	$23.44/$29.33	3.8	138	0.61	22.1	331.1	1.7
C&D	71%	27%	$18.64/$22.66	1.2	42.4	0.33	12.04	181	.455

In terms of volume, pallet recovery has increased at both MSW and C&D landfills. While the volume of pallets going into both MSW and C&D landfills has increased, the percentage of pallets recovered at MSW landfills has gone down slightly, and the percentage recovered at C&D landfills has remained the same (Corr and Bush 2000).

Low or No Value Uses

While there is potential for much greater recovery, the amount of pallet material recovered from MSW and C&D landfills does appear to represent a significant amount of lumber. Additionally, approximately 70% of pallet material is hardwood (Bush and Araman 1998a). Unfortunately, little of this material is recovered as lumber. Most landfill-recovered pallets are ground for low or no value uses.

Figure 2 illustrates that 55% of pallets recovered at MSW landfills are ground for landfill cover, boiler fuel, mulch, animal bedding, or compost. Generally, the "Other" category implies some kind of ground use of the pallet, increasing the percentage ground by 21%, to a total of 75%. Slightly less than 9% are given away or sold as-is (whole) for reuse, though more are given away or sold as-is for fuel. An additional 4% of pallets are repaired for reuse. Significantly, ground pallets are not disassembled in any way, including nail removal. It is important to note that it is not necessary to remove nails prior to grinding, meaning nail removal for value added products would be a new addition to the recovery process.

The breakdown of uses for pallets recovered at C&D landfills is also available in Figure 2. Ground uses and products account for almost 56%, with an additional 11% in the "Other" category, most of which are also due for grinding. More than 2 ½ times as many C&D recovered pallets are destined for as-is reuse as pallets, than those recovered at MSW landfills, which implies use of a system of sorting pallets to determine their condition. There was no report of pallets repaired at C&D facilities. Considerably less C&D pallets are burned for fuel as-is, than MSW pallets. Regardless, other than sales of reusable or repaired pallets, most of these uses represent low or no value.

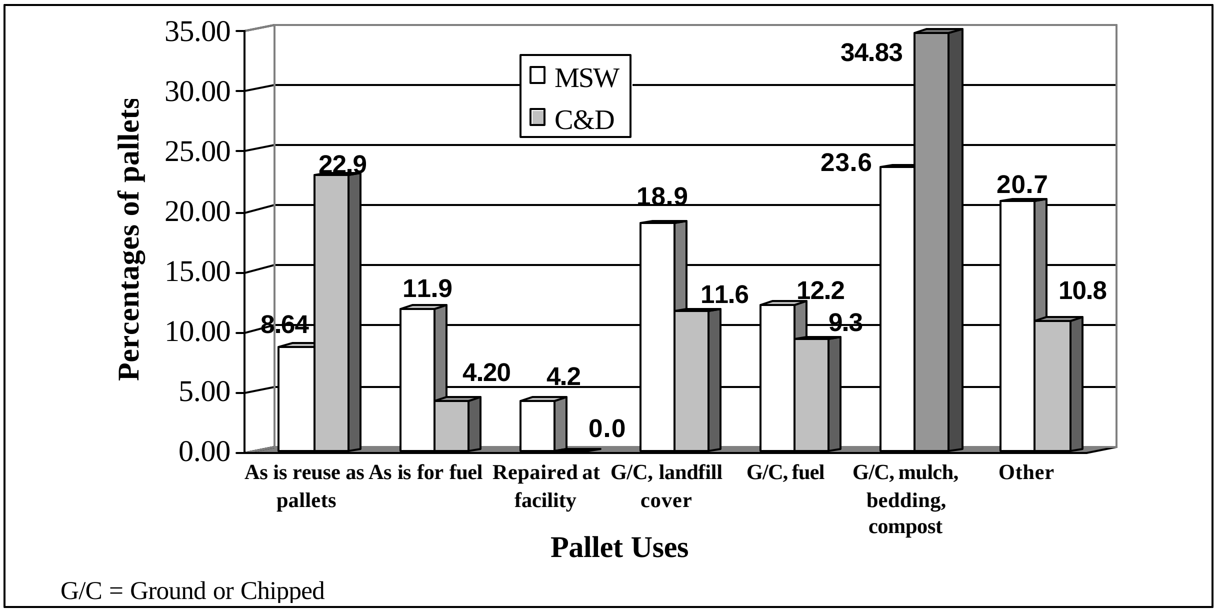

Figure 2: Use of Recovered Pallets at MSW and C&D Landfills

The American Forest and Paper Association National Wood Recycling Directory identifies 518 locations that accept pallets for recycling (American Forest and Paper Association (AF&PA) 2000). Many of these also accept other categories of wood including brush trimmings, tree waste, construction lumber and trim, demolition, preservative treated wood, and engineered wood. A rough survey of this list to categorize companies, based on name alone, shows:

- 105 (20.27%) <u>pallet companies</u> (Example: Alexander Pallet) (T represents only an approximate 20% of the pallet RRR operations in the U.S.)

- 103 (19.88%) identified as wood recovery and/or recyclers (Example: All Wood Recycling Inc.)
- 62 (11.97%) identified as Sanitation, Disposal, Public Works, Landfill, or Waste Management
- 45 (8.69%) identified as lumber, wood/forest products companies, or other wood based manufacturers including facilities belonging to large integrated firms
- 203 (39.19%) are either unable to be classified by name alone or are obscure, examples of the latter include: prisons, school districts, trucking companies, power generators, and a distillery

The following describes the breakdown how these recycled pallets are used. Note that some companies produce multiple products. For example a company may produce remanufactured pallets and grind the unusable boards, but they would only be listed on the remanufacture list, they would not count as a producer of ground products.

- 319 (61.6%) companies exclusively grind pallets, producing mulch, compost, hog fuel, sawdust, or chips
- 128 (24.7%) reuse or remanufacture pallets
- 58 (11.2%) produce composite wood products, paper products, or chips specified for use in those products. Products include particleboard, fiberboard, hardboard, “engineered wood material”, paper, pulp, cardboard, medium density fiberboard, plastic lumber composites, and composite lumber
- 12 (2.3%) produce a solid wood product. Many of these also accept

construction lumber, and trim and demolition lumber. The products they produce are listed along with the types of wood waste they accept, other than pallets, in Table 2. The low percentage of operations engaged in value added recovery shows the potential for wide spread improvement.

Table 2: AF&PA Wood Recyclers Producing Solid Products From Pallets

Product Produced	Wooden Material Accepted
Fencing	Pallets, Brush, Preservative Treated, Tree Waste
Crates, Dog Houses, Pallets	Pallets, Construction/Trim, Construction, Engineered, Other
Lumber, Trim, Flooring, Woodwork	Pallets, Brush, Construction/Trim, Demolition, Preservative Treated, Other
Flooring, Furniture, Crates, Pallets	Pallets, Engineered, Other
Finger Joints	Pallets, Brush, Tree Waste, Construction/Trim, Demolition, Engineered
Lumber	Pallets
Crates, Pallets	Pallets
Lumber, Wood Boxes, Pallets	Pallets
Boxes, Crates, Dimension, Lumber, Pallets	Pallets
Containers, Pallets	Pallets, Construction/Trim, Engineered
Furniture, Toys, Concrete Forms, Pallets	Pallets, Construction/Trim, Demolition, Lumber
Crates, Pallets	Pallets, Crates

Landfills and recovery operations commonly invest in grinding equipment to recover some value from wooden pallets. Based on this fact, if there is economic incentive, they may be willing to invest in equipment for recovering pallet material for higher value products. Recovering material for value added products could be done in cooperation with other pallet recovery companies, or in cooperation with a manufacturer to be supplied with recovered pallet material processed into, for example, flooring blanks.

Economic Potential for Recovery/Repair/Recycling Operations, PROACT

There is tremendous potential for the recovery of large quantities of valuable hardwood lumber from landfilled pallets. In 1995, oak represented approximately 27%, or 1.22 BBF, of the material used to produce pallets (Bush and Araman 1998b). Oak is now and has been historically in high demand for flooring and other value added hardwood products. Table 3 presents estimated values for a standard 48” x 40” pallet recovered through different options. The value of a recovered pallet is based on its size, condition, and the species of wood it contains.

Table 3: Estimating Values of Pallet Recovery Options

Recovery Option	Value Per 48” x 40” Pallet
Ground for fuel or mulch at $10/ton	$0.25
Ground for board products at $40/ton	$1.00
resold without repair	$3-6.00
Disassembled for replacement parts	$2-3.50
Disassembled for flooring and parts	$5.00-8.00

A recent study by the Center for Forest Products Marketing and Management at Virginia Tech and the USDA Forest Service Southern Research Station sought to determine the potential of a for-profit pallet recovery operation. This study helps address many of the economic questions that need to be answered in order to determine if pallet to flooring operations appear feasible. The tool used is PROACT, (Pallet Recovery Opportunity Analysis Computer Tool) a spreadsheet model focused on recovering pallets for reuse and disassembly for repair and replacement parts. PROACT is applied to landfills. It uses the number of pallets received, the tipping fees or costs associated with the pallets, the number of pallets recovered, repaired, and reused, and the prices charged for them. For the scenarios examined, it was determined that a landfill-based pallet RRR operation could be profitable (Araman et al 1998).

A standard 48x40 inch pallet with no need for repair can be sold for reuse. Pallets with little damage can be quickly repaired and sold. Damaged pallets can be disassembled for parts. Badly damaged parts can be ground for products or fuel. The spreadsheet confirms potential for higher profits if some of the parts are channeled into higher value hardwood products such as flooring, furniture, or other wood products. Data on the yield of pallet disassemblers and yield of high value material from recovered pallet boards will help to increase the accuracy of PROACT projections.

Hardwood Flooring

Hardwood flooring has been proposed as a potential high value product use for recycled pallet material. While flooring is only the 7th largest consumer of hardwood lumber, utilizing 1.1 MMBF in 1997, it is the fastest growing lumber user, increasing lumber consumption fivefold since 1982, and 120% since 1991 (Hansen and West 1998). Flooring and pallets generally use lower grade lumber, and flooring parts and pallet parts are typically of similar sizes. This compatibility makes flooring an excellent candidate for using pallet parts as raw material.

General Information About Hardwood Flooring

Most of the lumber used in hardwood flooring is NHLA 2A Common to 3A Common, with 3ACommon limited to around 25%-35% (Horne 2000). Some manufacturers who need to maintain quality across a larger area of flooring may purchase No. 1 Common lumber. Also, there has been an increased demand for 2A and 3A

Common lumber, as furniture and cabinet manufacturers have moved into lower grades of lumber. Some flooring manufacturers have been forced to purchase No. 1 Common lumber to maintain supply (Wahlgren 1999a). Lumber for flooring is dried to 6%-9% moisture content (MC), with 7% MC being common. Many mills produce and dry their own lumber, but often purchase some dried lumber to maintain needed supply (Spradlin 2000).

Wood flooring comes in several types of products. Solid flooring is divided into three categories. Strip flooring, which is usually around 2 ¼" wide, but may be as narrow as 1 ½" or as wide as 3 ¼". Plank flooring is typically 3-7 inches wide. Parquet uses small pieces of wood to create a geometric design, installed on square sections. Figure 3 shows a typical parquet design. A standard parquet section size is12"x12". Most of this flooring is traditionally ¾" thick, but new technology in milling allows for thickness of ½", 3/8", and 5/16" (Floor Search 2000). Parquet flooring and strip flooring are the products most commonly available in the thinner thickness. The size and thinner thicknesses used in parquet and strip flooring make them promising matches for pallet parts.

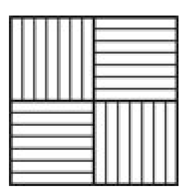

Figure 3: Example of Parquet Flooring 12" x 12" x 5/16" (Hartco 2000a)

Other categories of flooring include engineered flooring; made of two to five layers of veneer oriented 90 degrees from each other to give dimensional stability.

Wooden flooring can be injected with acrylics or other additives under pressure to give an extra hard, wear-resistant floor, often used commercially in high traffic areas. Finishes include polyurethane and acrylic urethane. These form the durable coating of the flooring known as the wear layer. The wear resistance can be further increased with additives such as aluminum oxide or ceramics.

Another product variation is prefinished flooring. These flooring products are finished in the factory, instead of after installation, which cuts the installation time down to a fraction of traditional flooring, which is sanded and finished after installation. Many of the prefinished floors use finishes that are cured under ultra violet (UV) lights, such as UV-urethane, which results in a tough water resistant finish. Prefinishing has the advantage of allowing as many as seven coats of finish in the factory, which would be difficult to duplicate in a traditional floor, installed and then finished after installation in the home. The majority of flooring is locked together during installation, via tongue and groove machining, as shown in Figure 4.

Figure 4: Tongue and Groove Flooring (Hartco 2000b)

Pallet material is typically less than ¾" thick, the dimension of traditional flooring. Recent trends in flooring are towards thinner products, which increases the compatibility of pallet material to flooring products. One misconception about the thinner prefinished floors is that they will not have as long a service life as traditional ¾" flooring. This is due to the traditional practice of sanding and refinishing floors. Modern finishes implement technologies such as polymer impregnation, and are extremely durable, going years without needing service. The top ply on engineered flooring, prized for its durability, is only 1/8" thick (Floor Search 2000). This means that thinner than traditional flooring produced from pallet parts would not need to be considered inferior in quality.

Traditional Flooring Manufacture

The most common grades of lumber that go into flooring are No. 2A Common and No. 3A Common. Occasionally to maintain supply or produce quality across a larger area, such as plank flooring, No. 1 Common will be purchased (Wahlgren 1999a). Most mills kiln-dry their own lumber, with target ranges between 6% and 9% MC. Lumber is then ripped into blanks. Strip flooring 2 ¼"wide requires a blank around 2 9/16" (Wahlgren 1999b). Because of the wide range of lumber grades purchased by manufacturers and the wide range of flooring products and sizes produced, it is difficult to narrow down a typical percentage yield that flooring manufacturers get from their raw material. While yield depends on the grade and size mix of the lumber and the size and technology of the product, anecdotal evidence from the flooring industry places a typical yield to be around 40-60% (Moore 2000).

Once the blank width has been reached major defects are cross-cut out of the length. Boards are sometimes preplaned, before reaching a sidematcher. The sidematcher planes the board to final thickness and cuts the tongue and groove into the sides of the boards. Boards are examined and oriented to ensure the best top face before sidematching. A finish saw then cuts out remaining defects, and reduces overly long boards to standard lengths. An endmatcher applies the tongue and groove to the ends, before the flooring is graded (Wahlgren 1999b).

While traditional flooring is installed and finished in the home, prefinished flooring is finished in the factory, usually with more applications of finish than traditional flooring receives. Generally prefinished flooring is lightly sanded on the bottom and sanded on top with three sandpaper grits ranging from 80 to 220 grit. Stain, if used, is applied with rollers and then brushed in opposite directions, before being dried under ultra-violet lights. A "denibber," with oscillating heads and a vacuum, removes burrs, dust, or grain raise. Now sealer and top-coats, a.k.a. the "walk-on" layers, are applied with a roller and ultra-violet cured. In between coats the flooring is abraded lightly to increase adhesion. Flooring is then graded under whatever rules apply (Wahlgren 1999c).

Hardwood Flooring Market

The wood flooring market is experiencing tremendous growth, giving further cause for the introduction of recycled pallet flooring. In 1998 the U.S. floor covering market had $16.9 billion in wholesales, a 4.8% increase over 1997. Hardwood flooring represented 7.2% of this market with $1.21 billion in sales. In 1999 hardwood flooring sales were estimated at around $1.35 billion, an increase of 12.5% from 1998. Volume shipped also experienced a double-digit increase, growing approximately 11.5% from 626 million ft^2 in 1998 to 699 million ft^2 (Tucker 2000). Hard surfaces continue to experience the fastest growth in the flooring market (Floor Covering Weekly 1999). In 1998 hardwood flooring enjoyed a 20% market share of the hard surface category (made up largely of hardwood, vinyl, ceramic, linoleum, and laminates) (Hardwood Council 1999).

Prefinished flooring represents around 55% of the solid wood market, thanks to improved finish technology and its ease of installation. Strip flooring shipments in 1999 increased 19% from 1998, to 536 MMBF.

Not only is the hardwood flooring market growing quickly, it has experienced steady, long-term growth. The National Oak Flooring Manufacturers Association (NOFMA 1999, 2000) keeps records on their member companies' shipments. Shipments of finished and unfinished solid strip flooring for oak, beech, maple, birch, hickory/pecan, ash, cherry, and walnut illustrate the growth in flooring sales. Much of the growth in flooring is attributed to the stable new home construction market, which represents 60% of wood flooring's market (Tucker 2000). A comparison of Figure 5 and 6 shows that since 1977, even when housing starts have decreased, flooring shipments have enjoyed a trend of steady growth, especially since 1992.

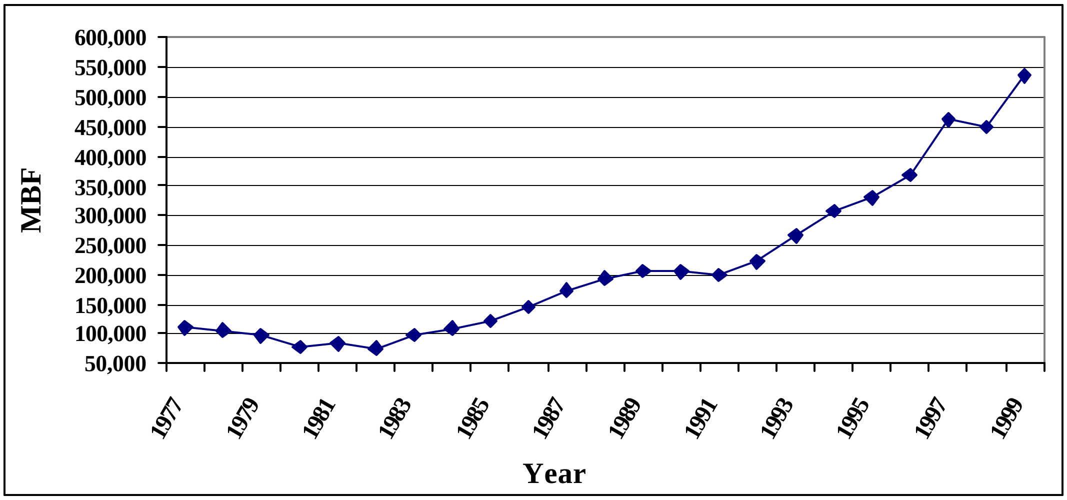

Figure 5: Strip Flooring Shipments 1977-1999 (Thousands of Board Feet)

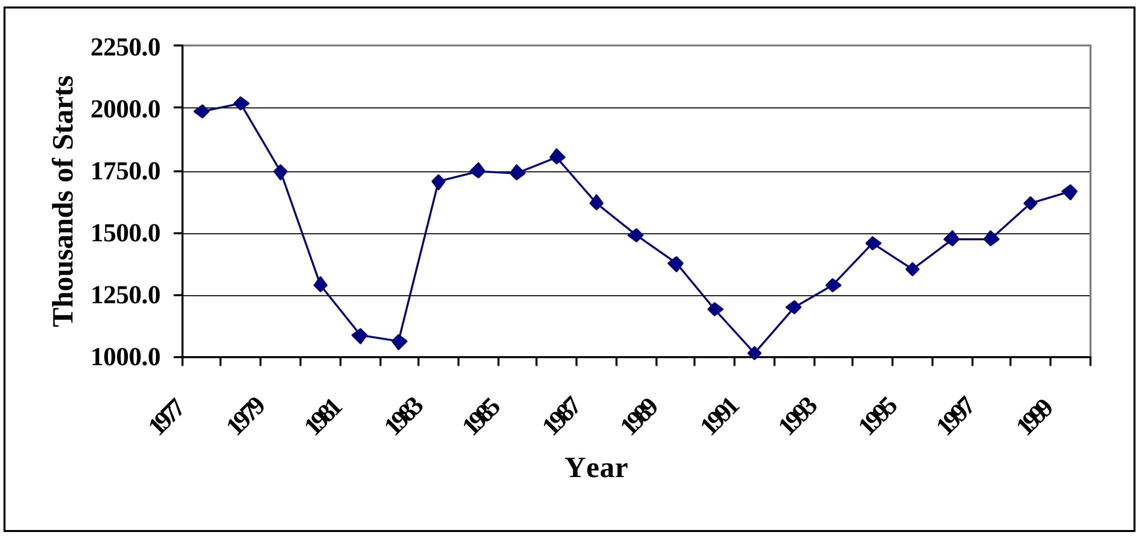

Figure 6: Residential Housing Starts 1977-1999

Examining Figure 7 shows the board feet of flooring shipped per housing start has experienced steady growth since 1985. This trend means that either the amount of flooring used in new homes has increased or that wooden strip flooring has expanded to other markets.

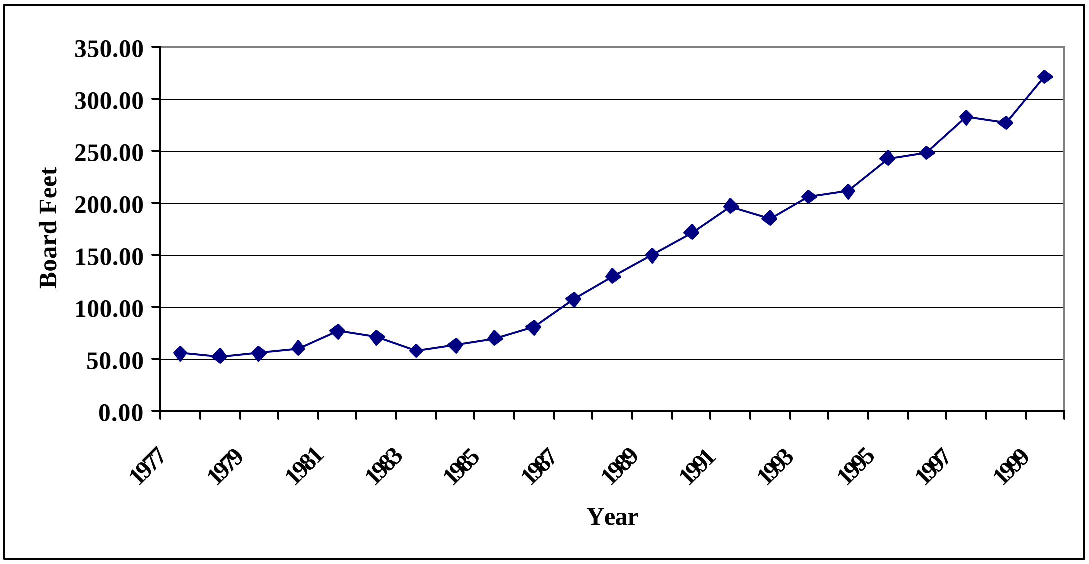

Figure 7: Board Feet of Strip Flooring Shipped per Residential Housing Start 1977-1999

The future looks bright for hardwood flooring. Hardwood was only 7.2% of the total 1998 floor covering market, yet a consumer preference study indicated that more than 50% of consumers name hardwood as the preferred floor covering. Some industry estimates project hardwood at 15% of the market share over the next five years. Hardwood floors increase the resale value of a home and can last the lifetime of a home, with warranties available up to 25 years.

The Hardwood Council reports an optimistic outlook for the flooring market, especially hardwoods. This outlook is based on steady growth in housing starts, strong sales of existing homes, high consumer confidence, broadening distribution channels, and consumer preference for high end products. Hardwood flooring is expected to enjoy annual growth rates of 3%-5% over the next 3 -5 years.

Price is the largest deterrent with consumers purchasing hardwood floors. Current wholesale costs are over \$1.90/ ft^2, and are projected to reach as high as \$2.50/ ft^2 in the next few years. These consumer-prohibitive costs are due to flooring mills operating at the mercy of lumber price fluctuations. Raw material represents over 50% of the cost of producing hardwood flooring (Tucker 1999a, Tucker 2000).

Marketing Tools: Eco-movement and Recycled/antique Flooring

Several trends suggest that flooring produced from recycled pallet parts might not have a better time to arrive than the present. Product differentiation can be difficult for flooring dealers to achieve. Often differentiation takes the form of services, such as difficult installations. Flooring companies are seeing benefits from the production and promotion of “green”, environmentally friendly, flooring. Part of this is driven by consumer preference, often expressed through building designers, both commercial and residential.

“Greeness” has been found to be a powerful marketing tool for both attracting customers to a product and promoting corporate responsibility. PermaGrain Products now offers two product lines with the option of selecting environmentally certified wood flooring, harvested from forests managed to be sustainable. They also advertise that they no longer use formaldehyde-based adhesives, improving worker safety and eliminating offgassing (Goodman 1999).

The opportunities presented by adopting sound environmental policies are viewed as long term. While it can be expensive for a company to revamp production and products to conserve natural resources and reduce waste and pollution, such practices are ultimately efficient, which typically translate into savings. Recycled pallet flooring presents an opportunity to produce and market an environmentally friendly product, with little anticipated modification of current production.

Another popular product line that reflects well on the potential market for recycled pallet flooring is reclaimed, recycled, and antique flooring. These products are by and large produced from timber, lumber, and even floors from barns, factories, houses, mills, ships, and other old structures. One of the most popular categories is heart pine, reclaimed antique Southern Long Leaf Yellow Pine, though oak, chestnut, walnut, white pine, and other species are popular. Products such as these are not only environmentally friendly, requiring no new timber to be cut, but they are a conversation piece or status symbol as well.

The manufacturers of most reclaimed, recycled, and antique flooring products are typically smaller, specialty operations, charging high-end prices. The December 1998/January 1999 issue of Hardwood Floors listed or ran advertisements for 21 companies specializing in these products, including one manufacturing a 1/2" unfinished and 3/8" prefinished recycled flooring (Hardwood Floors 1999). These companies included:

- Prestige Hardwood Flooring, Wilmington, NC
- Aged Woods, York, PA
- Whiskey Country Heartpine, York, PA
- The Woods Company, Chambersburg, PA
- Centre Mills Antique Floors, Aspers, PA
- Vintage Lumber, Woodsboro, MD
- Carlisle Restoration Lumber, Stoddard, NH
- America Heart Pine, Memphis, TN
- Authentic Pine Floors, Locust Grove, GA
- The Joinery Company, Tarboro, NC
- Natural Woods, Tarboro, NC
- Mountain Lumber, Ruckersville, VA
- Goodwin Heart Pine, Micanopy, FL
- J. L. Powell and Co., Whiteville, NC

Observations made by the author at the October 1999 Furniture Show in High Point, North Carolina identified a number of small specialty producers of high-end furniture made from reclaimed wood. The wood in these products contained character marks from as small as nail and worm holes, up to the size of large knots and patches of discoloration and decay.

Reclaimed and antique wood typically originated in timber of large dimensions not easily available today. It is revered for its quality and appearance of patina, a quality of aging, including the “natural beauty of knots, flags, worm holes, color variations, and other character marks” (National Wood Flooring Association 2000). So desired is this aged quality that the National Wood Flooring Association advises that new floors can be made to take on an antique look through various hand scraping techniques to distress the wood. It would not be unreasonable to assume that if products such as these are marketable, nail holes and other defects in pallet parts could find acceptance through market identification. This also establishes precedent for the manufacture of products from recycled pallet boards, in terms of defect removal.

As stated, most of these distressed and antique products are associated with smaller manufacturer, but larger manufacturers produce distressed pieces, though often character marks are artificially made. Distressing techniques include finishes that simulate weathering, rasping to give the appearance of wear, and specialized tools used to produced the appearance of insect holes, splits, and other character marks.

Working Example

Big City Forest, a New York City based pallet RRR organization collected pallets at a reduced tipping fee. The pallets were then reused, repaired, or disassembled for pallet parts, furniture, and flooring stock. (Anonymous 1997)

Big City Forest took the concept one step further, developing an integrated operation that included pallet repair and reuse, while converting high quality boards into tongue and groove flooring and furniture. (Anonymous 1997) Big City Forest estimated that the pallets they collect for tipping fees around $0.75 apiece, 6%-13% of the usual tipping fee (this indicates a very high tipping fee, which is assumed to be attributed to solid waste disposal costs in the New York City area), are worth $0.50 chipped, $4.50 as a reused or repaired pallet, around $20 as flooring, and as much as $200 if used in furniture, depending on the wood species, condition, and the type of furniture (Harper 1999).

Big City Forest reported values for pallets when used in different applications do not coincide with those found by other studies. Unfortunately, while Big City Forest served to demonstrate the technical feasibility of using pallets for value added products, the operation was forced to shut down due to unspecified management problems. The operation had been started using subsidized money as an economic development project.

Summary

The literature shows that while pallet recovery and recycling is established and increasing, there remains a potentially tremendous resource of post service life pallets. Most of the pallets that are recovered are used for low or no value ground products. Previous research has explored the potential for directing recovered pallet lumber into value added hardwood products. While these research efforts have shown that the physical conversion of recovered pallet boards into flooring products is commercially possible, the questions inherent to any industrial process, such as raw material supply characteristics and expected yields, have not been answered

Hardwood flooring is a product that is compatible with pallet parts, in terms of material grade and part sizes. Phil Araman has initiated most of the investigation of pallet to flooring conversion, and has successfully converted pallet boards to strip flooring on commercial lines (Araman 2000). The market for hardwood flooring has grown over time and this growth is increasing. Flooring traditionally uses lower grade lumber, but this resource is under new and increasing pressure from the furniture and cabinet industries. Environmentally friendly "green" and recycled "antique" or reclaimed flooring products have successfully made their way into the flooring market. The success experienced by these products and the interest they generate is noted in a flooring industry publication.

Producing flooring material from recovered pallet parts would have several benefits. Landfilling of pallets would decrease and jobs would be created in the form of increased landfill wood recovery and new pallet RRR operations. The profitability of existing operations would increase with some parts sold for high value use. Pallet recycling activities need not be reduced for the sake of part diversion into value added production, but could increase with higher volumes of material diverted from landfills, and only clear parts sent to value added products. The price and pressure on lower value lumber would decrease with the introduction of a new source of raw material. Timber resources would also be relieved of pressure as a result.

There are many potential benefits of wide-spread acceptance of pallet parts being used in hardwood flooring. While the physical process of converting pallet parts to flooring has been demonstrated, the issues related to obtaining pallet material compatible with value added products have not been properly explored. This study serves as a preliminary exploration into the part yields from recovered pallets, the characteristics of the boards that are recovered, and the yields of flooring sized blanks that can be produced from pallet boards.

Chapter 3

Research Methods

The techniques used by this study sought to evaluate the practical potential for manufacturing high value hardwood products from recovered pallet boards. Exploring the specific objectives intended to answer questions that will allow an operation to anticipate the requirements and costs of an operation. Questions examined were: how many pallet boards would need to be collected to make a certain amount of high value hardwood material? What sizes of material can be anticipated? What will the time, labor, and equipment requirements be? Are there unique obstacles to be addressed in terms of processing? The physical conversion of pallet parts to hardwood flooring and paneling has been proven (Araman 2000). This study and the techniques used were focused on the practical issues, such as yield, inherent in any wood products manufacturing operation.

Relating to Objective One

Identify the percentage of structurally sound pallet parts at the disassembler of a recovery/repair/recycling (RRR) operation.

Knowing the percentage of sound parts recovered from pallets serves as a planning tool. It allows pallet RRR operations to anticipate how many pallets need to be disassembled to recover a specific number of parts, whether they are used for pallets or value added products. This study distinguished the recovery of different types of pallets and recovery techniques, allowing even more accurate projections to be made.

Structurally sound parts were defined as deckboards and stringers, sufficiently undamaged such that they could be reused in a remanufactured pallet or used to repair other pallets. This objective focused on parts from pallets that were disassembled because they were either sufficiently damaged to be unsuitable for reuse or repair, or of an unmarketable size, but still having useable parts.

A hypothetical example is a RRR operation focused on producing 45”×48” pallets. They disassemble 40”×48” pallets, reusing the 48” deckboards or cutting them down to 45”. The remaining 40” boards are stored for use in repaired and recycled pallets. Unsound boards are removed from the recovery stream and recycled by grinding for fuel and/or ground products, mulch, bedding, particleboard furnish, etc.

This data was collected observing and recording the output of pallet disassembler saws at four pallet RRR operations. Data collection called for observation of 300 pallets at each of the four sites, for a total sample size of 1200 pallets. This data provided a representation of what percentage of each part type a RRR operation can expect to recover

Data Collection

Pallet disassemblers are band saws with a horizontal cutting blade, above an adjustable table. The pallet is pushed through the saw blade, and the nails connecting the deckboards to the stringers are cut on one side. The pallet is then passed through again, cutting the deckboards from the stringers on the other side.

Part movement was observed and recorded at the disassembled part sorting station. Data collection was typically done with both the saw(s) and sorting station visible. If the saw was not visible, it was necessary to identify the number of pallets disassembled while sorting was observed. This was done with cooperation of the disassembler operators. The total numbers of pallets, deckboards, and stringers processed was recorded at each disassembler, along with how many deckboards and stringers were disposed of by grinding. Reasons for grinding a pallet board usually involve structural problems, either parts were broken, decayed, or too thin. Boards ground for reasons other than being unsound were noted. The decision to grind a board was left entirely to the discretion of the saw operators. The number of sound boards was determined by material balance methods.

Two types of pallets were distinguished in data collection, stringer pallets and block pallets. Figure 8 shows examples of block and stringer pallets. Stringer pallets generally have three stringers, but some pallets observed by this study have two, three, or four stringers. Stringers are solid, continuous members, usually approximately 2”×4” in cross-section. Deckboards are typically oriented perpendicularly to the stringers for load-bearing. Stringers can be un-machined, as in Figure 8, or notched to facilitate forklift fork insertion.

Block pallets use a combination of blocks, approximately 4”×4” in cross-section, and deckboard sized boards, to form the base for the deckboards. For the purposes of this study, block pallets were recorded as having no stringers. For block pallet data recovery, the boards used in combination with the blocks were recorded as deckboards, and the blocks were disregarded.

Figure 8: Block Pallet (left) versus Stringer Pallet (right)

Initially data for the sites was handled on a per site basis. Data recorded at each site included:

- total number of pallets
- total number of deckboards
- total number of stringers
- number of deckboards disposed of by grinding
- number of damaged stringers disposed of by grinding.

Block pallet and stringer pallet data were recorded separately. If a group of pallets of the exact same manufacture were encountered, they were also recorded separately. This was done to identify any differences in disassembly or part handling their design may require. The percentages of sound and unsound parts were calculated for each site, and cumulatively for all sites. Part disposal was left at the discretion of the mill personnel. Additionally, pallets or parts disposed of for any reason other than being unsound were recorded with the ground parts, with the reason for disposal noted.

Distinguishing The Data Collection Sites

Four sites, pallet RRR mills, were selected for this study. The primary reason for the specific sites selected was their previous relationship and willingness to cooperate further with the Virginia Tech Department of Wood Science and Forest Products, and the USDA Forest Service Southern Research Station, which initiated contact for the study. The sites were also favorable because of their relatively close geographic proximity to the University. As shown in Table 4, and in the sections immediately following this one, the sites differ in size and focus of operations, in terms of percentages of new versus repaired versus recycled pallets produced.

Table 4: Comparison of Pallet RRR Data Collection Sites

	Percent of Pallets				**Numbers of Pallets**					
Site	New	Recycled	Repaired	Contain Recycled Parts	Sold Yearly	Received Daily	Avg. Disas-sembled Daily	Avg. Repaired Daily	Work-force	# Disas-semblers / % of Time Run
1	5%	85%	10%	95%	270,000	900-1,200	500-800	*	23	2 / 80%
2	35%	15%	50%	17%	1,100,000	3,700	1,400	2,000	90	3 / 90%
3	33%	10%	57%	77%	1,500,000	7,000	900+	3,200+	73	3 / *
4	*	*	*	*	*	*	*	*	*	*

* see text (Site 4 unable to respond)

Site 1 was the smallest of the four RRR operations used for data collection in this study. This operation primarily produced pallets from recovered parts. It was indicated by the plant manager, that producing new pallets from lumber was an unprofitable venture for the mill, and comprised only 5% of their business. Repairs also accounted for only a small part of the business, 10%. Generally pallets were only repaired about 3 days a week, with one repair worker covering 200-275 pallets daily. Site 1 manufactured 37 footprints, with the primary focus on a 45”×48” pallet used by the automotive industry.

Site 1 had 20 customers, with the largest ones accounting for about 15% of their business. Site 1 had recently begun grinding their waste and selling the ground product as mulch. They started to produce colored mulch, and while this had reportedly generated customer interest, the profitability of this venture had yet to be seen. The primary depositors of used pallets to Site 1 were large manufacturers, most notably, an automobile manufacturer, major appliance manufacturer, and a chemical company. Additionally, Site 1 had "pickers" who collect every pallet possible in the local area.

Site 2 did the largest segment of their business in repairs, but also produced over 1/3 of their pallets from new lumber. Site 2 manufactured approximately 200 footprints. They had 150 customers, with the top 5 representing around 50% of their business. Site 2 ground their waste, and sold ground products, but the capital investment in grinding outweighed any revenue it produced. However, it is important to note that despite the lost revenue, manufacturing and selling ground products was more cost effective than hauling waste away for disposal. Most of the lost money involved with grinding waste was maintenance costs, though the market for ground products was described as "poor". The majority of the pallets deposited at this site came from either grocery and food distribution centers or non-food retail distribution centers.

Site 3 produced about 1/3 of their pallets new from lumber, but the bulk of their business, almost 60%, was in repaired pallets. The mill had three disassembler saws, but usually only ran one or two at a time. They manufactured around 500 footprints for 574 customers. Their largest customer represented around 5% of their business, and their top 20 customers represented approximately 50%. Site 3 ground their waste using two grinders, and sold ground products including colored mulch and Raymond Safety Surface material. The ground material market was successful, but requires a large capital investment. The majority of their pallets arrived via a number of distribution centers.

Site 4: At the time of submission Site 4 had been unable to cooperate with request of the information required.

Relating to Objective Two

Characterize the deckboards recovered by a RRR operation.

Characterizing the deckboards recovered by pallet recovery operations served two purposes. It allowed for projections to be made regarding what species and sizes of parts can be expected. It allowed this study to give an accurate description of the parts that were used to generate all results. An operation exploring the use of pallet boards as raw material for value added products could use this information to anticipate the requirements for board sorting and collection. Stringers were not considered good candidates for value added products. After disassembly they had cut-off nails remaining in them, making them unfeasible for the board break down and planing needed for flooring production. In this study deckboard characteristics included:

- species breakdown divided into 3 classes: softwood, non-oak hardwood, and oak
- length and width of all boards recorded to the nearest 1 inch
- percentage of oak deckboards sufficiently free of defects for use in value added products
- moisture content of the useable oak deckboards
- specific dimensions of these boards, length, width, and thickness

This study focused on oak boards for the sake of simplicity and due to the fact that over 25% of all pallet boards are oak (Bush and Araman 1998a). Oak is usually easily identified versus other hardwoods that can be more difficult to identify in an industrial setting, such as elm, hickory, ash, birch, maple, and poplar. Also, oak is a species in high demand for flooring as well as other hardwood products. Nevertheless, pallets are accepted for recycling with no regard to wood species. The size of a pallet and consequently the sizes of parts it contains are much more important than species to RRR operations, who need certain size parts to meet recycling and repair needs, irregardless of species.

Useable oak boards were those with potential for use in value added products. Moisture content of these oak deckboards was recorded for evaluation of how much drying would be needed to reach approximately 7% MC, the target level for most flooring operations. If there was a wide range of MC's, then this might present difficulties. Drying a batch of boards with widely inconsistent MC's, either across the batch or within boards, could impact material recovery, drying strategies, and ultimately economics.

Data Collection and Handling

Disassembled deckboards are stored in pallet packs. A pallet pack of boards usually had one of two configurations; either a pallet with vertical boards nailed on for sides, or a pallet with boards stacked and strapped down. Packs were made up of boards of the same length, allowing for easy evaluation and transport when boards of a certain length were needed for repair or recycling. Some mills stacked boards in columns of the same width, presumably for ease of access when parts of certain dimensions were needed. From a pack of pallet deckboards several categories of data were collected. Boards were visually evaluated and tallied as softwood, non-oak hardwood, or oak. Also the length and width measurements for each board, rounded to the nearest 1”, were recorded. All non-oak boards were set-aside after species and length and width data were recorded. These boards were eventually returned to the pallet pack they came from. A customized device, Figure 9, with length and width measurements, along with a ½” thickness mark on an extension above the measuring surface, helped expedite this process. A second device, also shown in Figure 9, is a template for evaluating an area 2 ½” wide up to 40” long. This was used to determine whether a clear space of sufficient width was available over at least half the length of the board. Also found to be helpful were razor blades for clearing end grain and facilitating accurate species identification. This was needed when boards were heavily worn or soiled.

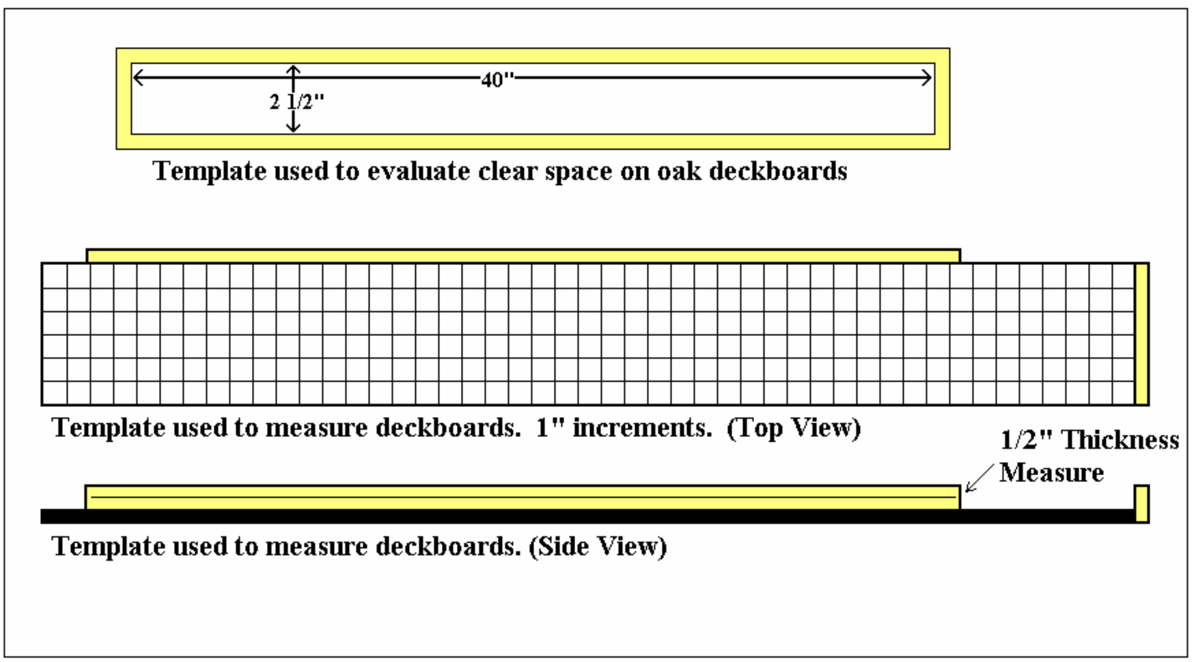

Figure 9: Template for evaluating clear space on oak boards (top), and template for deckboard dimension evaluation (bottom)

When located, oak boards, both red and white oak, were recorded as either useable or non-useable for value added products. Useable was defined as being at least ½" thick and having a clear area wide enough to make a 2 ½" wide blank over at least half the length. Based on visual inspection of the rough board, the clear area had to be free of defects that would have made it inadequate for use as flooring. If there was still doubt about the size of the clear area using the template, it was measured with a measuring tape. It is important to note that having a defect does not disqualify a board, but having a defect that interrupts the 2 ½" wide clear area caused disqualification. The following defects, interrupting the clear area, were recorded as having disqualified a board:

- Warp (bow, cup, and twist)
- Split (splits and checks through the thickness of the board)
- Thin (boards less than ½" thick)
- Decay (decay and insect damage)
- Knot (loose knots, decayed knots)
- Width (entire board less than 2 11/16" wide, the width of one blank allowing for edge trimming)
- Wane

Allowable defects included nail holes, small insect holes, color variations, minor streaking, small knots, and other small character marks. Boards with multiple unallowable defects were recorded in the category of their most dominant defect, generally the one that eliminated the largest area of the board. This data was recorded and the percentage of non-useable oak boards in each defect category was calculated for each site and over all the sites. Non-useable oak boards were set aside with non-oak hardwoods and softwood boards that had been evaluated. These boards were returned to their pallet packs at the end of data collection.

Useable oak boards were set aside for eventual conversion into blanks. Deckboard pack evaluation continued until 300 useable boards were collected at Site 1, and until 130 were collected at Sites 2, 3, and 4, for a total of 690 useable oak deckboards. The reason for the larger number of boards collected from Site 1 was the high level of cooperation afforded by the management of that facility regarding collection of material. It was assumed that this would not bias the results, since through their travels; pallets become well mixed in terms of their service lives, origins, and species.

The percentage of oak, non-oak hardwood, and softwood was calculated for each site and overall. The percentage of useable and non-useable oak boards was calculated from the total number of boards collected at each site and overall. Also, the percentage of useable and non-useable oak boards was calculated from the total number of oak boards for each site and overall.

The moisture content of each useable board was measured, using a hand-held Wagner L606 dielectric (electromagnetic wave) moisture meter(Wagner 2000). Most recovered pallet boards are stored outdoors, uncovered. Due to the presence of surface moisture that can severely bias moisture content readings, boards were transported from their respective RRR facility, stacked to allow airflow, and measured for moisture content after a period of 18-24 hours.

Moisture content (MC) due to rain can be unevenly distributed due to random water movement through the pack. Random water movement can cause MC variation from board to board and within individual boards. To examine the effect that this has on MC within individual boards, two moisture content meter reading were taken for each board. It was important that nothing was behind the board during measurement, as the meter will read through the board and include whatever was behind it. To avoid bad meter readings boards were held vertically, by the top of the boards, when MC meter reading were taken. MC's were taken from each end of each board approximately 6" from the end nails, which were eventually cut off. These meter readings were converted using the meter's manufacturer provided conversions found in Table 5. Also, Table 5 shows that for the same meter reading, the red oak MC is equal to or higher than the white oak MC after conversion. Oak species were not identified or separated, so therefore the red oak MC conversion was used for all boards, as it is the more conservative of the two conversion.

Table 5: Wagner L606 Moisture Meter Conversion Chart

MC Meter Conversions: Red Oak and White Oak				MC Meter Conversions: Red Oak and White Oak			
Meter Reading	Red Oak MC	Wt. Oak MC	Difference	Meter Reading	Red Oak MC	Wt. Oak MC	Difference
5	3	3	0	18	14.5	12.5	2
6	4	4	0	19	15	13.5	1.5
7	5	5	0	20	16	14	2
8	5.5	5.5	0	21	17	15	2
9	6.5	6.5	0	22	18	15.5	2.5
10	7.5	7	0.5	23	18.5	16.5	2
11	8.5	7.5	1	24	19.5	17	2.5
12	9	8.5	0.5	25	20.5	17.5	3
13	10	9	1	26	21	18.5	2.5
14	11	10	1	27	22	19	3
15	12	10.5	1.5	28	23	20	3
16	12.5	11.5	1	29	24	20.5	3.5
17	13.5	12	1.5	30	24.5	21.5	3

The moisture meter can only measure from 5%-30% MC. A maximum meter reading of 30 was recorded as 30% MC, and assumed to be fiber saturation point. Both MC's for each board were graphed on the same axis, allowing for a visual inspection of the within-board variation for each site. A within-board MC variation of 5% or more, unaccounted for during drying, can lead to wet pockets in lumber that cause warping in lumber (Lamb 2000). The difference within each board was calculated, using the format in Equation 1. Moisture Content One (MC_A) was taken within six inches of one board end and Moisture Content Two (MC_B) was taken with in six inches of the opposite board end.

$$MC_{DIff} = |MC_A - MC_B| \qquad \textbf{Equation 1}$$

Where: MC_{Diff} = *Within Board Moisture Content Difference*
MC_A = *Moisture Content from one board end*
MC_B = *Moisture Content from opposite board end*

The distributions of within-board MC differences for each site were evaluated using a histogram. Within-board MC difference values meeting or exceeding 5% were counted for calculation of the per-site percentage of such extremes. The average MC for each board and each site was not calculated, as this did not give a true representation for evaluating drying difficulty. Observation of the plotted MC's was the best way to determine the typical overall MC, and the implications the data has on potential drying problems.

Relating to Objective Three

Identify the percentage board foot yield from converting useable oak deckboards into standard flooring size blanks.

Blanks can be converted into flooring or other products, such as paneling, or possibly furniture. These standard blanks were manufactured at the USDA Forest Service Lab in Princeton, West Virginia. Knowing the yield of blanks, specific grade potential, and sizes of blanks, produced from the sampled deckboards allowed estimates to be made of how many boards need to be collected to produce a desired amount of blanks. Also, having the size values of the pallet boards used to generate the blanks was an important descriptive factor, which helped characterize the nature of the boards collected.

Data Collection

Length, width, and thickness were recorded for each useable oak board. Length and width were recorded using a measuring tape to the nearest 1/16”, and later converted to 0.001”. For example a board measured at 5 5/16” was converted to 5.313.” Thickness was recorded using calipers to the nearest 0.001”. Thickness was measured in one spot per board, a minimum of approximately 6” from where the board had been attached to the stringer, in order to avoid any compression in these areas. All boards were numbered using a permanent marker for data tracking purposes. Lengths, widths, and thicknesses for all boards collected were evaluated using a histogram, giving a profile of the boards collected by the study. The total board foot volume was calculated using Equation 2.

$$BdFt = (L \times W \times T) \div 144$$ **Equation 2**

Where: *BdFt* = *Board Foot Volume*
L = *Length (in.)*
W = *Width (in.)*
T = *Thickness (in.)*

Board foot volume and board area were evaluated using a histogram in order to further establish a profile of the boards collected. Also, the board foot volume and area of boards less than or equal to 4 ½" wide and the board foot volume and area of boards greater than 4 ½" wide were evaluated separately using a histograms. This separation allowed a comparison of the dimensional differences between the narrow and wide boards typical of pallets.

End-trimming boards was done to remove end nails, nail related splitting, and other end defects. End–cutting was performed using a cross-cut saw, specifically a radial arm saw with a 3/16" kerf. While the primary goal of this exercise was to remove the end nails, splits that usually formed along the grain lines where nails were located were a major defect, and were also removed during end-trimming. Typically trimming a split at its visible end reveals that it runs further than initially seen. Trimming approximately 1" past the visible end of the split was a good practice, helping to eliminate seen and unseen end splitting. Figure 10 shows a typical end trim placement in relation to split location.

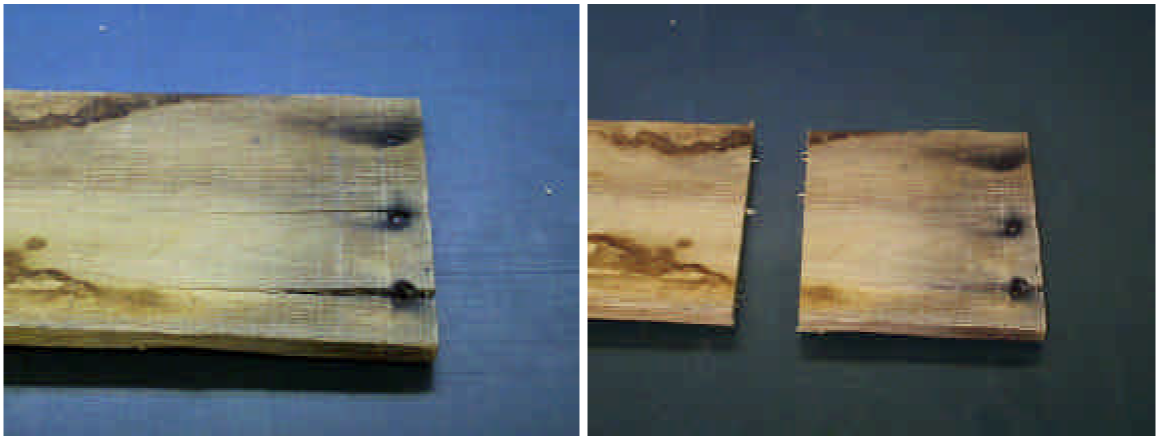

Figure 10: End Trimming Deckboards: Before (left) and After (right)

Boards that have no visible end-defects were not end-trimmed at all, especially if there were a small number of end nails. If a board was sufficiently wide to produce two 2 ½" wide blanks and contains a split that only affects one of the blanks, the split was not trimmed out at this phase. This practice allows maximum recovery of the unaffected blank. The affected blank has the split removed after both blanks were ripped for width. A measuring tape was useful to determine where blanks could be cut out around splits, especially on boards wide enough to produce two blanks.

All board lengths were re-measured after end-trimming, the end-trimmed length was recorded with the original length, for calculation of percentage loss, and average loss per board. Percentage loss was determined using the format in Equation 3. The distribution of the percentage loss after end-trimming was evaluated using a histogram.

$$\%LOSS = 100\% - (M_A - M_B) \times 100 \qquad \textbf{Equation 3}$$

Where: $\%LOSS$ = *Percentage Lost*
M_A = *Initial Value*
M_B = *Value After Loss*

At this point, all of the boards were grouped together for yield analysis. The boards were no longer associated with the mill they were collected from. Yield was looked at on the basis of volume of blanks from the total volume of boards.

Center and remaining end nails were removed by hand using a 1/32” nail set to loosen the nail, and a claw hammer to complete extraction. Also useful for nail removal were awls and pliers, especially when staples were encountered. Care needed to be taken during nail removal to extract wires that occasionally remain in the nail holes of pallets manufactured using nail guns. The total time for nail removal was noted and used to calculate an approximate time for nail removal per board.

Boards were converted into blanks at the USDA Forest Service Lab in Princeton, West Virginia. The blanks were 2 ½” wide. This corresponds with common commercial practices. Flooring plants producing 2 ¼” strip flooring produce blanks that average around 2 9/16” wide (Wahlgren 1999b). Blanks were reduced to either 0.7”, 0.45”, or 0.35”. Blanks were planed until all rough spots on both sides were cleaned up. If they had not cleaned up at 0.7”, they were reduced to 0.45”, and if they were not cleaned up at 0.45” they were reduced to 0.35”. Blanks that had not cleaned up at 0.35” were not used in the study. Blanks of the same thickness were stored together.

Blanks were planed to desired thickness using an abrasive planer, the Timesaver Speedbelt Sander. Blanks were at least Surfaced One Side (S1S), and Surfaced Two Sides (S2S) whenever possible. Blanks that were already S1S, were not made S2S if it requires them being reduced to the next lowest thickness. All blanks were planed first to 0.7”. Those that were S1S and had been partially surfaced on the back side were left at 0.7”. Blanks that were not surfaced completely on either side were reduced to 0.45”.

If neither side was completely surfaced at 0.45” than the blanks were reduced to 0.35”.

Blanks were ripped to width on an Ekstrom (E) Carlson straight line rip saw, with a 3/16” kerf. Careful observation and planning were necessary to ensure the best quality blanks. Total processing time was recorded. Blanks with any remaining defects were then re-cut to length. The length, width, and thickness of the manufactured blanks were recorded for the calculation of the board foot volume of the blanks.

Blanks were graded using North American Oak Flooring Association Prefinished Oak Strip Flooring Grading rules as a guideline (NOFMA 2000b). One exception to the grade rules made by this study was ignoring nail holes as a defect. Additionally, the grading rules are intended for finished flooring products. The blanks produced by this study were assumed to be a potential source for the same flooring products. Three grades used for evaluation were Prime, Standard, and Tavern. Blanks of the same thickness were sorted into groups of thickness/grade designation, for example .45” Prime blanks.

- Prime Grade
  - Allowable:

    -sapwood
    -natural color variations
    -occasional small burls
    -light brown streaks < 1/8” wide and < 6” long
    -occasional tight $\leq$ 1/8” knot
    -limited 1/32” pinworm holes (must be properly filled)
    -minimum average length 3’ 3”
- Standard Grade
  - Allowable:

    -worm holes
    -season and kiln checks
    -broken knots up to $\leq$ 3/8” diameter
    -minor imperfections in machining
    -torn grain and burns
    -other characters not affecting the soundness of the blank
    -larger, open characters must be properly filled and finished

- Not Allowable:
  - -large grub worm holes
  - -splits extending through the piece, shake, unsound defects
  - -minimum average length 2’ 6”

- Tavern Grade
  - Allowable:
    - -limited unfilled and open characters
  - Not Allowable:
    - -mismanufactured boards
    - -shattered or rotten ends
    - -large open knots or other unsound defects
    - -no minimum average length

Blanks were measured for length to the nearest 1/16”. These measurements were converted to 0.001”. The distribution of the blank lengths was evaluated using a histogram. The blank length measurements, along with their standardized width and thickness values, were used to calculate the board foot volume of the blanks. Percentage yield was found for the total board feet of blanks versus to total board feet of deckboards. Also, percentage yield for blanks of individual species/thickness was calculated. An example of this is the percentage yield of 0.45” Standard Grade boards from the original deckboards.

Percentage yields was used to find the ratios of blanks to deckboards. The procedure finding these ratios is found in Equation 4.

$$\frac{BL/BL}{BD/BL} = R$$ **Equation 4**

Where: *R* = *Ratio of Blanks to Boards*
BL = *Board Foot Volume of Blanks*
BD = *Board Foot Volume of Boards*

Chapter 4

Results and Discussion

The results of the methods used to explore each of this study's objectives are presented in this chapter. Results and related discussion were organized by the objective they examine.

Relating to Objective One

Percentage of structurally sound parts from a pallet

The results of surveying disassembler output at the four RRR operations are outlined in Table 6. Overall, 1,180 pallets were processed during operation. The original methods called for 1200 total. A labor shortage caused an extremely slow rate of disassembly at the final site, consequently only 150 pallets were able to be observed in the allotted time on site. This deficit was balanced out by Sites 1-3, where more than 300 pallets were observed at each site. The pallets observed were of both the stringer and block type. They yielded 2,725 stringers and 12,436 deckboards, of which, 817 (30%) stringers and 2,398 deckboards (19%) were ground.

It was observed that not all of the parts that were ground were unsound, especially deckboards. This observation was due to disassembly operating philosophies at the different operations. Some sites did not completely disassemble some parts, choosing to grind potentially recoverable sound parts. The decision to not disassemble a pallet or part of a pallet was based on the time required for disassembly, the difficulty of disassembly, or a combination of both. The decision to grind a board was left at the discretion of the saw operator. These practices caused the high percentages of parts disassembled for some of the pallet sets at various sites.

Table 6: Pallet Disassembler Output, All Sites

					Grinder			
Site #	**# In Pallet Group**	**Group Type**	**Stringers**	**Boards**	**Stringers**	**%**	**Boards**	**%**
1	112	Stringer	332	781	114	34%	20	3%
	113	Stringer	329	1227	329	100%	395	32%
	139	Stringer	407	1327	29	7%	43	3%
Total:	364		1068	3335	472	44%	458	14%
2	129	Stringer	382	1180	51	13%	74	6%
	223	Block	0	2689	0	0%	1358	51%
Total:	352		382	3869	51	13%	1432	37%
3	255	Stringer	812	3034	233	29%	212	7%
	59	Block	0	703	0	0%	169	24%
Total:	314		812	3737	233	29%	381	10%
4	147	Stringer	463	1454	61	13%	115	8%
	3	Block	0	41	0	0%	12	29%
Total:	150		463	1495	61	13%	127	8%
TOTAL	1180		2725	12436	817	30%	2398	19%

Site 1 disassembled three distinguishable groups of pallets. The distinguishable groups were one of 112 pallets, one of 113, one of 139 indicated by the “Pallet Group” column in Table 6.

The pallets in the group of 112 at Site 1 were of a special design, used at a major appliance manufacturer. These pallets contained a heavy, 3”×4” stringer, notched to accommodate forklift forks, and two 2”×2” stringers. The heavy stringers were of an unusable size and contained too many nails to be machined into a more common stringer size, so they were all ground, accounting for 112 of the 114 stringers ground for this group. Two of the 2”×2” stringers were ground, and the rest were saved, because of their high quality, although a use for them had not been determined.

The pallets in the group of 113 at Site 1 were designed in a way that made them difficult to disassemble. For unspecified and unapparent reasons the pallets pinched the disassembler blade. The first pallet disassembled proved very difficult, and the second caused the disassembler saw blade to break. After this only the top boards were cut off, while the three stringers and bottom three boards were ground, accounting for 329 stringers (some pallets were missing stringers), and around 339 of the 395 boards ground for this group.

The group of 139 pallets was a mix of various sizes and types of stringer pallets. They were completely disassembled with stringers sorted into un-machined 2”×4” stringers and machined stringers. The 2”×4” stringers were cut to shape and size, while machined stringers were inventoried for future use. Boards were sorted by length, and stacked with similar widths of the same length in packs.

Disassembler yield results from Site 2 were affected by the operation’s practice regarding the disassembly of block pallets. The design of the 223 block pallets incorporated block “stringers,” made up of a combination of three blocks, one at each end and one in the middle, connected with a deckboard on the top and bottom (Figure 11). Boards used in block pallet “stringers” of the same dimension and quality as deckboards were treated as deckboards by this study.

Five deckboards were on top of the “stringers,” perpendicular to the stringer orientation. The top five boards (Figure 11) were cut off for recovery, while the stringers were ground. Boards in the ground “block pallet stringers” accounted for 1338 of the deckboards ground. The persons collecting data observed only three broken boards throughout all the ground block “stringers” indicating a significant potential for greater recovery. However, the block stringers were not disassembled due to the large amount of time required. Disassembling them would have required sending them through the saw one at a time, requiring two passes per stringer. The operators' decision was to make one pass and recover 5 boards, versus making seven passes and recovering 11 boards.

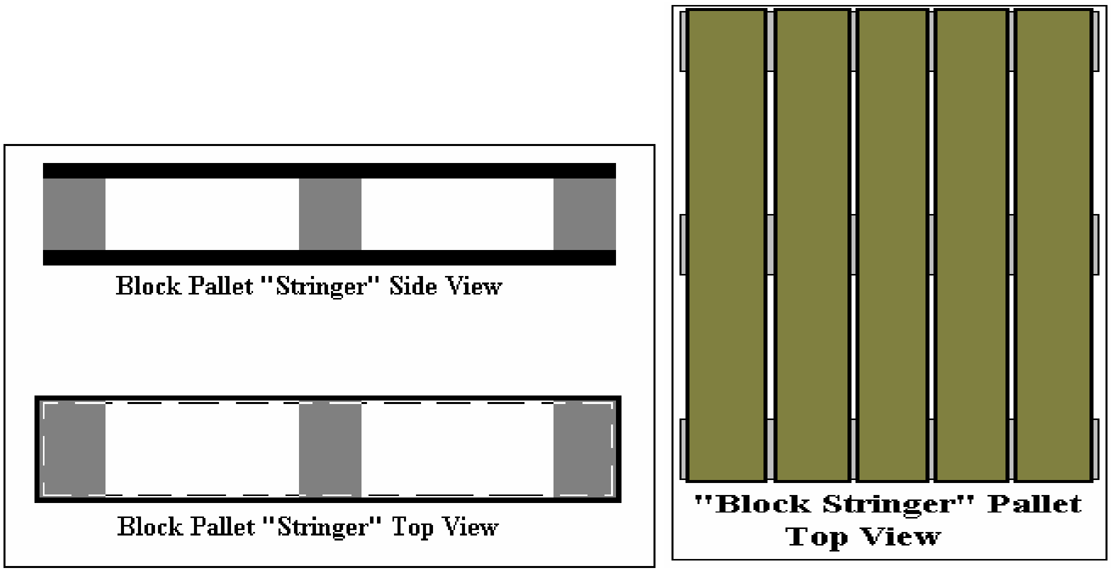

Figure 11: Site 2 Block "Stringer" (left) Dotted lines indicate bottom board.

Site 2 "Block Stringer" Pallet (right)

Site 3 had two types of block pallets. One type of block pallets was the same as those encountered at Site 2, and described in the preceding paragraphs. These pallets were disassembled, except for the bottom board of each block "stringer," which was ground attached to the three blocks. The sequence used removed the bottom three "stringer" boards on the first pass, and the deckboards on the second, leaving three boards with three blocks attached to each that were ground. This process used two passes through the disassembler to recover eight boards.

The other Site 3 block pallet type had a similar design to those encountered at Site 2, but the top boards parallel to the bottom boards were fastened to the inside edge of the blocks. Two boards, perpendicular to the other boards, were nailed to the outside of the top boards, across the blocks (Figure 12). Five to seven deckboards were fixed to the top of the base (Figure 12). The second design was completely disassembled in three passes through the saw. The first pass removed the top deckboards. The second pass removed the three bottom boards of the stringer assembly (indicated by the dotted lines on the pallet base design shown in Figure 12). The final pass removed the top boards of the pallet base design (Figure 12). Because of complete pallet disassembly at Site 3, only a few deckboards were sent to the grinder.

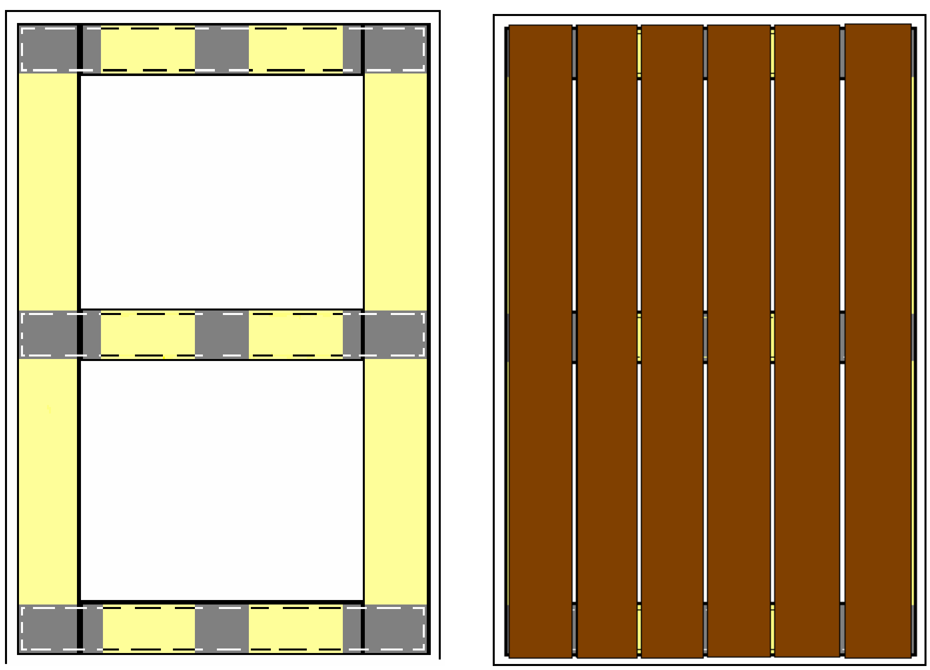

Figure 12: Site 3 Block Pallet Base Design (left) (dotted lines indicate bottom board position)

Site 3 Block Pallet with Deckboards (right)

Site 4 disassembled all pallets of both block and stringer design completely. Site 4 did have one distinguishing practice, boards were sorted and inventoried not only by length, but also thickness, with ½" – 5/8" serving as the mill's dividing line between thick and thin boards. This is considered a good practice, because inconsistent thickness in pallet deckboards will force the thicker boards to bear all the load weight, as the thinner boards will not come in contact with the load. Also, this practice is helpful for an operation collecting boards for value added products, as board thickness is an important factor in material selection, especially for flooring.

The frequent incomplete disassembly of block pallets had an effect on the overall disassembler yield data (Table 7). Block pallets accounted for only 24% of the pallets in the study and deckboards from block pallets accounted for only 28% of the boards surveyed. Despite this, block pallets accounted for 1,539 of the 2,398 boards ground, or 64% of the boards ground. Block pallet boards were ground at a rate five times greater than stringer pallet boards, for the reasons outlined in the preceding paragraphs.

Table 7: Affect of Block Pallet Disassembly Practices

Comparison of Deckboard (bds.) Yield: Block vs. Stringer Pallets

	Boards	Boards Ground
1180 Pallets	Total: 12436	Total: 2398 (19% of overall bds.)
285 Block (24% of pallets)	3433 (28% of bds.)	1539 (45% of Block bds.)
895 Stringer (76% of pallets)	9003 (72% of bds.)	859 (10% of Stringer bds.)

Non-standard, non-stringer type pallets typically had an affect on part recovery. This suggests the possibility for designing pallets with disassembly in mind. The data collected and observations made suggest that stringer pallets are easier to recover than block pallets. Another feature that would help recovery is using stringers that are the same height and deckboards that are the same thickness.

This would keep the nails connecting the boards to the stringers level to facilitate smooth movement through the disassembler blade.

Relating to Objective Two

Characterization of the deckboards recovered by a Recovery/ Repair/ Recycling (RRR) operation

Species Characterization

Boards were first evaluated in terms of overall species distribution. The original plan called for every third useable oak board to be collected. If the rate of useable oak boards was too low for the arbitrary number of boards to be collected in the time allowed, then the rate of collection was to be increased. Due to a low useable board rate, 17% at the first site visited, the rate of collection was reduced to every useable oak board collected. In the interest of uniformity this rate was maintained through all the sites.

Oak has been reported to be in excess of 25% of the lumber going into pallets (Bush and Araman 1998a). This is consistent with the overall species mix identified by this study, which was approximately 1/3 each of oak, non-oak hardwood, and softwood (Table 8). However, the overall species mix pattern does not reflect the pattern seen at individual sites. Site 1 showed a high percentage of non-oak hardwood, with a sizeable amount of poplar, maple, and birch observed during data collection.

Site 4 had a very high percentage of oak boards, at 41%, compared to the other sites. No pattern was apparent for non-oak hardwood, with considerable variability among the sites. The differences in the species patterns at the individual sites indicated significant variability of types and origins of the pallets disassembled for a particular mill run. Softwood was around 45%-50% of the species for all sites, except Site 1, which had a much lower softwood percentage and a high occurrence of non-oak hardwood. Any concentration of parts of similar species was likely due to one of the pallet packs containing boards from a large set of pallets of the same kind, from the same source, that used these species heavily.

Table 8: Deckboard Species Breakdown All Sites and Overall

	#1	#2	#3	#4	Total
# Bds	1503	569	631	451	3154
Oak Bds	451 (30%)	187 (33%)	158 (25%)	185 (41%)	981 (31%)
Non Oak H.W.	813 (54%)	90 (16%)	191 (30%)	58 (13%)	1152 (37%)
Softwood	239 (16%)	292 (51%)	282 (45%)	208 (46%)	1021 (32%)

Useable Oak Boards

The second factor examined during board evaluation was the sorting of useable and non-useable oak boards. A useable oak board was at least ½" thick, and had to have an area over more than half its length, 2 ½" wide or wider, free of critical defects (see Chapter 3). The results of oak boards sorting can be found in Table 9.

The original plan called for 300 useable oak boards from Site 1, and 100 from each of the others. Due to a miscount, 299 boards were collected from Site 1, but closer evaluation after leaving the site showed that 38 of them had been misidentified, and were actually non-oak hardwoods. After this misidentification error was realized, razor blades were used at subsequent mills to clear end grain of boards whose species was in doubt. The collection rate was increased to 130 each for the remaining sites, to make up the lost boards and as a precaution in case of further species misidentification. This number was not adhered to completely due to miscounting and occasional species misidentification.

Misidentified boards were later corrected in the data for the appropriate site. Miscounts were often difficult to avoid. Useable boards were stacked together, so counting was done using the board ends as a reference. Often 5”-6” wide boards had large end splits, often centrally located, and would appear to be two narrow boards. Again, all errors in data were corrected upon discovery.

Table 9: Oak Board Sorting Results

	#1	#2	#3	#4	Total
Oak Bds	451	187	158	185	981
Useable	261	132	115	147	659
% Overall / % Oak	17% / 58%	23% / 71%	18% / 73%	33% / 79%	21% / 67%
Non-Useable	190	55	43	38	326
% Overall / % Oak	13% / 42%	10% / 29%	7% / 27%	8% / 21%	10% / 33%

All sites except Site 1 had over 70% of the oak boards ruled useable (Table 9). The low rate of useable oak boards, 58%, at Site 1 was attributed to board storage practices that led to high and variable moisture contents in the boards, which will be discussed further in this section. Another notable observation occurred in Site 4, which had the highest rate, 33%, of useable oak among all boards at the site. This large overall percentage of useable oak boards at Site 4 was attributed to the high rate of oak boards observed there, 41%, 8% higher than the second highest site (Table 8).

The occurrence of defects in the non-useable oak boards is detailed in Table 10. Boards with multiple defects were counted in the category of their most dominant defect. Overall, splits were the dominant defect in 45% of the rejected boards, and were the leading defect at each site. Boards under ½”, too thin to be used, were also a significant problem. Site 1 experienced a disproportionately large number of defects and a greater percentage of defects in several categories, especially knot, decay, and warp. Most of the knots that disqualified boards were rotted or open. All of the major Site 1 defect categories appear to be moisture related. Site 1 boards, as stated, were stored in a manner conducive to repeated moisture exposure, which will be further explained in the next section.

Table 10: Occurrence of Defects in Non-Useable Oak Boards

Non-Useable Oak Boards	#1	#2	#3	#4	Total
	190	55	43	38	326
Splits	62 (33%)	23 (42%)	33 (77%)	28 (74%)	146 (45%)
Thin	50 (26%)	13 (24%)	0 (0%)	8 (21%)	71 (22%)
Knot	34 (18%)	4 (7%)	4 (9%)	0 (0%)	42 (13%)
Decay	21 (11%)	6 (11%)	3 (7%)	2 (5%)	32 (10%)
Wane	8 (4%)	6 (11%)	3 (7%)	0 (0%)	17 (5%)
Warp	14 (7%)	3 (5%)	0 (0%)	0 (0%)	17 (5%)
Width	1 (1%)	0 (0%)	0 (0%)	0 (0%)	1 (0%)

Moisture Content of Useable Oak Boards

The MC's for all useable oak boards were evaluated. Moisture content is important because boards recovered for value added products must be dried for use. Ideally moisture contents will be well below the fiber saturation points, around 30% MC, and relatively uniform throughout the boards and within individual boards to allow for uniform drying.

Two moisture contents MC's were taken from each board, one from each end, and were used to determine within-board MC variation. The variation proved large enough over some boards that it was determined an average would not properly describe the overall MC. Each board had both MC's graphed together on the same vertical axis. This allowed overall MC to be approximated by observation of the graph, while illustrating within-board MC over each site.

Figure 13 shows the highly variable MC of the useable oak boards collected at Site 1. Each board had two MC measurements. Measurement 1 was shown as a point on the gray line, and measurement 2 was shown on the same vertical axis, in the black points. The gray line showed overall MC variation between boards, while the black line plots indicated the degree of within board MC variation. It should be noted that the MC's shown were determined using the moisture meter's red oak conversion for all oak boards. The white oak conversion is 0%-3.5% MC lower than the red oak conversion (Table 5). Because of the wide range of MC both overall and within individual boards, Site 1 received special analysis.

At Site 1, 19% of the boards collected had within-board MC differences of 5% or greater, with a few exceeding 10% (Table 11). A difference this high would make drying the boards very difficult without experiencing heavy drying defects. What this data meant from a practical standpoint was a MC reading from one location on a board from this sample had an 80% chance of being accurate, within 0%-4% MC, for the entire board. The high MC and high variability was attributed to poorly designed board stacking and storage practices, alluded to earlier in this section. Boards were loosely stored in pallet packs outside. Rain, which had fallen heavily the week leading up to data collection, can run into a pack and settle randomly throughout. Figure 14 shows an example of Site 1 board stacking compared the technique used at Sites 2, 3, and 4.

Table 11: Distribution of Within-Board MC for Site 1

Differences	Number	%
15+	1	0.4%
11 to 15	9	3.4%
5 to 10	40	15.3%
0-4	211	80.8%

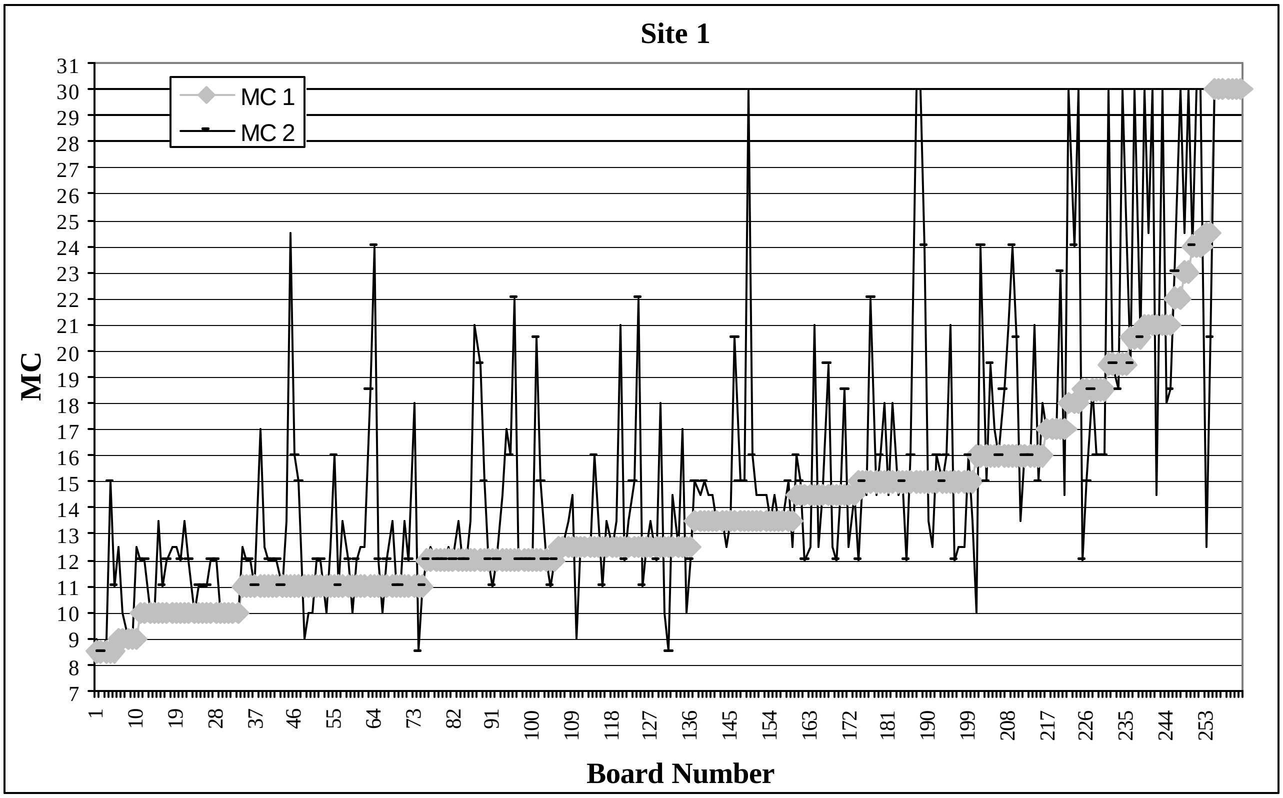

Figure 13: Site 1 MC Distribution

Figure 14: Board Stacking Site 1 (left) Versus Sites 2, 3, and 4 (right)

Figure 15, Figure 16, and Figure 17, respectively show the MC data for Sites 2, 3, and 4. The MC pattern for the boards collected at these sites would be much less troublesome in drying applications. Overall, MC's for these sites were lower than Site 1, and within-board MC variability was much lower. MC's for Site 2 and 3 were below 15% MC, and within-board MC variation was rarely as high as 3%. Even Site 4, which had a few high readings attributed to recent rain on the top boards of the stack, had around 90% of it's boards 15% MC or lower. Site 4 did have 4 boards with within-board MC differences greater than 5%. Two boards had a 7% within-board MC difference, and two had a 6% difference. The low and stable MC found at these sites was attributed to board stacking practices shown in Figure 14. These sites sorted boards by length and stacked them on top of boards of approximately the same width. The boards were then strapped together tightly, further limiting access for moisture. The effectiveness of this was reflected in the MC data for these sites, especially when compared with Site 1.

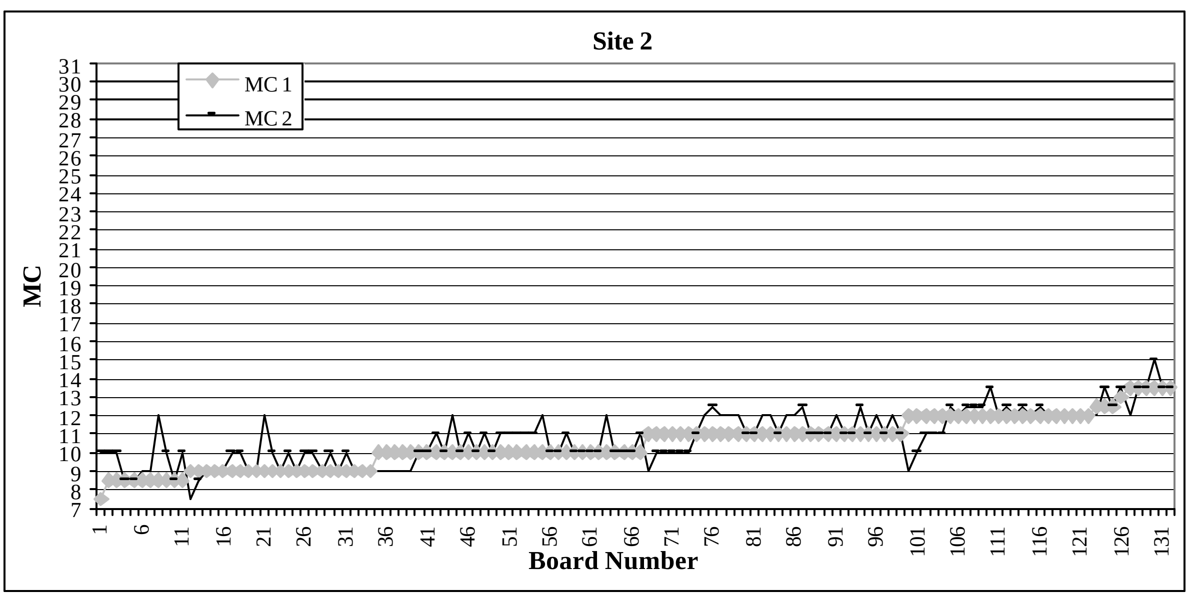

Figure 15: Site 2 MC Distribution

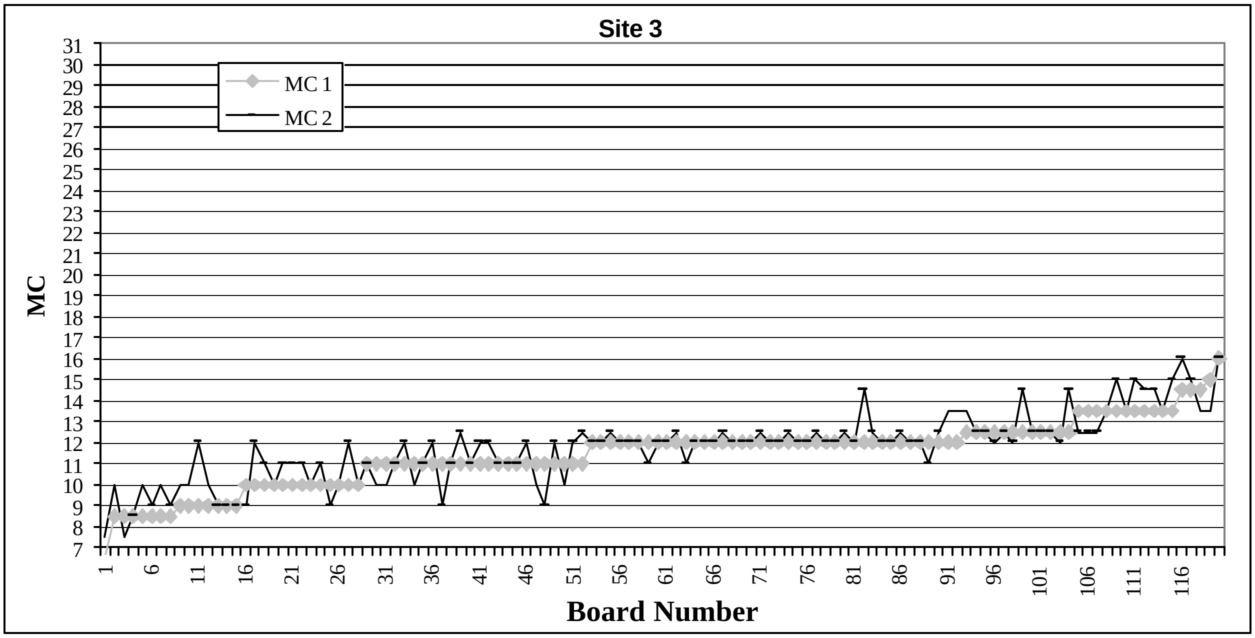

Figure 16: Site 3 MC Distribution

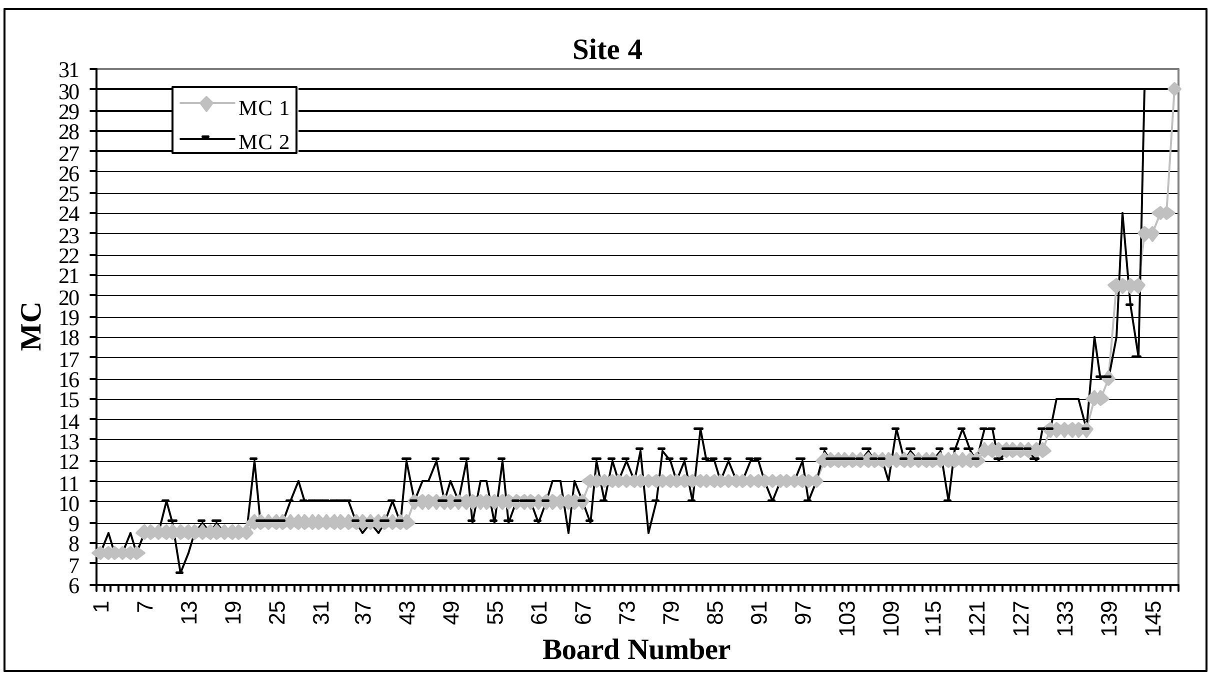

Figure 17: Site 4 MC Distribution

Relating to Objective Three

Yield from useable oak deckboards converted into standard size blanks

It was important to define the physical dimensions of the useable boards collected as this affected the blank yield. Especially important were width and thickness. Thinner boards would lose less thickness in planing and consequently have a greater board foot yield. Boards that contained a majority of wide boards, greater than two blank widths wide, could have a higher or lower yield of blanks depending on how many yielded two blanks.

Determining the board foot yield for blanks from boards (useable oak deckboards) involved several steps. Boards were measured for length, width, and thickness for both board characterization and board foot yield calculation. Boards were end-cut for end nail and defect removal, and re-measured to determine end loss distribution. Standard sized flooring blanks were manufactured to 2 ½” wide and planed into three thickness classes, 0.7”, 0.45’, and 0.35”. Blanks were then measured for length after final defect removal.

Length of Boards

Board length profile (Figure 18) showed over 75% of the boards fell into two length groups, 44% of the boards were between 39” and 40”, while another 32% were between 41” and 42”. The next largest group of boards was between 43” and 44”. Observation during data collection suggested that many of the boards between 40” and 41” and 42” and 43”, were closer to the lower measurement, and were probably designated for reuse as 40” and 42” pallet boards, respectively.

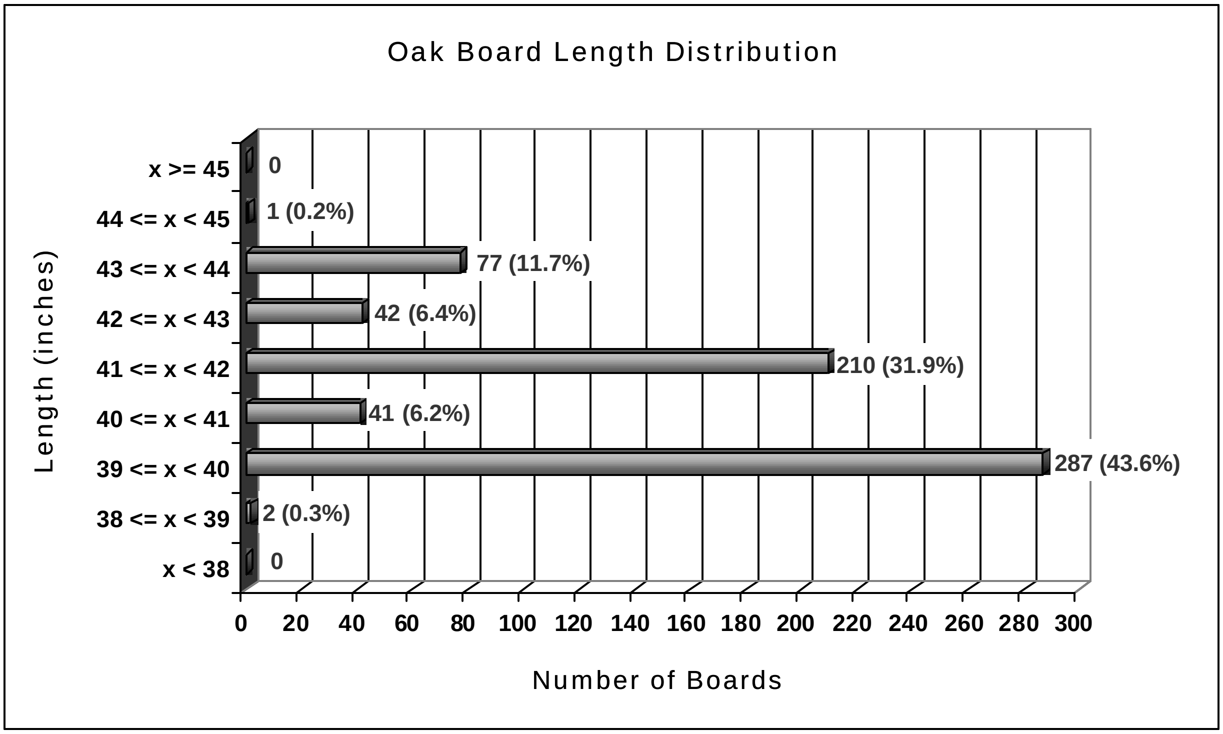

Figure 18: Oak Board Length Distribution

Width of Boards

The distribution of oak board widths is shown in Figure 19. Just over 57% of the boards were between 3” and 4” in width, while another 38% of the boards were between 5” and 6”. This was not unexpected, as pallets typically have four wide outer deckboards, and 1.5 to 2 times as many narrow boards. The remaining 5% of the boards were within ½” of these figures. This width distribution was not surprising as most pallets are made of a mix of wide and narrow boards. The increments of 2.688” and 5.688” were included because these were the minimum widths for a board to have one and two blanks cut from them, respectively. Only 69 boards, 10.5% were wide enough to produce two blank widths. It is important to note that boards only needed to be able to yield one blank width. Meaning that, during the selection process, if the width of a board was sufficient to produce two blanks, but defects would limit it to yielding just one blank, it was still selected. Area was calculated. The boards averaged 1.25 square feet, and totaled 823.5 square feet. These figures were needed for future yield calculations.

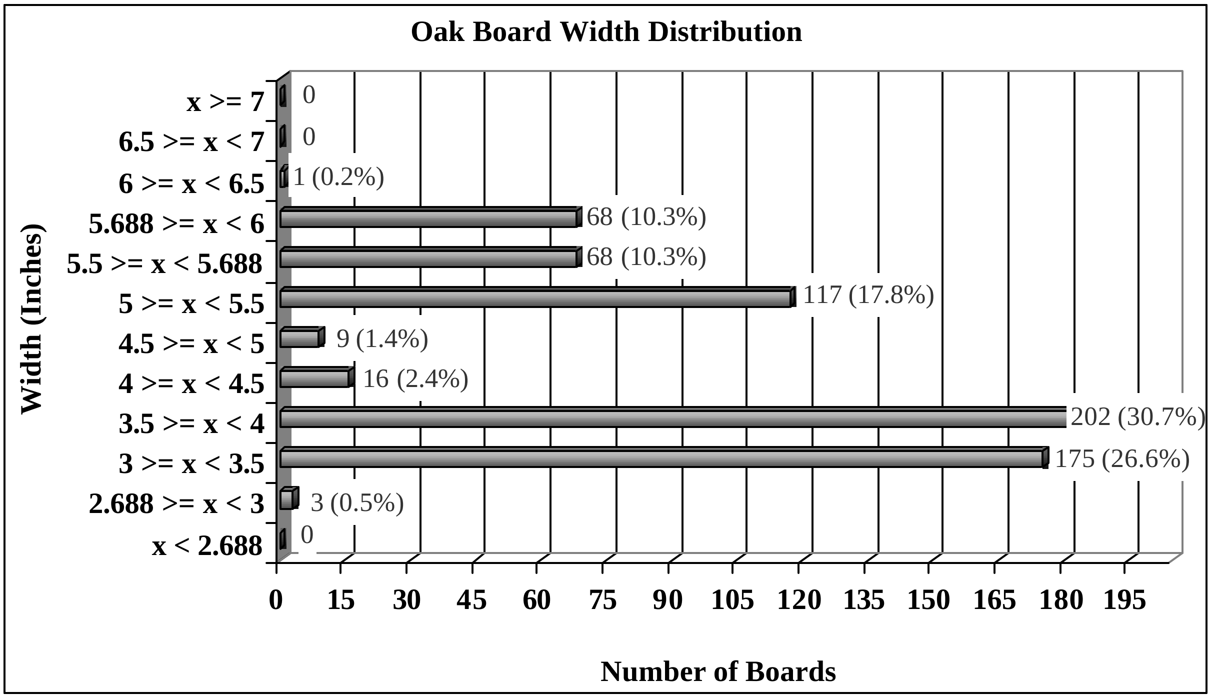

Figure 19: Oak Board Width Distribution

<u>*Affect of Width on Board Foot Volume*</u>

Board foot volume is an important measurement for lumber products, as it is the volume measurement used when making transactions in the wood industry. Lumber purchases are based on units of thousands of board feet, MBF. Examining board foot volume characteristics helped determine the requirements to assemble a potential order of a given number of board feet of recovered pallet deckboards. The difference in board foot volume (BF) between boards in the narrower, 3”-4”, width category and the wider, 5”-6”, width category was compared using a histogram. The BF volume distributions of boards less than or equal to 4.5” and boards greater than 4.5” are shown in Table 12.

Narrow boards, those less than 4.5”, represented 60% of the boards collected (Table 12), and had an average volume of 0.63 BF per board. These boards represented 50% of the total BF volume. The majority, 69%, of the narrow boards were between 0.5 and 0.7 BF (Table 12). The single largest grouping fell between 0.6 and 0.7 BF. Only 23% were 0.7 BF or greater. Wide boards, those greater than 4.5” wide, made up approximately 40% of the boards collected, averaging 0.97 BF each (Table 12). The wider boards made up 50% of the BF volume. The BF distribution of the wider boards was spread out fairly evenly from 0.7-1.2 BF, with the single greatest concentration at 1.0-1.1 BF. Only a little over 3% of the wider boards (1.4% of the total boards) had a BF volume under 0.7 BF

Table 12: Oak Board Width/ Board Foot Volume Distribution

Board Foot Volume Distribution	Oak Boards <= 4.5" Wide		Oak Boards > 4.5" Wide	
BF Vol. Range	#of Boards	% Overall	# of Boards	% Overall
X < 0.3'	0	0.0%	0	
0.3 <= x < 0.4	4	0.6%	0	
0.4 <= x < 0.5	29	4.4%	0	
0.5 <= x < 0.6	110	16.7%	0	
0.6 <= x < 0.7	164	24.9%	9	1.4%
0.7 <= x < 0.8	66	10.0%	29	4.4%
0.8 <= x < 0.9	18	2.7%	38	5.8%
0.9 <= x < 1.0	3	0.5%	56	8.5%
1.0 <= x < 1.1	1	0.2%	83	12.6%
1.1 <= x < 1.2	1	0.2%	39	5.9%
1.2 <= x < 1.3	0		8	1.2%
1.3 <= x < 1.4	0		1	0.2%
x > 1.4	0		0	0.0%
Total	396	60.1%	263	39.9%

Affect of Width on Board Area

The specific focus of this study was the conversion of pallet parts to flooring. Surface area is obviously the most important measurement of flooring products, since they are ordered by a factor of area, usually square feet. The surface area observed by this study was the surface measure in square feet ($ft.^2$) of the widest face, not the total surface area of the board or blank.

A histogram was used to analyze the difference in surface area between boards less than 4.5" and boards greater than 4.5". The results are shown in Table 13. The distribution pattern of area for the wider and narrower boards was similar to that of BF volume shown in Table 12. The primary difference in the distribution patterns shown in the two tables is the complete lack of overlap in the area distribution. No boards under 4.5" wide had the same area as boards over 4.5" wide, while some of the wider and narrower board's BF volumes overlapped (Table 12). Also, as in the BF volume comparison, each width category accounted for close to 50% the total area, even though the narrower boards comprised 60% of the boards collected.

The majority, 95%, of the narrow boards had an area between 0.9 and 1.2 square feet. Boards under 4.5" wide accounted for 413.2 square feet, and averaged 1.0 square foot in area. Boards over 4.5" wide averaged 1.6 square feet in area, and accounted for 410.4 square feet. The majority, 93%, of the wider boards had an area between 1.4 and 1.7 square feet. Overall, boards of all widths averaged 1.3 square feet and totaled 832.5 square feet.

Table 13: Oak Board Width/Area Distribution

Area Range	Oak Boards <= 4.5" Wide		Oak Boards > 4.5" Wide	
Area Range (Ft^2)	# of Boards	% Boards	# of Boards	% Boards
X < 0.7	0	0.0%	0	
0.7 <= x < 0.8	1	0.2%	0	
0.8 <= x < 0.9	9	1.4%	0	
0.9 <= x < 1.0	99	15.0%	0	
1.0 <= x < 1.1	180	27.3%	0	
1.1 <= x < 1.2	97	14.7%	0	
1.2 <= x < 1.3	10	1.5%	0	
1.3 <= x < 1.4	0		5	0.8%
1.4 <= x < 1.5	0		57	8.6%
1.5 <= x < 1.6	0		127	19.3%
1.6 <= x < 1.7	0		61	9.3%
1.7 <= x < 1.8	0		13	2.0%
X > 1.8	0		0	0.0%
Total	396	60.1%	263	39.9%

Oak Board Thickness

The thickness distribution of the oak boards can be found in Figure 20. The bulk of the boards, 82%, were spread fairly evenly between 0.5” and 0.75” thick, with a noticeable drop-off among the boards between 0.65” and 0.7”. Despite the stipulation than no boards under 0.5” be collected for processing, 75 boards, 11.6%, were under 0.5”. Indicating that more careful measurement was needed on boards near the ½” thickness mark on the dimension template (Figure 9, bottom).

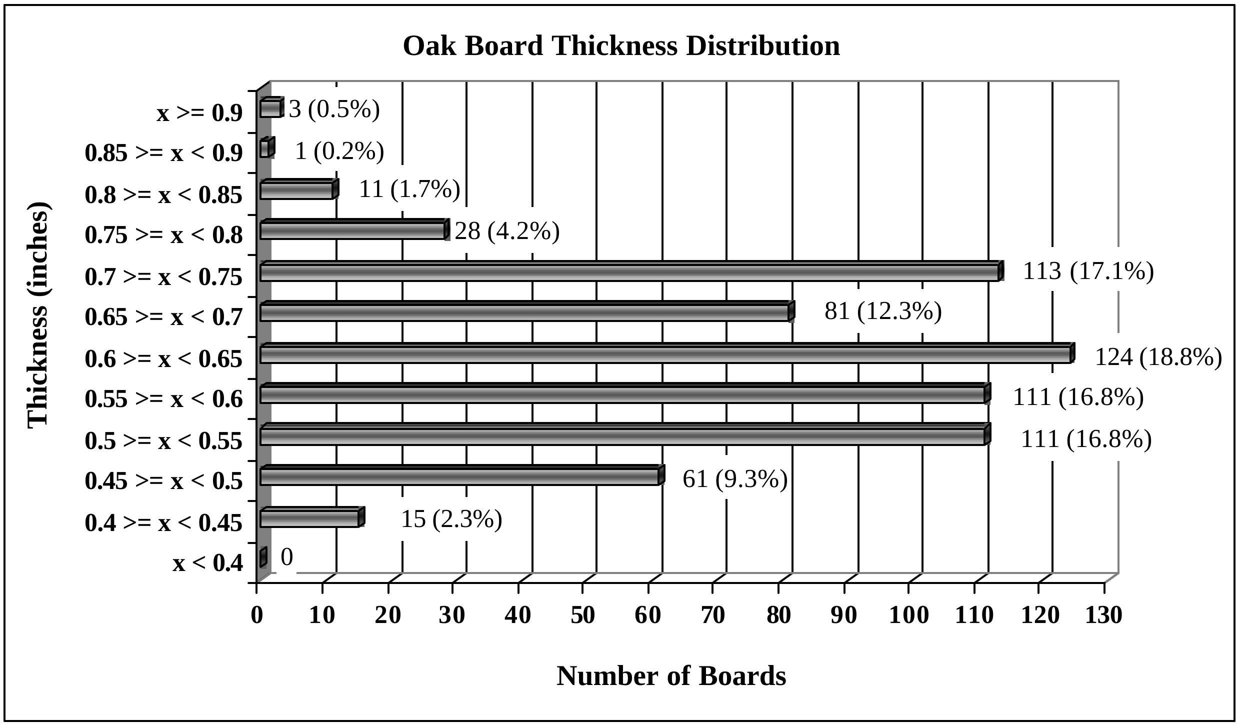

Figure 20: Oak Board Thickness Distribution

End-trim Loss

End-trimming was done to remove the end nails and any end defects, often in the form of splits formed along the grain lines the nails are in. Figure 10 shows an example of a typical end-trim placement. The original cumulative BF volume of 507.7 BF was reduced by 12% to 444.6 BF, due to end-trimming. The average board lost 5.23" of length in end-trimming. Table 14 shows 72% of the boards lost between 0% and 14% of their BF volume during end-trimming, with another 14% of the boards losing 15% and 19% of their BF volume. No board lost greater than 50% of it's BF volume in end-trimming.

Table 14: Oak Boards: End-Trim % Loss Distribution

Oak Boards End Trim
% Loss Distribution

End-Trim % Loss	Number of Boards	% of Boards
0 to 4	86	13.1%
5 to 9	223	33.8%
10 to 14	165	25.0%
15 to 19	89	13.5%
20 to 24	35	5.3%
25 to 29	29	4.4%
30 to 34	13	2.0%
35 to 39	8	1.2%
40 to 44	6	0.9%
45 to 49	5	0.8%

Oak Flooring-Blank Yield

Time required for blank manufacture was observed. One operator did end-trimming and nail removal. Time for end-trimming was approximately 30 seconds per board, with considerable variability for wider boards to measure for determination if two blanks could be made from the boards. Nail removal required approximately one minute per board. This was affected by the extensive time required to remove the staples found in some boards. It was observed that two people could cut the time of the nail removal operation by more than half. Machining, including planing, ripping, and any additional cross-cut defect removal required two persons working 12 and one half hours for 659 oak boards converted to 805 oak blanks. This worked out to approximately 55 seconds per blank produced. This time observation is affected by planing the blanks to three different thicknesses, making this step by far the largest time sink. Possible solutions include multiple planers of descending thickness, producing thicker blanks requiring less planning, and simply adding more labor.

Oak blanks were manufactured to the largest of three thicknesses possible. Blanks were planed to either 0.35”, 0.45”, or 0.7”. Finished blanks were then graded using North American Oak Flooring Association’s Prefinished Oak Flooring Grading rules modified to ignore nail holes as a defect. For each thickness/grade category Table 15 shows the number of blanks, their board footage, and area.

The majority of the blanks, 83%, were cut to 0.45” thick. Only 3% made the 0.7” thickness, and the remaining 14% were reduced to 0.35”. A total of 805 blanks were produced, approximately 1.2 for each board. Prime Grade made up the largest group, occupying 50% of the blanks, while another 45% made the Standard Grade. Overall 78% of the blanks were in the 0.45” Prime and Standard Grade categories, making these thickness/grade categories the focus of subsequent yield projections.

Table 15: Oak Blanks Number, Board Foot Volume, and Area per Grade/Thickness

Blanks	# Blanks	%	Board Feet	Avg.	%	Area (Ft.^{2})	Avg.	%
0.35" Prime	60	7.5%	12.53	0.21	5.7%	35.8	0.60	7.2%
0.35" Standard	50	6.2%	10.76	0.22	4.9%	30.8	0.62	6.2%
0.35" Tavern	3	0.4%	0.58	0.19	0.3%	1.7	0.57	0.3%
0.45" Prime	323	40.1%	88.39	0.27	40.3%	196.4	0.61	39.7%
0.45" Standard	303	37.6%	84.87	0.28	38.7%	188.6	0.62	38.2%
0.45" Tavern	40	5.0%	11.12	0.28	5.1%	24.7	0.62	5.0%
0.70" Prime	20	2.5%	8.66	0.43	3.9%	12.4	0.62	2.5%
0.70" Standard	6	0.7%	2.61	0.43	1.2%	3.7	0.62	0.7%
0.70" Tavern	0	0.0%	0.00	0.00	0.0%	0	0.00	0.0%
Total:	805		219.54	0.27		494.1	0.61	

Average area per blank, which is very important for blanks intended for flooring products, was 0.61 square feet. Area measurements, specifically square feet, are used for ordering flooring commercially, hence the significance of these measurements. Table 16 shows the distribution of area and board foot volume for all blanks. A ratio of the total board feet, 219.54, and the total area, 494.1 square feet, yielded 2.2 square feet per board foot of blanks. This allowed estimates to be made on how many board feet of blanks would be needed to produce a given area of flooring product. Calculating the board foot to area ratio for the 0.45" thick blanks produced the same result, with negligible differences. This was done to ensure that the differences in board foot volume of the 0.70" and 0.45" blanks (Table 15) do not impact the estimate. If there had been a more even distribution in each blank thickness category, it would have been necessary to calculate the blank board foot to area ratio for each thickness.

Table 16: Oak Blanks: Distribution of Area and Board Foot Volume

Distribution of Area: Oak Blanks (Ft^2)			Distribution of Board Foot Volume: Oak Blanks		
Range (Ft^2)	# Boards	%	Range (BF)	# Blanks	%
x < 0.2	0		x < 0.08	0	
0.2 <= x < 0.3	4	0.5%	0.08 <= x < 0.09	1	0.1%
0.3 <= x < 0.4	13	1.6%	0.09 <= x < 0.1	1	0.1%
0.4 <= x < 0.5	52	6.5%	0.1 <= x < 0.2	49	6.1%
0.5 <= x < 0.6	188	23.4%	0.2 <= x < 0.3	591	73.4%
0.6 <= x < 0.7	478	59.4%	0.3 <= x < 0.4	139	17.3%
0.7 <= x < 0.8	70	8.7%	0.4 <= x < 0.5	23	2.9%
x > 0.8	0	0.0%	x > 0.5	1	0.1%
Total	805		Total	805	

The distribution of lengths for the blanks is illustrated in Figure 21. Table 17 shows the distribution of lengths for each grade/thickness category. The majority of the blanks, 88%, were in excess 30", which is the minimum average length for Standard Grade flooring pieces. The average length is 35.5". Less than 20% of the .45" blanks that were sufficiently free of defects to qualify for Prime Grade, made the 39" minimum average length required (Table 17). Slightly over 92% of the .45" blanks that defect graded into the Standard Grade met the 30" minimum average length for this grade, meaning all could have been used for Standard Grade. Both .45” Standard and Prime blanks had average lengths in excess of 35”, qualifying all these boards for Standard Grade, but not for the Prime Grade’s minimum average length requirement.

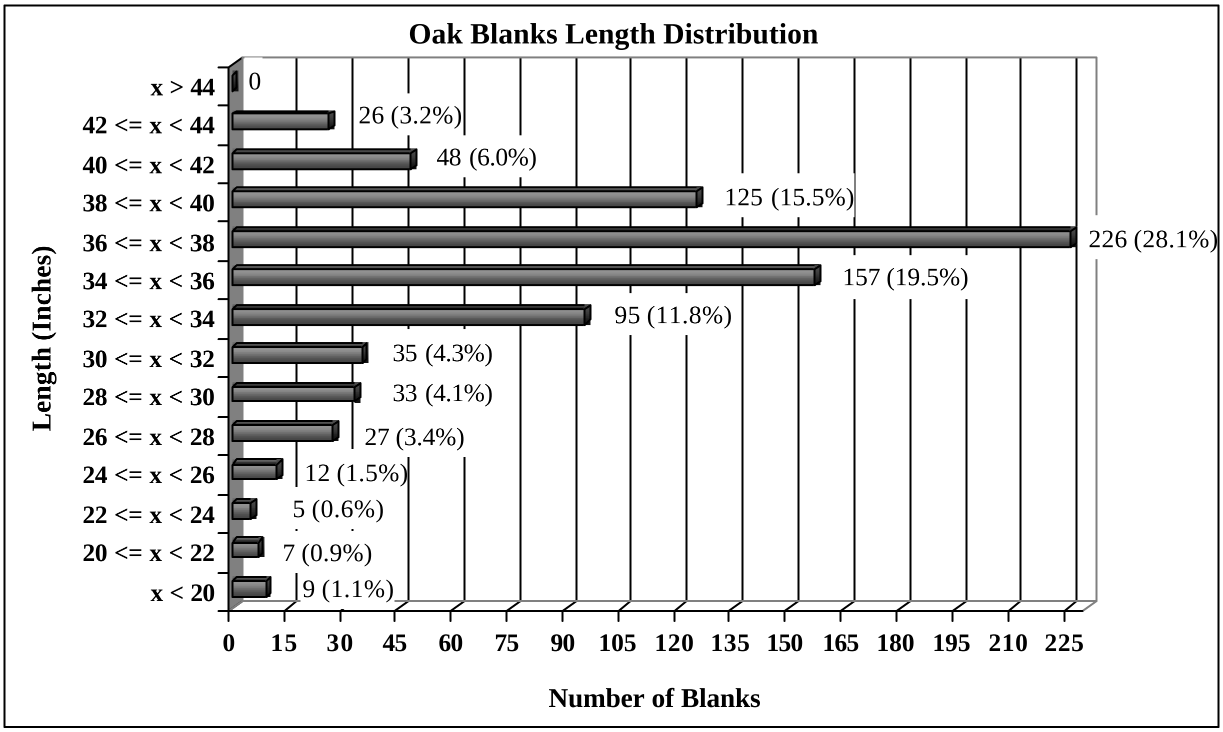

Figure 21: Oak Blanks Length Distribution

Table 17: Oak Blanks: Length Distribution for Thickness/Grade Categories

	Tavern Grade			Standard Grade			Prime Grade		
Range (Inches)	.35"	.45"	.70"	.35"	.45"	.70"	.35"	.45"	.70"
x < 20	1	0	0	0	0	0	3	5	0
20 <= x < 22	0	1	0	0	1	0	0	5	0
22 <= x < 24	0	0	0	2	2	0	1	0	0
24 <= x < 26	0	1	0	1	6	0	0	3	1
26 <= x < 28	0	0	0	3	9	0	3	12	0
28 <= x < 30	0	0	0	1	7	0	3	22	0
30 <= x < 32	0	0	0	0	16	0	3	16	0
32 <= x < 34	0	6	0	10	33	2	10	31	3
34 <= x < 36	0	11	0	4	60	0	9	68	5
36 <= x < 38	0	15	0	13	85	3	11	90	9
38 <= x < 40	2	3	0	9	53	1	9	47	1
40 <= x < 42	0	2	0	7	19	0	6	14	0
42 <= x < 44	0	1	0	0	12	0	2	10	1
x > 44	0	0	0	0	0	0	0	0	0
	3	40	0	50	303	6	60	323	20

<u>Discussion of Oak Flooring-Blank Yield</u>

The board foot volume of the blanks was influenced by thickness (Table 15). The 0.45" blanks averaged about 0.28 BF. Average area per blank was approximately 0.61 Ft^2. In practical terms this meant over 160 blanks would be required to make the flooring for a 10'×10' room. In terms of yield calculation is it important to note that this yield is applicable to blanks from boards that fit the characteristics of the boards described earlier in this chapter.

- It was calculated that 1 BF of blanks = 2.2 Ft^2 of blanks

BF Volume Yield:

- Overall 659 oak boards totaling 508 BF yielded 805 blanks totaling 220 BF for a 43% BF yield.

- 659 oak boards totaling 508 BF yielded 323 0.45" Prime Grade blanks totaling 88.4 BF for a 17.4% BF yield. 5.8 BF of boards to produce 1 BF of 0.45" Prime blanks.
- 659 oak boards totaling 508 BF yielded 303 0.45" Standard Grade blanks totaling 84.9 BF for a 16.7% BF yield. 6.0 BF of boards to produce 1 BF of 0.45" Standard Grade blanks.

Area (Ft^2) Yield:

- Overall 659 oak boards totaling 824 Ft^2 yielded 494 Ft^2 of blanks for a 60% Ft^2 yield.
- 659 oak boards totaling 824 Ft^2 yielded 196.4 Ft^2 of 0.45" Prime Grade blanks for a 23.8% Ft^2 yield. 4.2 Ft^2 of boards to produce 1 Ft^2 of 0.45" Prime Grade blanks.
- 659 oak boards totaling 824 Ft^2 yielded 188.6 Ft^2 of 0.45" Standard Grade blanks for a 22.9% Ft^2 yield. 4.4 Ft^2 of boards to produce 1 Ft^2 of 0.45" Standard Grade blanks.

The BF yield for all blank sizes and grades produced from the pallet board lumber was 43%. A flooring industry source reported industry wide yields fell somewhere between 40%-60% (Moore 2000). This range took into consideration the wide range of lumber grades purchased and the wide range of sizes, types, and grades of flooring products produced.

Projections Using Yield Data

Consider a hypothetical pallet RRR operation feeding a small custom flooring manufacturer who produces a 7/16” thick (0.438”) 2 ¼” wide oak strip flooring from pallet boards. The following projections use the data collected in this study to estimate the requirements for a hypothetical order of an arbitrarily selected amount of flooring, in this case 1,100 Ft^2 of flooring, 7/16” thick, 2/3 Prime Grade and 1/3 Standard Grade. The following projections show the requirements of meeting this order:

- 739 Ft^2 of Prime Grade blanks
- 370 Ft^2 of Standard Grade blanks
- Using the factor 2.2 Ft^2 of Blanks = 1 BF of Blanks
    - 739 Ft^2 of Prime Grade blanks = 336 BF
    - 370 Ft^2 of Standard Grade blanks = 168 BF
- Using the factor 1.0 BF .45” Prime blanks = 5.8 BF useable Oak Deckboards
    - 336 BF of 0.45” Prime blanks require 1,939 BF useable oak deckboards
- Using the factor 1.0 BF .45” Standard blanks = 6.0 BF useable Oak Deckboards
    - 168 BF of 0.45” Standard blanks require 1,005 BF useable oak deckboards
- Summary: to produce the blanks for 1,100 Ft^2 of flooring, 7/16”, 2/3 Prime Grade, 1/3 Standard Grade, would require 2,943 useable oak boards, fitting the characteristics of the boards collected by this study.

- This study found an overall rate of 21% useable oak boards for all boards sorted. Using this percentage, to locate 2,943 useable oak boards would require sorting 14,014 recovered deckboards, leaving 11,071 boards to be used in pallet repair and recycling.
- Disassembled pallet boards were ground if they were unsound or if the parts containing the boards were not economically or practically feasible to disassemble. The rate of sound boards per pallet disassembled was 8.5. At this rate 1,649 pallets would need to be disassembled to produce the needed 14,014 boards.
- These projections did not account for species misidentification in sorting, thickness measuring error, drying loss, machining loss, or flooring installation error.

Chapter 5

Summary

This study sought to develop the groundwork for better understanding the feasibility of producing value added products from recovered pallet parts. Specific issues studied were those that will ultimately affect the economics of using recovered pallets as a raw material source.

The specific objectives of the study were:

1) Identifying the percentage of structurally sound pallet parts, stringers, and deckboards at the disassembler stage of a RRR operation.
2) Characterizing the deckboards recovered by a RRR operation. Features observed were species percentage divided into softwood, non-oak hardwood, and oak, approximate size, and percentage of oak deckboards sufficiently free of defects for use in value added products and the moisture content of these deckboards.
3) Identifying the percentage board foot yield from converting useable oak deckboards into standard, flooring-size blanks.

Relating to Objective One

Percentage of structurally sound parts from a pallet

At all sites combined 1,180 pallets were disassembled, 895 stringer pallets and 285 block pallets. Stringer pallets contained 2,725 stringers, with 1,908 (70%) recovered. Block pallets contained 3,433 deckboards, including both deckboards and deckboard sized boards used in “block stringer” assemblies and pallet bases (Figure 11 and Figure

12, respectively). Only 1,849 (55%) block pallet boards were recovered due to the high rate of incomplete block pallet disassembly. A total of 895 stringer pallets containing 9,003 deckboards were disassembled, 8,144 (90%) were recovered. Overall 1,180 pallets containing 12,436 deckboards were disassembled, with 10,038 (81%) deckboards were recovered, at a rate of 8.5 sound boards per pallet.

The disassembler observation data was affected by the varying approaches to disassembling block pallets and pallets containing non-standard size parts. Site 1 disposed of 472 stringers, but 112 of them were too large in cross section for reuse and were unable to be cut to size due to the large number of nails they contained. Site 2 and Site 3 did not completely disassemble certain types of block pallets and their parts due to the low yield of boards per time required for part disassembly. At Site 2 alone 1,338 deckboards were ground from block pallets “stringers.” Data collectors estimated that all of these, except for 10-20 were sound and could have been recovered. Pallet design clearly influenced the ability to recycle pallets.

Recovery data had not previously been recorded at the sites. The saw operators at Site 1 expressed considerable interest in how many parts they had recovered from several sets of pallets disassembled, indicating the lack of information on this subject. It was surprising that this data had not been informally recorded at the pallet manufacturers for planning purposes. This implies that they store any and all sound boards for presumed use at some point.

Relating to Objective Two

Characterization of the deckboards recovered by a Recovery / Repair/ Recycling (RRR) operation

Species Characterization

Overall, 3154 boards were examined, with a species distributions of 31% oak, 37% non-oak hardwoods, and 32% softwoods. This pattern was not reflected at the individual sites. Each site had at least one species category that varied 10% or more from the overall distribution, though all sites were between 25%-41% oak, which somewhat reflected the published oak percentage in pallets of 25% (Bush and Araman 1998a). The data on species distribution was not conclusive. Three of the four sites had softwood percentages 45% or higher and two had non-oak hardwoods under 20%.

Useable Oak Boards

Of the 3,154 boards examined 981 (31%) were oak and 659 (21%) were useable oak. The 659 useable oak boards represented 67% of the oak boards examined. This pattern was observed at the individual sites with a few variations. Site 1 had a lower rate of useable boards per oak boards (58%) which was attributed to poor board stacking, exposing them to moisture and moisture related damage (Figure 13, Figure 14). Site 4 had a high rate of useable oak boards (79%) this was attributed to the high rate of total oak boards (41%) at the site.

Moisture Content of Useable Oak Boards

Strong evidence was found that controlling moisture content is tied to board stacking practices (Figure 14). Site 1's MC trend showed 80% of the boards between 8%-15% MC, with extremely high within-board MC variability (Figure 13). This high MC range was attributed to loose stacking of boards stored uncovered outdoors, allowing condensation and precipitation to enter freely and randomly disperse throughout. Sites 2, 3, and 4 all stacked boards in piles of the same length and width, with little space in between stacks, and the boards strapped down tightly. Despite the fact that these boards were stored outside, uncovered, their MC's typically ranged from 7%-15% MC, and within-board MC variation rarely exceeding 3%. A range of 7%-15% MC meant that the boards will need to be dried 1%-8% MC to get to the average of 7% MC typical for flooring. This data established that through simple board stacking procedures the MC of the boards can be kept in a range that facilitates ease of drying to MC levels of value added products.

Useable Oak Boards Dimension Characteristics

Knowing the physical dimension characteristics of the boards that the blanks were produced from is important. Yield results would probably be different for boards that had a different length, width, or thickness distribution

Only approximately 50% of the boards were within ½" of 40" long, with another 38% within ½" of 42" long. Most of the remaining 12% of the boards were within ½" of 44" long. The boards lost an average of 5.23" of length during end nail and end defect trimming.

Approximately 60% of the boards were between 3”-4” wide, or within ½ “ of this range. The remaining 40% of the boards were between 5”-6” wide, or within ½” of this range. Boards under 4.5” wide averaged 0.63 BF, while boards over 4.5” wide averaged 0.97 BF for an overall average of 0.77 BF.

Boards under 4.5” wide averaged 1.0 Ft^2, with boards over 4.5” wide averaged 1.6 Ft^2. Overall the boards averaged 1.3 Ft^2.

Approximately 82% of the boards were between 0.5”-0.75” thick, with an average thickness of 0.62”. These sizes confirmed a compatibility with strip flooring products, especially modern prefinished flooring that tends toward thinner thicknesses. Other products that these boards may be suitable for include furniture parts and cabinet door frames and door panel material.

Relating to Objective Three

Yield from useable oak deckboard conversion into standard size blanks

Oak Flooring-Blank Yield

Blanks were planed to three thicknesses 0.7”, 0.45”, and 0.35”, with 83% of the blanks fitting into the 0.45” thickness. Of the three grades, Prime, Standard, and Tavern, Prime Grade defect rules allowed 50% of the blanks, and Standard Grade defect rules allowed another 45%. The two largest thickness/Grade categories were 0.45” Prime Grade (40%) and 0.45” Standard Grade (38%).

Board foot volume of the blanks was influenced by board thickness (Table 15). The 0.45” blanks averaged about 0.28 BF. Average area per blank was approximately 0.61 Ft^2. The average blank length was 35.5”. The minimum average length for Prime

Grade flooring is 39”, less than 20% of the blanks of all Grades made this limit. The minimum average length for Standard Grade flooring pieces is 30”, over 88% of the blanks were in excess of 30”.

Yields were calculated for the blanks on several levels. Overall BF and area (Ft^2) yields were calculated, along with the yields of 0.45” Prime and Standard Grade blanks. These categories received specific focus, because they were by far the two predominant categories of blanks produced. Overall 659 oak boards totaling 508 BF yielded 805 blanks totaling 220 BF for a 43% BF yield. A flooring industry source reported industry wide yields fall somewhere between 40%-60% (Moore 2000). This range takes into consideration the wide range of lumber grades purchased and the wide range of sizes, types, and grades of flooring products produced. Prime and Standard Grade 0.45” blanks had yields of 88.4 BF (17.4%) and 84.9 BF (16.7%), respectively.

In terms of area yield, the original 659 oak boards totaled 824 Ft^2, and yielded 494 Ft^2 of blanks for an overall area yield of 60%. Prime and Standard Grade 0.45” blanks yielded 196.4 Ft^2 (23.8%) and 188.6 Ft^2 (22.9%) respectively. It was found that 40% of the boards’ volume were lost in cross cutting and ripping to width, the remainder of the volume loss was thickness lost in planing. To aid in converting a needed area of flooring to blanks, it was found that 1 BF of blanks equaled 2.2 Ft^2 of blanks.

Conclusions

The data collected exploring disassembler yield, part characteristics, blank characteristics, and blank yield were preliminary figures, and should be treated as such. Using the mills visited and the data collected as a frame of reference, the data allowed projections to be made on:

- Approximately how many useable oak boards, fitting the characteristics of the boards collected by this study, would be needed to produce an arbitrary number of blanks of a certain size and grade?
- Approximately how many recovered pallet deckboards would need to be sorted to locate the number of useable oak boards needed?
- Approximately how many pallets would need to be disassembled in order to get the number of boards needed to sort out the useable oak boards required.

There was interest expressed by workers at Site 1 regarding the number of parts recovered from sets of pallets they had disassembled, indicating how little information there is regarding pallet disassembly. The part yield data can be used to refine the effectiveness of PROACT, by providing estimates of how many parts a proposed operation could expect to recover. Another key point is that the pallet type had an effect on recovery. Non-stringer, non-standard pallet designs sometimes proved non-cost and/or non-time effective for recovery. This led to the grinding of potentially sound recoverable parts.

The data also allowed issues in the pallet part to flooring process to be discussed and addressed and enabled suggestions and planning for future research that could more thoroughly explore the issues covered by this study.

Pertinent Issues and Future Research

A number of issues were raised during the study that are pertinent to an organization exploring the use of recovered pallet lumber in value added products. The first issue to be dealt with was the incomplete disassembly of some pallet designs due to time requirements or design factors. Several avenues could be used to explore this. One avenue would be an investigation of the board yield per time required to completely disassemble different pallet designs. This study could also explore designs of pallets that lend themselves to quick, complete disassembly. The "block stringers" (Figure 11) that were not completely disassembled presented another problem. One idea, worthy of investigation regarding alleviating these wasted parts entails the feasibility of inventorying the entire "block stringer" and reusing them in recycled pallets.

The data collection methods at the disassembler point need refining. Future research should investigate this more thoroughly. Suggestions include greater cooperation and communication with mills. This would allow the data collectors to deliberately arrange to record the results of disassembling a larger number of samples of a variety of pallet designs. This would provide a broader and more insightful sample.

Board characterization also needs further exploration. In the most basic terms a larger sample needs to be examined. Examining boards of a variety of sizes that had arrived at mills over a long period of time would allow a greater understanding of the potential value of this resource. Another suggestion is the collection of samples of a wide range of board sizes and types for more in-depth species mix evaluation. Also, mills that acquire most of their pallets from a few sources may consequently have a limited number of design types, making them less valuable for sample collection sites. Identifying the percentages of certain types and designs of pallets in circulation and locating mills they are disassembled at, would be another possible avenue of sample construction. An additional possibility might be involving cooperating mills to accumulate certain pallet types until disassembly observation is possible.

There are a number of ways that potential yield and yield improvement could be explored further. One suggestion would be the development of a grading standard to improve deckboard sorting efficiency. A clearly defined standard set of allowable character features, unallowable defects, and dimension requirements could be designed. This would eliminate ambiguity about board usability, and would allow a potential board user to understand what they were getting. Also, investigating the development of a pallet grade for flooring would be prudent. Suggestions for the grade would include allowing nail holes or filled nail holes in finished flooring, and lowering minimum average lengths for higher grades. Minimizing average lengths would address the issue of pallet flooring qualifying under grade defect rules only to be demoted a grade based on inadequate length.

Other suggestions for yield studies would include a study of the ideal blank size for maximum yield. Suggested methods involve tracking the maximum yield of each individual board collected, by producing the largest surfaced two-side piece of lumber possible from each board.

Ideal blank size data could be used to find the largest average dimension that can be consistently produced, which would help develop a better understanding of what is the optimum board size for collection and what size product maximizes the yield.

The high occurrence of softwood seen at three of the four mills visited in this study raised another idea for future studies. A large amount of this softwood was observed to be Southern Yellow Pine, at least 75% of the softwoods based on casual observation while handling the boards during data collection. A preliminary investigation, similar to this one, could develop a better understanding of the potential for Southern Pine flooring from pallet material. Pertinent issues would be species yield, part sizes, part quality, and blank yield from boards.

Practical suggestions for a mill considering sorting parts for high value products:

- Sort boards by thickness, as well as length and width, using ½" as the dividing line.
- Store boards using the practice observed at Sites 2-4 (Figure 14).
- Sort by species, at least separating hardwoods and softwoods, ideally separating oak, non-oak hardwoods, and softwoods. The more species sorting the better.
- Board recovery percentages could be increased by the following means:
    - Design pallets for disassembly-avoiding block pallet designs or other styles that prevent easy, complete disassembly.

- Only accept pallets types that can be easily and completely disassembled or pay a premium for desirable pallet types/charge deposit fee for undesirable pallet designs.
- Develop methodologies for less favorable designs or set them aside for periods of low volume, when more time is available to address their special disassembly requirements.

- Pallet parts of uniform size, equal height stringers and equal thickness deckboards facilitate ease of disassembly. These features keep the pallet nail connection parallel to the disassembler saw blade reducing operator manipulation of the pallet, and increasing the rate of disassembly.
- End-coating pallet boards would help reduce the end splitting that caused an average of 5.23” of length to be removed from each board during end nail/end split defecting. This would allow a greater portion of the boards to make the 39” minimum average length required for Prime Grade flooring.

Final Thoughts

Recovered pallet parts represent a tremendous potential source of lumber useable in flooring and other value added products. This study further confirmed the potential benefits of the addition of high value recovery to existing pallet RRR mills. One anonymous industry source reported a mill absorbed a cost of $0.10 per recovered deckboard, if the pallet it came from arrived at no cost to the mill. If the mill absorbed a

30% overhead, the board's cost jumps to $0.14, and the addition of a 10% margin raises the cost to $0.16 (Anonymous, 2000a). Araman (2000b) projected a board value of approximately $0.60 per board as a flooring blank, versus a value of approximately $0.20 per board as a pallet part. Another anonymous industry source reported selling recovered boards for 48”×40” pallets at $0.175 per board (Anonymous 2000b). This left a net board value of $0.015 to $0.075 for pallet parts versus $0.50 to $0.44 as flooring blanks.

It was not felt that nail holes should be a prohibitive obstacle to use of pallet boards in value added products. These holes can be puttied, but could also be left open. Furniture and cabinet manufacturers charge a premium for antique, vintage, distressed, and rustic finishes. These product lines include discoloration, mineral streaks, insect holes, checks, even decay, and other defects, both naturally occurring and artificially produced. With the success of products featuring characteristics such as these there is no reason recovered pallet boards could not be used in economically viable products given proper market identification and product design.

Recovery of value added parts could have many positive effects. First, it would increase the value of recovered pallets, presumably influencing an increasing in the rate of pallet recovery, both within the pallet industry and at the landfill level. This would create jobs in the recovery industry, and decrease the number of pallets going into landfills. Also, the greater volume of recovered material in the RRR system would increase the rate of pallet repair and recycling, decreasing the demand for new pallet lumber, easing pressure on the timber resource. A new source of material for flooring would decrease the consumption of low-grade lumber, conserving timber resources.

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