An Assessment of Manufacturing Quality Variation and an SPC Handbook for the Pallet and Container Industries

by

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(ABSTRACT)

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Today, American industries are in a highly competitive international market. To achieve the competitive edge, manufacturers are demanding excellence from their vendor/suppliers. The pallet and container industries are the suppliers to the other companies. Statistical Process Control (SPC) is one-way to prove to the buyer the quality level of their products. One part of the this thesis is a handbook, which explains a step by step process of implementing an SPC program for the pallet and container industry. In addition, the thesis examines the quality levels of materials that goes into the pallet including the finished product such as raw material, cut-stock, fasteners, and workmanship.

The raw material proved quite variable from the different sawmills. The between board variation was greater than the within for both the thickness and width. The cut-stock had less size variation in thickness than width. The workmanship of the finished pallets showed that the number of nail splits and uniformity of deckboard spacing to be a problem. While the number of missing nails, protruding nail points and heads, and the "out of squareness" was not a problem. The physical characteristics of the fasteners proved extremely variable from one characteristic to another. There are a number of fasteners being produced outside of the NWPCA criteria for wire diameters. The most popular fastener gauges are the 11 and 11.5. In addition, the most popular fastener length is 2.25 and fastener flute number is 4. The MIBANT angle variation is higher for the stiffstock fasteners then the hardened fasteners.

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1.0 Introduction

Historically, quality has been considered a cost of production. Japanese manufacturers, however, have demonstrated that quality can be profitable. The consumer is now more willing to spend more on a quality product with superior performance and reliablity. In order for companies to produce quality products, close monitoring and control of manufacturing is necessary.

It is proven that the most successful companies have extremely high standards for their products and employees. Often the goals of these companies are not just to meet these standards, but to exceed them. Conformance to high quality standards in manufacturing will lower manufacturing costs, raise profit margins, and result in a larger market segment (Juran, 1984).

Today, American industries are in a highly competitive international market. The standard for excellence is no longer set by U.S. manufacturing industries. In order to get back a high ranking in this international marketplace, the U.S. manufacturers are listening more closely to their customers (Deming, 1982). Customer satisfaction is now a principle corporate concern. In turn, manufacturers of consumer products are now demanding excellence from their vendor/suppliers. In order to stay competitive, corporations need quality in all facets of production (H.J. Harrington, 1987). In the quality realm of manufacturing, QC stands for Quality

Control. It "is the regulatory process through which we measure actual quality performance, compare it with standards, and act on the differences." QA stands for Quality Assurance, which is "the activity of providing, to all concerned, the evidence to establish confidence that the quality function is still being performed adequately" (Juran, 1984). However, Statistical Process Control (SPC) is a QC/QA method, which "...is the use of statistical methods, such as control charts, to analyze a process or its output over time so as to take appropriate actions to achieve and maintain a state of stability/predictability and improve the capacity of the product" (Ford, 1984).

The wood pallet manufacturing industry which functions as a vendor/supplier to the many manufacturers setting up aggressive QC/QA programs is just now being asked by customers to set up in house SPC programs. In addition to customer satisfaction, additional potential benefits of such a program to the pallet industry are reduced target sizes of sawn parts (ie. measured yields), lower remanufacturing costs, and reduced maintenance costs. QC/QA programs are used today in the lumber industry with positive results (Brown, 1979 and Sullivan, 1981).

2.0 Objective

The objective of this research is the development of a generalized statistical process control methodology for the wood pallet and container industry. This research will:

1. Develop estimates of the current level of the quality variation of raw material, parts, finished goods, and fasteners within the U.S. wood pallet industry.

2. Identify the measures required for the statistical process control program.

3. Identify statistical procedures to determine the appropriate sample size(s), sampling frequency(ies), and location(s) of sampling necessary for a reliable SPC program.

4. Recommend quality criteria.

Chaper 4, to follow, concerns the current levels of quality variation of raw material, pallet parts and finished pallets (objective 1). Chapter 5 concerns the variation in fastener quality. Objectives 2, 3, and 4 will be addressed in chapter 6, "The SPC Handbook".

3.0 Technical Literature Review

Quality control is an acceptance decision-making tool for scientific management of manufacturing. Quality control is used by many management levels for the purpose of reducing and maintaining variability to an economic minimum, while being consistent with management objectives (Hingwe, 1982). Once identified, causes of quality variability can be reduced and/or eliminated.

In order to control a process, one must predict the process behavior. All continuing performances are subject to variation. In any production process, some variation in quality is unavoidable. Shewhart (Duncan, 1986) defines two variations: random and assignable. Certain variations in quality are due to causes over which we have some degree of control such as: different quality of raw material, or new unskilled workers. This type of variation is called assignable. Random variation is the normal variation that occurs solely due to chance. It is the variation in quality which is the result of many complex causes. In order to correct the random variations, the entire process has to be modified.

Statistics can be used to separate variability due to assignable causes from that due to random causes. The assignable causes are calculated by the law of probability in such a way that it is highly improbable that random variations will be present in the assignable causes.

Likewise, a process with assignable causes cannot be included in the random variation. These separations of variations can be divided by lines. These lines are called control limits. When the process is inside the control limits, then it is considered in control by random variations. However, when the process is outside of the limits, it is considered out-of-control due to assignable causes. This enables the manufacturer to spot difficulties when and where they occur. With continued use of control limits, the assignable causes can be eliminated. Therefore, control charts are simple devices that enable us to define the state of statistical control more precisely and distinguish between the causes of variation. It is also a graphic comparison between process performance data and computed "control limits" drawn as limit lines on the chart. The limits are based on historical observations.

3.1 Control Charts

Shewhart (Duncan, 1986) originated two control charts. The X-bar chart was used to observe the average level of data and the R-chart was to evaluate the standard deviation or variation of the data. The standard deviation method is based on measures of dispersion of individual measurements. Historically, the standard deviation was not well understood by some. Therefore the use of the chart of ranges is calculated instead (differences between the highest and lowest values in a subgroup).

The Shewhart control charts rely on two fundamental principles: central limit theorem and the relation between chart sensitivity and sample size. According to the central limit theorem, the distribution of sample means will tend toward a normal distribution as sample size (n) increases. More common in the industry a sample size of 5 is taken (Duncan 1986; Juran, 1979).

The second fundamental feature of the Shewhart chart is that the sensitivity of the control chart to small fluctuations in the production process increases as the sample size (n) increases. Specifically, the control chart sensitivity varies with the square root of the sample sizes. By computing the range for each sample, the variability of the population can be estimated.

3.1.1 Preparatory decisions to the control charts

1. The choice of the variable for the X-bar and R charts must be something measured and expressed in numbers, such as dimensions, hardness number, tensile strength, weight, etc. However, the best candidate is the variable that reduces the production cost to a minimum. Note: This does not include the savings in the cost of inspection. Usually a variable is chosen which will impact on cost. More often the variable that is chosen is the one with the highest cost of rework or spoilage value.

2. The division of observations into rational subgroups is a key method to the Shewhart charts. A subgroup is the sample size (n) of items taken in order of production at constant time intervals. Every time a sample size of n is taken, a subgroup is added to the data sheet. They should be chosen based on uniformity and the ability to give the maximum opportunity for variation from one subgroup to another. It is important to keep the production sequence within the subgroups for the purpose of detecting shifts in the process average.

   Dr. Shewhart suggests four as the ideal subgroup size. However, in the industry five is more common. This is because the sample size of five is easier to calculate the averages by multiplying the sum by two and moving the decimal point to the left one place. Even though these subgroup sizes appear to be small, they help to minimize the variation within a subgroup. There are times when the sensitivity of the study is the main issue. In these cases the subgroup sizes are large (ten to twenty) to catch slight changes in the variations where the limits are narrow to catch these changes. With large sizes, ie. 15 or more, the standard deviation charts are used instead of the range charts. This is due to the loss in the accuracy with the R-chart.

When control limits are determined from historical data, it is important to have larger sample sizes to start. When the process is controlled, small subgroup sizes can be used.

3. Subgroup sampling frequency follows no set rules, however it is important to weigh the consequences of the cost of taking and analyzing the measurements and the benefits of the results. It is common in industry to measure subgroups at 1 hour intervals. Initially frequent samples should be taken until the process is under control, then less frequent sampling can be taken, starting with half hour sampling. However, it is more desirable to take small subgroup sizes more frequently then to take large subgroup sizes less frequently (Wetherill, 1969).

4. It is also important to determine the widths of the control charts or control chart limits. This is called the risk factor based on the ability of catching an out-of-control sample. At 3σ, the risk of spotting an undesirable sample is 1%. Where as, if 1.5σ is used then the risk is increased to 34%. Duncan (1986) suggests the use of 2σ or even 1.5σ, for a more economical chart, and when the cost of inspection is low. However, if the cost of inspection is high, it is more economical to use the 3.5σ and 4σ in computing the control limits.

3.1.2 Interpretation of processes

Any point that falls outside the limits of the X-bar, is evidence that a general change affecting all pieces has occurred between samples. This could be due to changes in materials, processes, or other factors. Any point outside the limits of a R-chart, is evidence that the uniformity of the process has changed. This could mean a change in either man, machine, or material factors (Juran, 1979). These changes are due to what is known as assignable causes. However, when no points fall out of the limits we cannot say there are no assignable causes present, but rather that the process is in control. During manufacturing, a number of errors occur that would constitute assignable causes, but not necessarily as a basis for action. This may lead to a practical working rule on the relationship between satisfactory control and the number of points that fall outside the limits. For example, one such rule is to consider not more than 1 out of 35, or 2 out of 100 points outside the control limits as evidence of control.

It is also important to examine the randomness of the data, which indicates whether the process is biased or not, or if there is some other factor that is effecting the charts performance. This can be done by counting the points that run in succession of the same class. One class could be the points above the average in succession as one class and the points below as the other class (not including the points exactly on the average). This is considered as the runs above the average and runs below the average. There are two key characteristics to look at when determining the randomness of the data: 1) count the total number of runs of any given class, and 2) note the length of the longest run of a given type.

3.2 *Acceptance Sampling*

In the field of statistical quality control, a common practice is acceptance sampling. When a company receives a shipment, a decision can be made to accept or reject it based on the conforming standards set by the buyer. Inspection can be made at various stages in manufacturing: 1) incoming material and parts, 2) process inspection at various points in the manufacturing operation, 3) final inspection by a manufacturer of his own product or, 4) final inspection of the finished product by one or more purchasers.

When inspection is 100%, the defective items can be eliminated if detected. Therefore, the final lots will meet all standards. However, this is not practical due to the high cost of inspection and inspection fatigue. There is also a greater chance of product damage due to more handling of the product with 100% inspection. This is why inspections based on samples from a lot are more desirable.

The purpose of acceptance sampling is to determine a course of action, not to estimate the lot quality or to control quality. Acceptance sampling prescribes a procedure that will give a specified risk of accepting lots of a given quality. In other words, acceptance sampling yields quality assurance, and an acceptance sampling plan merely accepts or rejects lots.

There are two types of acceptance sampling employed in statistical quality control; attributes and variables. Which method to use is dependent on how the characteristics under evaluation are measured. The attributes can be separated into two groups; good or bad. While the variables can be evaluated along a scale of measurements; 6.000, 8.000, etc.

3.2.1 Limitations of Acceptance Sampling by Variables

Most of the acceptance sampling in the industry is currently by attributes, and this method will more than likely continue to predominate. However, with continued use of statistical quality control techniques, the use of acceptance sampling by variables has increased.

One obvious limitation to the variable acceptance plans is the cost of inspection per item. It is easier and less time consuming to use the "go/no go" attributes principle where the data is not measured nor recorded. With the variable plans data has to be quantitatively measured and recorded for analysis such techniques involve clerical costs with the attributes plans.

Perhaps the most serious limitation to sampling by variables is that quality characteristics have to be separated. If there are 20 characteristics of a product to be examined, then there has to be 20 different variables acceptance plans. This is not true for the attributes sampling plans, only one plan is needed for all characteristics.

3.2.2 Advantages of Acceptance Sampling by Variables

The great advantage to the sampling by variables is that more information can be obtained about a quality characteristic. This may lead to a number of desirable results:

1. For the same quality protection, a smaller sample size may be used with variables than with attributes.

2. Variables information usually gives a better basis for guidance toward quality improvement.

3. In recording the variables, the previous history may provide a better basis to make acceptance decisions.

4. Errors in measuring are more likely to be found with the variables information.

Most quality characteristics evaluated in the wooden pallet and container industry can only be examined along a scale of measurement known as acceptance sampling by variables. It is the purpose of section 6.0 to outline the acceptance sampling techniques by variables and attributes to determine the raw material, fastener, and workmanship sampling plans.

3.3 QC/QA in Related Industries

The pallet industries are seeking better ways to improve their product. An on going cooperative research agreement between the USDA Forest Service, National Wooden Pallet and Container Association (NWPCA) and Virginia Polytechnic Institute and State University (VPI&SU) resulted in the Pallet Design System (PDS), which is a structural design procedure for wood pallets. The program predicts the level of performance of a wood pallet. Once an appropriate design is selected and a specification written and sales agreement reached the pallet must be manufactured according to the required specification. Failure to do so can result in great risk to life, high costs due to damage goods being shipped, high material handling cost and a violation of the sales agreement. It is therefore important for the manufacturer to know when his process is in control or not, and that the pallet is manufactured according to the quality standard required by the customer.

Parts of the lumber industry have adopted SPC programs. Terence D. Brown (1979) discussed several aspects of introducing a quality control into a lumber company. He states that if quality control is implemented correctly, an old company with excellent quality control can out perform a new company with poor quality control. Machinery problems can be diagnosed and solved simply by analyzing the data collected. However, Brown found that the acceptance of a SPC program is difficult to implement due to a lack of understanding of how to use it. Brown (1979) describes a step by step process for implementing an SPC program in the lumber industry. As a result, mill operators have become increasingly aware of how their machines are operating and often call for additional testing if they suspect problems (Brown, 1982). Today's lumber quality control programs include all phases of manufacturing: logging, processing, drying, planing, grading and shipping. Brown concluded that there are few opportunities to improve lumber as it is being processed, but many ways to loose value (Brown, 1988).

Sullivan (1981) developed a statistically-based information system which informs management whether the mill is performing as intended. He computed confidence intervals for the limits, instead of implementing the X-bar and R charts. The X-bar and R charts are more powerful than the confidence limits (Juran, 1979). Next, the target sizes were calculated based on allowances for shrinkage, planing, kerf, sawing variation and the final dimension, for a certain headrig.

4.0 Quality Variations Within The Pallet Industry

4.1 Introduction

The largest user of hardwood lumber in the U.S. is the wood pallet and container industry. In 1987, this industry consumed an estimated 5.5 billion board feet of hardwood lumber in the production of over 400 million pallets (NWPCA, 1988). Pallet manufacturers purchase wood in various forms depending on their manufacturing capability. These are logs, cants, lumber or cut parts (also called cut-stock) are sawn on a wide variety of machinery in various operationing conditions. The affect of these variations in the cutting equipment will be variations in sawing accuracy and subsequently lumber yields. Ultimately this will result in different levels of production efficiency and product quality.

Pallet manufacturers assemble cut parts into pallets using various equipment. These include hand-held hammers, hand-held pneumatic tools and single head or tandom nailing machines.

The quality of assembly, also called workmanship, is dependent on the type of assembly equipment, its operating condition, and the level of expertise of the operators.

The objective of this study is to assess the current level of product quality within the pallet manufacturing industries, more specifically the level of quality of cants, lumber, cut-stock and workmanship.

4.2 Literature Review

The raw material of most pallet manufacturers is cants and lumber. In this thesis, conditions of raw material quality will be limited to lumber and cants. Softwood lumber purchased by the pallet industry is typically S4S structural lumber of the utility or economy grades. Hardwood lumber and cants purchased are typically factory lumber below 2 common in grade. Some hardwood material is purchased log-run. Under these circumstances, the hardwood cants and lumber purchased may contain higher grades.

4.2.1 A TYPICAL Pallet Manufacturer

A TYPICAL pallet mill operation is shown schematically in Figure 1. The mill receives raw material (A) in the form of cants, lumber or cut-stock (B). The material is then inventoried and/or transfered to the infeed conveyor as needed. Cants or lumber are typically cut to length (C) and then ripped (D) to the desired width and thickness. The material is then sorted and/or graded (E). However, in mills cutting softwood the lumber will be graded after trimming and before ripping. Ripping is done on gang resaws or splitter saws. Rejected material is scrapped or remanufactured (F). Accepted material is either chamfered, notched, or unaltered (F), and then sent to nailing machine or table for assembly.

4.2.2 The Quality of Pallet Lumber, Cants, and Cut-Stock

Since the volume of the wood in pallets constitutes over 60% the total cost of a pallet lumber yield or cut-stock yield is a critical concern of the pallet industry. The target size of a board, reduction of sawing target sizes, and reduction of saw kerf to improve yield and reduce manufacturing costs are dependent upon 1) final size (F), 2) a planing allowance (P), 3) a shrinkage allowance (Sh), and 4) sawing variation (St). Figure 2 displays these variables. The relationship between these variables and target sizes is shown mathematically in Equation 1. The moisture content of lumber in pallets is rarely specified, most are made of green lumber. Also lumber used in pallets is rarely planed. Therefore in pallet milles the target size is typically the final size plus sawing variation. Oversizing is defined as "The amount (in either thickness or width) by which the average lumber size exceeds the required minimum target size. Excessive target sizes and oversizing reduces lumber yields by implementing a mathematically derived target size in a sawmill where oversizing is occurring, longer, wider, thicker and/or additional pieces of lumber will be produced instead of oversizing" (Piercy, 1983).

When lumber is sawn, some variation in sizing is to be expected, this is known as sawing variation. It is classified as "within" or "between" board. Within board sawing variation refers to variation in length, thickness, or width within the pieces (Sw). Between variation refers to consistent differences in these dimensions between board (Sb). Total sawing variation (St) in the geometric average of both Sw and Sb is typically measured and calculated to the nearest 0.001 inch. Good practice dictates that all lumber be of the same minimum dimension. If sawing variation is zero, then the target would be equal to the critical size shown in Equation

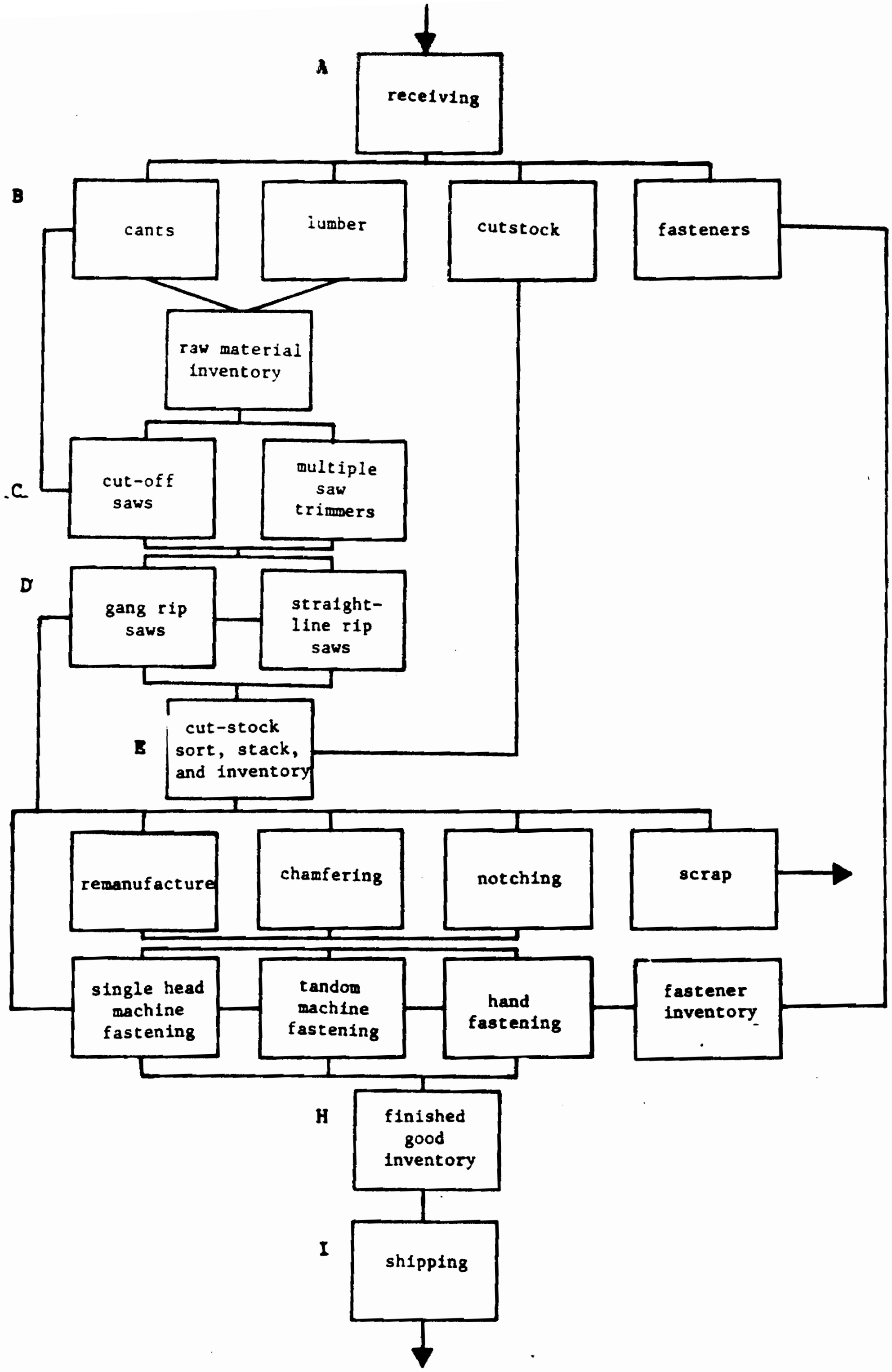

Figure 1. Flow chart for a TYPICAL pallet mill.

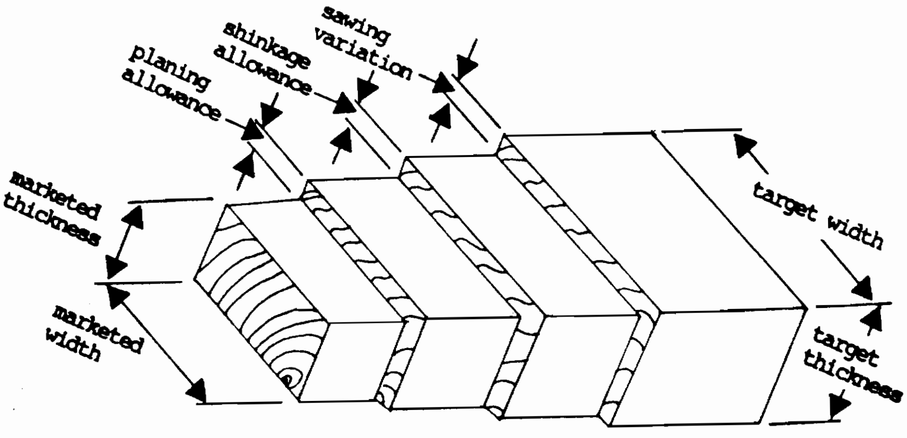

Figure 2. A diagram of the different characteristics that affect the final dimensions of a board.

1. Since sawing variation is never zero, some allowance or oversizing is necessary. Low sawing variations result in higher lumber yields, greater manufacturing efficiency and higher quality lumber.

As the sawing variation increases, so must the target size increase. There are different ways to determine the sawing variations Sw, Sb, and St. Simple size control programs define variations as the "range" from the thickest to the thinness part or piece. However, this method does not accurately determine the undersizing, whereas the standard deviation does. Therefore, standard deviation will be referred to as the sawing variation. The target size (T) can be calculated as follows from the Wood Handbook (1987):

Equation 1 $$T = Cs + (Z + St)$$

where:

Equation 2 $$Cs = \frac{F + P}{1 - \frac{Sh}{100}}$$

In a study by McLain et. al. (1986) over 2,700 samples of green, eastern oak deckboards and stringers were randomly sampled and graded from mills located throughout the Eastern United States.

Table 1. McLain et. al (1986) data of over 2,700 sampled green, eastern oak deckboards and stringers.

		mean (in)	*s (in)*	*range (in)*
Deckboards				
1x4	width	3.870	0.200	3.32-4.64
	thickness	0.805	0.076	0.59-1.03
1x6	width	5.827	0.211	5.16-6.98
	thickness	0.820	0.105	0.60-1.25
Stringers				
2x4	width	3.742	0.096	2.76-4.06
	thickness	1.596	0.162	1.11-2.00

s = standard deviation

Some of this variability can be explained by different target sizes from the different mills. Each mill produces to its own unique target size based on the saw machines used. Even though the final sizes are assumed the same for all the mills, the target sizes are not.

In another study for Dimensions and Tolerances for Pallet Deckboards and Stringers, W.B. Wallin (1986) measured 1017 deckboards and 623 stringers from 32 mills across the U.S. The range of coefficient of variation (in %) for the board specifications are as follows:

Table 2. Wallin (1983) data of 1017 deckboards and 623 stringers from 32 mills across the U.S.

	range (in)	*coefficient of variation (%)*
Deckboards		
width	3.625 to 6.000	0.62 to 11.38
thickness	0.500 to 1.25	1.01 to 17.87
Stringers		
width	1.250 to 2.625	0.60 to 16.10
thickness	3.625 to 4.625	0.27 to 16.52

NWPCA (1982) has recommended manufacturing tolerances for cut-stock:

Table 3. The NWPCA recommended tolerances for cut-stock.

Deckboards	
thickness	±1/16" maximum deviation
width	+unlimited - 1/4" maximum deviation
length	+1/8" - 1/4" maximum deviation
Stringer	
thickness	+1/16" maximum deviation
width	±1/16" maximum deviation
length	+1/8" - 1/4" maximum deviation

4.2.3 Effect of Milling Machinery on Sawing Variation

Individual machine performance at over 850 sawmills from 38 states were evaluated by Steele, Wagner, and Seale (1986). The double arbor gang resaw significantly the lowers within board sawing variation over all other machines except for the single arbor gang, sash gang, and circular linebar resaws. The double arbor gang resaw also resulted in lower variation than all other machines except for the band reman edger. The double arbor gang resaw significantly lowers total sawing variation over all other machine types. This type of resaw is the most common breakdown system for pallet cants.

4.2.4 Pallet Assembly or Workmanship Quality

After the material is cut to size and sorted, the pallets are assembled with hammer, hand held pneumatic tools and single head or tandom nailing machines. The NWPCA (1982) lists typical workmanship defects that can occur during assembly: 1) "out of square" deviation, 2) deviation of overall pallet lengths and widths, 3) uniformity of deckboard spacing, 4) nail splits, 5) protruding nail heads, and 6) protruding nail points.

The "out of square" deviation is determined by comparing the difference between the measures of the diagonal dimensions across one face of the pallet from corner to corner. NWPCA has recommended that squareness be within 1.5% of the longest dimension or 1 inch, whichever is greater.

Pallet length is determined by measuring the distance between the leading edge of lead top deckboards. NWPCA recommends an allowable deviation of ±1/4-inch for pallet lengths.

Pallet width is determined by measuring the outer edge to the edge distance between the stringers. NWPCA recommends an allowable deviation of ±1/4-inch for pallet widths.

Uniformity of deckboard spacing is determined by measuring the spaces between the deckboards with a tape measure to the nearest 1/16-inch. Deckboard spacing will depend on secondary packaging size and stiffness. Proper spacing is necessary to adequately support the load. NWPCA has not set standards for the uniformity of deckboard spacing.

Nail splits are defined as those separations or cracks in individual pieces generally occurring in the ends of the piece caused by the wedgelike action of the nail shank in the joining parts. There are two types in pallets: 1) hairline - where the shank of the nail is not visible and 2) open - where the split is wide enough to expose the shank of the nail. Splits that do not reach the ends or outer edges of a board have little effect upon the overall serviceability of the pallet. In addition, splits on the ends of the inside deckboards are of minor importance, while splits on the ends of the outside or lead deckboards will significantly affect the life and serviceability of the pallet. Deckboard damage occurs 70% of time at the leading edge board. Splits reduce the resistance to head pull-through of the nail in the deckboard and reduce the shock resistance at the primary impact point of the heels of lift-truck's forks. Splits may not be visible immediately after nailing green lumber. Latent splits often develop due to the shrinking in the final stage of seasoning. NWPCA has recommended different criteria depending on the type of pallet assembled shown in Table 4.

Protruding nail heads are considered a defect in pallets. All nail heads should be flush or below the surface of the wood. For bag operations nails should be countersunk from 1/32" to 1/8" depending on the moisture content of the deckboards and stringers. If a head is protruding, it could snag and damage the merchandise. No protruding nail heads are permitted in NWPCA standards.

Any protruding nail points on the outer surfaces of a pallet are also considered defects, because they will tend to snag merchandise. Nails poorly placed and whose points protrude will have less withdrawal resistance than properly placed nails, since the shank is not completely in contact with the wood. Certain NWPCA criteria permits for an occasional protruding nail point in expendable pallets. No protruding points on the exposed face of the outside stringers or blocks for hardwood warehouse permanent, or returnable pallets are permitted.

Table 4. The NWPCA criteria for hardwood pallet nail splits.

	PRECISION GRADE	PREMIUM GRADE	"AA" GRADE	"A" GRADE
End Boards	(1a) At outside stringers, stringer boards or blocks-hairline splits permitted on any nail but limited to one per board end. If on first or lead nail must have a compensating nail.	(1a) At outside, stringeers, stringer boards or blocks-hairline splits permitted on any nail but limited to one per board end. One open split permitted on one end if compensated for by additional nail provided split does not reach both end and edge of board. Any split on first or lead nail must have a compensating nail.	(1a) At outside stringers, stringer boards or blocks-hairline splits permitted on any nail but limited to one per board end. One open split permitted on one end if compensated for by additional nail. Any split on first or lead nail must have a compensating nail.	(1a) At outside stringers, stringer boards or blocks-hairline splits permitted on any nail but limited to two per board end. One unlimited open split permitted at each end if not first or lead nail or not accompanied by other splits. Open split at first or lead nail must be compensated for by additional nail.
	(2a) At center stringer, stringer board or blocks-one split per endboard is permitted provided it does not reach the edge of the board.	(2a) At center stringer, string board or blocks-splits permitted on any nail provided it does not reach the edge of the board.	(2a) At center stringer, stringer board or blocks-splits permitted on any nail provied it does not reach the edge of the board.	(2a) At center stringer, stringer board or blocks-splits permitted on any nail provided it does not reach the outside edge of the board.
Inside Boards	(1b) At outside stringer, stringer boards or blocks-one hairline split per board end permitted on no more than one-half number of boards. One open split on one end of one board permitted if compensated for by additional nail, provided split does not reach both end and edge of board, and if no other split appears in the same board end.	(1b) At outside stringers, stringer boards or blocks-hairline splits permitted on any nail on no more than one-half the number of boards. One open split per board end in no more than one-half the number of boards is permitted if compensated for by additional nail, provided split does not reach both end and edge of board, and if no other split appears in same board end.	(1b) At outside stringers, stringer boards or blocks-hailine splits permitted on any nail on no more than one-half the number of boards. One open split per board end in no more than one-half the number of boards is permitted if compensated for by additional nail, and if no other split appears in same board end.	(1b) At outside stringers, stringer boards or blocks-hairline splits permitted on any nail. One unlimited open split per board end in no more than three boards if no other splits appears in the same board end.
	(2b) At center stringer, stringer board or blocks-one nail split per board on no more than two inside boards provided split does not reach edge of board.	(2b) At center stringer, stringer board or blocks-splits permitted on any nail provided it does not reach the edge of the board.	(2b) At center stringer, stringer board or blocks-splits permitted on any nail provided it does not reach the edge of the board.	(2b) At center stringeer, stringer board or blocks-splits permitted on any nail. Splits reaching the edge of the board are limited to two per pallet.
Outside Stringers and Stringer Boards	No nail splits permitted.	No nail splits permitted in ends of pieces. Splits other than at ends are permitted but limited to one per piece.	One hairline nail split unlimited in length shall be permitted on one end of each. One stringer or stringer board permitted, provided it is not combined with corresponding nail splits in deckboards and is compensated for by a corrugated fastener driven at right angle across split. Splits other than at ends or under endboards are permitted, but limited to two splits per stringer or stringer board.	One unlimited nail split permitted on one end of each outside piece provided it is not combined with corresponding nail splits in end deckboards. Splits other than at ends are permitted but limited to two unlimited splits per stringer.
Center Stringers and Stringer Boards	Nail splits permitted provided none in ends and limited to one per piece.	One hairline or one open nail split permitted on one end. Splits other than at ends are limited to two per piece.	One hairline or one open nail split permitted on one end. Splits other than at ends are permitted.	One unlimited nail split permitted on both ends of piece. Splits other than at ends are permitted.
Blocks	No nail splits permitted.	One hairline nail split unlimited in length shall be permitted on one end of blocks limited to no more than three blocks per pallet. One open nail split no longer than one-half penetration length of nail permitted on the center block and one outside block provided it is not combined with corresponding nail splits in deckboards or stringer boards.	One hairline nail split unlimited in length shall be permitted on one end of blocks limited to no more than one-half of the blocks per pallet. One open nail split permitted on one-third of blocks per pallet provided it is not combined with corresponding nail splits in deckboards or stringer boards.	One hairline nail split unlimited in length shall be permitted on all blocks. One open nail split unlimited in length permitted on all blocks provided split does not run entire length of block, and provided it is not combined with corresponding nail splits in deckboards or stringer boards.

4.3 *Material and Methods*

4.3.1 Raw Material

Measures of the widths, thickness, lengths, species, and target size of pallet lumber and cants were taken at 8 sites in Tennessee, Ohio, and Virginia. A tape measure will 1/16-inch increments was used for measuring the widths, thickness, and lengths. Species were grouped according to the Pallet Design System (PDS) species classification as shown in Table 5 and 6.

4.3.2 Cut-stock

Variation of cut-stock quality was determined at 9 pallet manufacturing sites. This was based on measurements of 1710 boards. The boards were measured to the nearest 0.001 inch at 4 locations along the width and thickness and at 2 locations along the length. In addition, measures from 2800 boards previously recorded by McLain et al. (1986) from 32 pallet companies are included. In some cases the grades were not present nor were 4 thickness, 4 widths, and 2 lengths. The species were grouped into the PDS species classifications as shown in Tables 5 and 6. The grades were based on NWPCA standards (Spurlock, 1986).

Table 5. The Pallet Design System (PDS) hardwood species classes.

<table>
<tr><th colspan="5">< —— Increasing Strength < ——</th></tr>
<tr><th>1</th><th>2</th><th>4</th><th>6</th><th>21</th></tr>
<tr><td rowspan="10">Hickories
Yellow Birch
Sweet Birch
Sugar Maple
Black Maple
Red Maple
Green Ash
White Ash
Beech
Rock Elm
Slippery Elm
Black Locust
Black Cherry
Eastern Oaks
Dogwood
Persimmon
Tanoak
Eucalyptus</td><td rowspan="2">Bigleaf Maple
Oregon Ash</td><td rowspan="6">Oregon White Oak
Ca. Black Oak
Cascara
Chinkapin
Myrtle
Madrone</td><td>Red Alder</td><td rowspan="3">VPI
Eastern Oak
File</td></tr>
<tr><td rowspan="2">7</td></tr>
<tr><td rowspan="2">3</td></tr>
<tr><td rowspan="5">Yellow Poplar
Eastern Cottonwood
Bigtooth Aspen
Quaking Aspen
Catalpa
Buckeye
Butternut
American Basswood</td><td rowspan="2">29</td></tr>
<tr><td rowspan="6">Sweet Gum
Black Tupelo
Water Tupelo
Cucumbertree
Southern Magnolia
Paper Birch</td></tr>
<tr><td rowspan="5">VPI
Yellow Poplar
File</td></tr>
<tr><td>5</td></tr>
<tr><td rowspan="3">Black Ash
Pumpkin Ash
Hackberry
Sycamore
Silver Maple
Striped Maple
Box Elder
Sassafras
Sugarberry</td></tr>
<tr><td>8</td></tr>
<tr><td>Black Cottonwood
Balsam Poplar</td></tr>
</table>

Table 6. The Pallet Design System (PDS) softwood species classes.

<———— Increasing Strength <————			
11	12	13	14
Douglas Fir Western Larch Loblolly Pine Longleaf Pine Shortleaf Pine Slash Pine	Western Hemlock Mountain Hemlock California Red Fir Grand Fir Noble Fir Pacific Silver Fir White Fir	White Spruce Black Spruce Red Spruce Englemann Spruce Sitka Spruce Sugar Pine Western White Pine Ponderosa Pine Monterey Pine Jack Pine Red Pine Eastern White Pine Pitch Pine Pond Pine Spruce Pine Virginia Pine Subalpine Fir Balsam Fir Baldcypress Eastern Hemlock Western Red Cedar	Alaska Yellow Cedar Incense-Cedar Port-Oxford-Cedar Atlantic White Cedar Northern White Cedar Eastern Red Cedar

4.3.3 Workmanship

A total of 365 pallets were measured at 8 different pallet manufacturers to assess workmanship variation. The squareness was measured with a tape measure to the nearest 1/16-inch. The level of protruding nail points, protruding nail heads, nail splits, and missing nails was determined by counting the characteristic of interest. The uniformity of deckboard spacing was determined by the following steps:

1. The nominal widths, number of deckboards, and the overall width of the pallet was known. The total spacing dimensions was determined by subtracting the overall width from the product of the number of deckboards times the nominal deckboard dimension (Equation 3).

   Equation 3: total spacing dimension = overall pallet width - (nominal deckboard width - number of deckboards)

2. The total spacing dimension was divided by the number of spaces to get the nominal deckboard space (Equation 4).

   Equation 4: (total spacing dimension) ÷ (number of spaces) = nominal deckboard space

3. The percent of deviation for a deckboard space was determined by the absolute value of the nominal space subtracted by the actual space dimension divided by the nominal space times 100% (Equation 5).

   Equation 5: (nominal space - actual space) ÷ (nominal space) x 100% = % deviation deckboard space

4. The summation of all the percent of deviations within a pallet determines the overall percent of deviation of deckboard spacing in a pallet (Equation 6).

Equation 6: sum of % deviation deckboard space = overall % deviation deckboard spacing in a pallet

Quality variation within pallet manufacturing was determined in three categories: 1) raw material, 2) pallet cut-stock and 3) workmanship data. The raw material and cut-stock, within and between sawing variations, were measured. The workmanship, within and between board variations, were compared between companies, pallet type and assembly method.

4.4 Results

4.4.1. Raw Material

Table 7 contains the quality variations for hardwood raw material sampled from the different pallet mills in Tennessee, Ohio, and Virginia according to the different sawmill suppliers. The total board variability of width and thickness were quite large ranging from 0.111 to 1.370. Between board sawing variation accounted for a higher proportion of the total variation than the within board variations. Within board variations occurs when the workpiece moves relative to the saw during cutting. Between board variations are due to a number of factors such as setting accuracy of the saw setworks, saw condition, feed speed variation, etc.

The mean value of the boards' thickness and width were closer to the nominal size than the actual size except for the 4″. For example, 4″ actual size is 3 1/2 inches, and 6″ actual size is 5 1/2 inches. Table 8 shows the average mean values to be 3.931, 3.896, and 4.058. Since pallet mills are typically cutting to 3 1/2 to 3 3/4 or 5 1/2 to 5 3/4 wide. In Table 9, the percent below the _1/2, _5/8, _3/4, and 1+_ are recorded. The majority of the % are in the 1+_ column. The oversizing is important because the pallet company will further reduce the material to the common pallet dimensions.

4.4.2. Cut-Stock

The cut-stock data is divided into two groups: data collected by McLain et al (1986) and data collected by the author in 1986. Table 10 contains the quality variations of 1986 data for hardwoods and softwoods. The total variability on lengths and some of the within variability could not be accounted for in most of the boards due to only one measurement being recorded. The total variations ranged from 0.67% to 4.86% for width and thickness. Within variations are similar to the between variations. The species had no major affect on the between board variability based on high a F statistical value of 11.663. The between board variations for the softwoods and hardwoods were both similar, even though the sawing techniques are slightly different for the two. The hardwoods are gang resawn from cants while the softwoods are more commonly split from structural lumber. The softwoods ranged from 0.019 inches to 0.160 inches while the hardwoods ranged from 0.006 inches to 0.181 inches.

According to Mclain et al. (1986) the between board thickness variations were similar to the width variations (see Tables 11, 12, and 13). The variations ranged from 0.43% to 7.25% versus the width variations of 0.67% to 6.53%. This could be due to the importance that deckboard thickness has on the overall pallet performance. Therefore, the thickness sizing is more critical than the width. The between board thickness variability measured in 1983 was slightly lower than that measured in 1986.

Table 7. The variations of raw material quality from the different pallet mills by their sawmill sources.

com	source	n	mean (in)	sw (in)	sb (in)	st (in)
width 4x						
2	1	92	3.802	0.066	0.257	0.265
2	22	112	3.844	0.291	0.372	0.472
3	5	264	3.986	0.177	0.336	0.380
4	2	72	4.038	0.060	0.094	0.111
4	3	72	4.026	0.077	0.228	0.241
4	4	100	3.953	0.101	0.178	0.205
4	5	76	4.020	0.067	0.144	0.159
5	4	160	3.933	0.155	0.304	0.341
6	6	24	3.576	0.100	0.244	0.264
6	7	40	3.940	0.129	0.452	0.470
6	8	112	3.781	0.231	0.296	0.375
6	9	8	3.494	0.165	0.066	0.178
6	10	8	3.953	0.101	1.061	1.065
6	11	12	3.615	0.188	0.235	0.301
6	13	12	4.094	0.148	0.094	0.175
6	14	20	4.028	0.072	0.151	0.167
6	15	104	4.053	0.145	0.206	0.252
6	21	16	3.547	0.064	0.171	0.183
7	16	88	3.997	0.039	0.104	0.111
7	17	12	4.037	0.201	0.266	0.333
7	18	56	3.773	0.085	0.207	0.224
7	19	16	4.074	0.161	0.174	0.237
8	5	8	3.485	0.025	1.370	1.370
width 6x						
3	5	60	6.056	0.128	0.208	0.244
thickness x4						
3	5	48	4.119	0.091	0.166	0.189
6	7	12	3.875	0.088	0.062	0.108
8	5	48	4.017	0.088	0.166	0.188
thickness x6						
4	3	72	6.070	0.079	0.172	0.190
4	5	76	6.057	0.265	0.391	0.472
5	4	112	5.994	0.154	0.222	0.270
6	6	12	6.110	0.194	0.515	0.550
6	7	28	6.083	0.176	0.225	0.285
6	8	24	6.313	0.123	0.306	0.328
6	11	12	6.266	0.110	0.093	0.144
6	13	12	6.308	0.083	0.172	0.191
6	14	20	6.216	0.098	0.217	0.238
7	16	176	6.080	0.243	0.272	0.365
7	17	12	6.016	0.090	0.196	0.215
7	18	56	5.889	0.096	0.223	0.243
7	19	60	6.180	0.175	0.271	0.323
8	5	48	5.731	0.090	0.627	0.634
thickness x8						
2	1	20	7.622	0.063	1.318	1.320
5	4	44	8.004	0.207	0.371	0.424
6	8	88	8.353	0.144	0.170	0.223
6	15	96	8.013	0.216	0.461	0.509
6	21	16	8.090	0.105	0.191	0.218
8	5	148	7.842	0.160	0.377	0.409

com = company, source = supplier to company, n = sample size, sw = standard deviation within boards, sb = standard deviation between boards, st = total standard deviation.

Table 8. The raw material quality variations for the different board measurements sampled.

boards	sp	n_1	mean (in)	sw (in)	COV(%)	n_2	sb (in)	COV(%)$_2$
thickness								
2x	1	240	1.584	0.096	6.04	58	0.258	16.28
	3	84	1.547	0.090	5.83	21	0.193	12.45
	7	32	1.538	0.082	5.33	8	0.244	15.84
4x	1	1268	3.931	0.134	3.40	188	0.239	6.07
	3	264	3.896	0.134	3.44	57	0.317	8.14
	7	76	4.058	0.139	3.43	19	0.368	9.07
6x	1	60	6.056	0.121	2.00	15	0.212	3.50
width								
x4	1	44	4.084	0.130	3.18	11	0.438	10.72
	3	40	4.072	0.087	2.14	10	0.168	4.13
	7	12	4.005	0.106	2.64	2	0.048	1.20
x6	3	144	6.037	0.155	2.57	28	0.424	7.02
	7	72	6.081	0.133	2.19	18	0.291	4.78
x8	1	236	8.016	0.121	1.51	55	0.340	8.02
	3	144	8.078	0.118	1.46	35	0.302	8.08
	7	20	7.966	0.184	2.32	5	0.378	7.97
length								
8'	1	-	100.939	-	-	81	4.690	4.65
	3	-	115.154	-	-	21	20.291	17.62
10'	1	-	126.548	-	-	101	30.715	24.27
	3	-	124.603	-	-	26	3.926	3.15
	7	-	123.948	-	-	6	1.723	1.39
12'	1	-	144.74	-	-	81	3.658	2.48
	3	-	146.65	-	-	23	5.675	3.87
	7	-	152.73	-	-	16	12.221	8.00
14'	1	-	170.80	-	-	57	9.431	5.52
	3	-	171.16	-	-	18	1.781	1.04
	7	-	172.69	-	-	3	0.272	0.16
16'	1	-	186.612	-	-	25	11.986	6.42

sp = species; sw = standard deviation within boards; n_1 = the total number of observations within and between boards; COV(%) = coefficient of variation for sw; sb = standard deviation boards; n_2 = total number of boards; COV(%)$_2$ = coefficient of variation for sb; - = data not available.

Table 9. The percent below sawmill cutting target sizes in raw material.

target	n	±.5 (in)	±.625 (in)	±.75 (in)	1±.0 (in)
width					
2 in.					
total below	392	53	263	321	360
% below		13.52	67.09	81.89	91.84
4 in.					
total below	1324	21	79	160	476
% below		1.59	5.97	12.08	35.95
6 in.					
total below	60	0	0	0	14
% below		0	0	0	23.33
thickness					
4 in.					
total below	116	0	0	2	27
% below		0	0	1.72	23.38
6 in.					
total below	1208	14	21	38	356
% below		1.16	1.74	3.15	29.47
8 in.					
total below	418	12	24	38	133
% below		2.87	5.74	9.09	31.82

Table 10. The variations of cut-stock quality from the different pallet mills in Virginia, Ohio, and Tennessee.

com	species (PDS)	n	mean (in)	sw (in)	sb (in)	st (in)
width 0.5x						
1	7	284	0.501	0.009	0.031	0.032
width 0.625x						
2	1	12	0.635	0.008	0.011	0.014
2	5	48	0.638	0.010	0.010	0.100
3	12	110	0.656	-	0.047	-
5	11	100	0.689	-	0.027	-
6	11	71	0.667	-	0.020	-
8	12	105	0.663	-	0.019	-
9	12	90	0.697	-	0.027	-
width 0.75x						
1	1	212	0.805	0.013	0.015	0.020
2	1	40	0.763	0.007	0.006	0.009
2	5	60	0.771	0.008	0.022	0.023
width 1x						
4	1	32	0.947	-	0.027	-
4	7	51	0.992	-	0.034	-
4	11	7	1.001	-	0.023	-
width 2x						
1	7	120	2.218	0.022	0.060	0.064
width 3x						
1	1	92	3.828	0.053	0.047	0.071
1	7	148	3.805	0.102	0.034	0.107
2	1	128	3.761	0.042	0.080	0.090
thickness x2						
1	1	92	1.744	0.007	0.016	0.017
1	7	268	1.602	0.018	0.043	0.047
2	1	128	1.430	0.015	0.036	0.039
8	12	104	2.939	-	0.160	-
thickness x4						
1	1	156	3.912	0.038	0.080	0.088
1	7	224	3.847	0.053	0.117	0.128
2	1	52	3.765	0.030	0.100	0.104
2	5	108	3.748	0.025	0.181	0.182
3	12	81	3.438	-	0.104	-
5	11	81	3.507	-	0.078	-
6	11	36	3.415	-	0.105	-
thickness x6						
1	1	56	5.755	0.122	0.252	0.280
1	7	60	5.819	0.031	0.024	0.039
3	12	28	5.430	-	0.106	-
4	1	32	5.593	-	0.118	-
4	7	50	5.649	-	0.119	-
5	11	15	5.509	-	0.061	-
6	11	35	5.403	-	0.079	-
7	12	111	5.478	-	0.068	-
9	12	90	5.540	-	0.042	-
length 35"						
1	7	136	35.275	0.023	0.332	0.333
2	1	64	35.879	-	0.166	-
length 42"						
1	7	74	41.588	-	0.032	-
length 44"						
1	7	52	43.993	0.022	0.043	0.048
2	1	6	43.959	-	0.096	-
2	5	24	43.959	-	0.055	-
length 48"						
1	1	46	48.172	-	0.296	-
2	1	20	47.969	-	0.033	-
2	5	30	47.930	-	0.115	-
length 52"						
1	7	14	52.009	-	0.024	-

com = company, source = supplier to company, n = sample size, sw = standard deviation within boards, sb = standard deviation between boards, st = total standard deviation, - = not available.

Table 11. Lumber sizing data for eastern oak pallet parts for 1x4 deckboards.

Cut-Stock		thickness		width	
company	n	mean (in)	s (in)	mean (in)	s (in)
deckboards					
1	28	0.843	0.041	4.060	0.132
2	30	0.817	0.023	3.757	0.041
3	27	0.766	0.042	3.937	0.150
4	29	0.814	0.021	3.772	0.101
5	33	0.715	0.037	3.755	0.041
6	26	0.749	0.042	3.729	0.103
7	25	0.771	0.020	3.930	0.132
8	30	0.617	0.010	3.850	0.050
9	27	0.967	0.019	4.327	0.077
10	33	0.827	0.054	3.771	0.177
11	28	0.864	0.012	4.072	0.118
12	28	0.837	0.036	3.832	0.065
13	30	0.829	0.015	3.767	0.048
14	29	0.887	0.019	3.616	0.054
15	30	0.748	0.011	3.761	0.030
16	30	0.765	0.028	3.734	0.164
17	29	0.813	0.022	3.931	0.128
18	31	0.718	0.019	3.885	0.097
19	27	0.810	0.042	3.704	0.052
20	28	0.977	0.037	4.125	0.299
21	29	0.784	0.035	3.937	0.135
22	30	0.817	0.010	4.041	0.116
23	29	0.891	0.036	3.947	0.110
25	30	0.863	0.030	3.795	0.021
26	28	0.744	0.017	3.700	0.098
27	30	0.769	0.015	3.781	0.051
28	28	0.753	0.014	3.631	0.042
29	30	0.823	0.014	3.868	0.015
30	30	0.825	0.023	4.274	0.091
31	27	0.766	0.020	3.842	0.038

n = sample size, s = standard deviation (McLain, et al., 1983)

Table 12. Lumber sizing data for eastern oak pallet parts for 1x6 deckboards.

Cut-Stock		thickness		width	
company	n	mean (in)	s (in)	mean (in)	s (in)
deckboards					
1	17	0.835	0.049	5.979	0.084
2	19	0.740	0.022	5.779	0.037
3	21	0.774	0.028	5.732	0.061
4	5	0.800	0.007	5.701	0.124
5	19	0.710	0.049	5.676	0.044
6	20	1.138	0.056	6.169	0.043
7	18	0.764	0.024	5.985	0.263
8	20	0.618	0.011	5.801	0.024
9	20	0.969	0.025	6.144	0.149
10	19	0.749	0.020	5.551	0.016
11	20	0.887	0.012	5.750	0.074
12	20	0.849	0.022	5.744	0.092
13	19	0.837	0.014	5.787	0.054
14	15	0.886	0.023	5.653	0.020
15	19	0.734	0.013	6.253	0.070
16	20	0.775	0.024	5.489	0.167
17	20	0.799	0.014	5.794	0.024
18	20	0.963	0.052	5.699	0.158
19	20	0.831	0.016	5.747	0.039
20	17	0.100	0.051	6.078	0.190
21	18	0.763	0.023	5.993	0.050
22	19	0.815	0.024	5.726	0.131
23	20	0.887	0.014	5.886	0.151
25	20	0.843	0.041	5.751	0.024
26	20	0.747	0.026	5.682	0.080
27	19	0.754	0.010	5.645	0.100
28	18	0.756	0.007	5.941	0.028
29	19	0.821	0.017	5.994	0.097
30	20	0.825	0.015	5.876	0.224
31	20	0.713	0.015	5.720	0.135

n = sample size, s = standard deviation (McLain, et al, 1983)

Table 13. Lumber sizing data for eastern oak pallet parts for 2x4 stringers.

Cut-Stock		thickness		width	
company	n	mean (in)	s (in)	mean (in)	s (in)
stringers					
1	50	1.788	0.038	3.803	0.033
2	50	1.738	0.023	3.749	0.055
3	47	1.644	0.027	3.772	0.065
5	46	1.355	0.031	3.718	0.044
6	50	1.506	0.043	3.802	0.078
7	45	1.515	0.023	3.716	0.041
8	48	1.633	0.160	3.800	0.027
9	46	1.630	0.030	3.755	0.035
10	50	1.491	0.040	3.729	0.136
11	49	1.873	0.049	3.717	0.120
12	50	1.662	0.066	3.829	0.051
13	48	1.598	0.185	3.763	0.051
14	47	1.408	0.075	3.634	0.075
15	53	1.425	0.041	3.747	0.038
16	17	1.742	0.017	3.735	0.051
17	47	1.755	0.011	3.808	0.017
18	48	1.730	0.015	3.721	0.024
19	46	1.702	0.037	3.614	0.095
20	47	1.324	0.059	3.881	0.041
21	48	1.385	0.032	3.721	0.040
22	50	1.726	0.109	3.642	0.039
23	49	1.538	0.043	3.739	0.016
25	51	1.788	0.043	3.787	0.042
26	46	1.535	0.036	3.604	0.076
27	51	1.555	0.031	3.735	0.069
28	41	1.444	0.015	3.524	0.043
29	48	1.679	0.036	3.844	0.059
30	50	1.766	0.020	3.765	0.039
31	50	1.407	0.084	3.806	0.021

n = sample size, s = standard deviation (McLain, et al, 1983)

In Table 14, the boards are further broken down into target sizes set by the pallet companies. The R-square and F values are extremely variable ranging from 0.276 to 0.874 and 1.152 to 30.06, respectively. This proves that the variability between the boards are still high by company targets. The R-square and F values provides information about the population by examining the sample status.

In Table 15 the cut-stock data was compared to the NWPCA criteria. The majority of the cut-stock was within the NWPCA limits except for the 0.4375 deckboard and the 3.75 stringer targets. This could be due to a number of factors such as poor communication between the cutup line or even poor accuracy of the saws.

In a three stringer, 48x40, 4-way flush pallet, the minimum and maximum cut-stock data from Table 16 was inputed into the PDS program to look at the deviations of a pallet strength and durability when the top deckboards were changed from 0.8125 x 5.75. If the top edge deckboards were adjusted to 0.833 from 0.8125, the maximum load increases 11 lbs. with no change in deflection when racked across the stringers. The maximum pallet load increases 7 lbs and no change in deflection when racked across the deckboards. The adjusted pallet also has one more trip before repair. When the pallet is reduced to the 0.755 from 0.8125, the maximum pallet load decreases 73 lbs, while deflection stays the same when racked across the stringers. When racked across the deckboards, the maximum pallet load decreases 266 lbs and deflection increases 0.1 inch. In addition, the number of trips decreases by 3 before the pallets first repair. Overall, the number of trips changes 9%, the racked across deckboards 11% and racked across stringers 1.5%. This indicates such sizing variation will significantly affect pallet performance. The width variation has less of an effect in pallet performance.

Table 14. The cut-stock statistical values for the 1986 data.

com	species (PDS)	n	mean (in)	sw (in)	sb (in)	st (in)
width 0.5x						
1	7	284	0.501	0.009	0.031	0.032
width 0.625x						
2	1	12	0.635	0.008	0.011	0.014
2	5	48	0.638	0.010	0.010	0.100
3	12	110	0.656	-	0.047	-
5	11	100	0.689	-	0.027	-
6	11	71	0.667	-	0.020	-
8	12	105	0.663	-	0.019	-
9	12	90	0.697	-	0.027	-
width 0.75x						
1	1	212	0.805	0.013	0.015	0.020
2	1	40	0.763	0.007	0.006	0.009
2	5	60	0.771	0.008	0.022	0.023
width 1x						
4	1	32	0.947	-	0.027	-
4	7	51	0.992	-	0.034	-
4	11	7	1.001	-	0.023	-
width 2x						
1	7	120	2.218	0.022	0.060	0.064
width 3x						
1	1	92	3.828	0.053	0.047	0.071
1	7	148	3.805	0.102	0.034	0.107
2	1	128	3.761	0.042	0.080	0.090
thickness x2						
1	1	92	1.744	0.007	0.016	0.017
1	7	268	1.602	0.018	0.043	0.047
2	1	128	1.430	0.015	0.036	0.039
8	12	104	2.939	-	0.160	-
thickness x4						
1	1	156	3.912	0.038	0.080	0.088
1	7	224	3.847	0.053	0.117	0.128
2	1	52	3.765	0.030	0.100	0.104
2	5	108	3.748	0.025	0.181	0.182
3	12	81	3.438	-	0.104	-
5	11	81	3.507	-	0.078	-
6	11	36	3.415	-	0.105	-
thickness x6						
1	1	56	5.755	0.122	0.252	0.280
1	7	60	5.819	0.031	0.024	0.039
3	12	28	5.430	-	0.106	-
4	1	32	5.593	-	0.118	-
4	7	50	5.649	-	0.119	-
5	11	15	5.509	-	0.061	-
6	11	35	5.403	-	0.079	-
7	12	111	5.478	-	0.068	-
9	12	90	5.540	-	0.042	-
length 35"						
1	7	136	35.275	0.023	0.332	0.333
2	1	64	35.879	-	0.166	-
length 42"						
1	7	74	41.588	-	0.032	-
length 44"						
1	7	52	43.993	0.022	0.043	0.048
2	1	6	43.959	-	0.096	-
2	5	24	43.959	-	0.055	-
length 48"						
1	1	46	48.172	-	0.296	-
2	1	20	47.969	-	0.033	-
2	5	30	47.930	-	0.115	-
length 52"						
1	7	14	52.009	-	0.024	-

com = company, n = sample size, sw = standard deviation within boards, sb = standard deviation between boards, st = total standard deviation, - = not available.

Table 15. The percent above and below the NWPCA limits for the cut-stock data.

target		NWPCA criteria	n	above	below
width-deckboards					
3.75"	number %	-1/4" to ∞ 3.5-unlimited	475	-	3 0.63%
5.75"	number %	-1/4" to ∞ 5.5-unlimited	84	-	0
height-stringers					
1.25"	number %	±1/16" 1.1875-1.3125	48	0	0
1.50"	number %	±1/16" 1.4375-1.5625	196	0	2 2.5%
1.75"	number %	±1/16" 1.6875-1.8125	90	0	0
thickness-deckboards					
0.4375"	number %	±1/16" 0.3750-0.5000	164	78 47.56%	0
0.50"	number %	±1/16" 0.4375-0.5625	120	0	4 3.33%
0.625"	number %	±1/16" 0.5625-0.6875	60	0	0
0.75"	number %	±1/16" 0.6875-0.8125	100	0	0
0.8125"	number %	±1/16" 0.7500-0.8750	212	0	0
thickness-stringers					
3.75"	number %	±1/16" 3.6875-3.8125	324	69 21.30%	13 4.01%
length-deckboards and stringers					
35"	number %	-1/4" to +1/8" 34.750-35.125	30	0	0
35.5"	number %	-1/4" to +1/8" 35.250-35.625	46	0	0
36"	number %	-1/4" to +1/8" 35.750-36.125	47	0	1 2.13%
38"	number %	-1/4" to +1/8" 37.750-38.125	15	0	0
40"	number %	-1/4" to +1/8" 39.750-40.125	24	0	0
41"	number %	-1/4" to +1/8" 40.750-41.125	16	0	0
42"	number %	-1/4" to +1/8" 41.750-42.125	21	0	0
44"	number %	-1/4" to +1/8" 43.750-44.125	59	0	0
48"	number %	-1/4" to +1/8" 47.750-48.125	48	4 8.33%	1 2.08%
52"	number %	-1/4" to +1/8" 51.750-52.125	7	0	0
60"	number %	-1/4" to +1/8" 59.750-60.125	13	0	0

Table 16. The Pallet Design System (PDS) applied to the min. and max. of cut-stock data from 1986.

	thickness (in.)			width (in.)		
dimensions	0.8125	0.7550	0.8330	5.7500	5.6250	5.8130
racked across the stringers						
max. load (lbs.)	2466	2439	2477	2466	2459	2470
deflection max. load (in.)	0.22	0.22	0.22	0.22	0.22	0.22
racked across the deckboards						
max. load (lbs.)	3208	2942	3301	3208	3209	3232
deflection max. load (in.)	0.39	0.40	0.39	0.39	0.39	0.39
max. load for 0.25 in. defl. limit (lbs.)	1646	1468	1704	1646	1649	1660
economic life (trips)	56	51	57	56	55	56
life to first repair (trips)	31	28	32	31	31	31
cost/one-way /trip ($)	0.20	0.22	0.19	0.20	0.20	0.20
avg. cost/ trip before repair ($)	0.22	0.24	0.21	0.22	0.22	0.22

lbs. = pounds, in. = inches, max. = maximum, deflec. = deflection

4.4.3. Workmanship

The assessment of workmanship quality is based on 5 measures. These included 1) deck squareness, 2) number of nail splits, 3) number of protruding nail heads and 4) points, 5) number of missing nails, and 6) deckboard spacing. All samples that had any "out of squareness" deviation did not exceed the NWPCA criteria of 1.5% of the longest dimension or 1 inch, whichever is greater. Therefore, pallets assembled with nailing machines do not have the squareness problem. This is because all the pallets tested were assembled by automatic nailing machines, and this may not be true for pallets nailed with hand-held fastening tools.

The number of nail splits, protruding nail heads and points, missing nails, and deckboard spacing were statistically analyzed for within-pallet variations by company, nailer type, and pallet type. The results are shown in Tables 17 to 20. Of the 5 defects, the number of nail splits and deckboard spacing varies the most.

For the percent of deviation from uniform deckboard spacing, the majority of the results were in the 9 to 15 range by company, nailer type, and pallet type. The variations ranged from 2.435 to 6.709. The deck placement was more variable for the single head than the tandom nailers. This could be due to the automated deckboard placement in most the tandom machines versus the hand placed boards for the single head machines.

The small variability of the number of protruding nail points and heads could be due to the automation of the pallet assembly and the visibility of these defects. Nail points and heads are easier to detect than the number of nail splits or the uniformity of deckboard spacing. In addition, the variability by company, nailer type and pallet type are also relatively low.

Table 17. The effect of workmanship quality variation by company, nailer type, and pallet type.

	mean	s	R^2	F-value	PR>F
by company					
nail splits	4.258	4.475	0.406	34.84	0.0001
protruding nail heads	0.655	1.584	0.253	17.30	0.2533
protruding nail points	0.162	0.486	0.338	26.07	0.3383
missing nails	0.077	0.296	0.125	7.29	0.1251
uniformity of dkbd. spacing	11.862	4.646	0.179	8.99	0.1792
by nailer type					
nail splits	4.258	5.316	0.150	31.89	0.0001
protruding nail heads	0.655	1.655	0.174	38.24	0.001
protruding nail points	0.162	0.587	0.022	4.09	0.0176
missing nails	0.076	0.307	0.051	9.70	0.0001
uniformity of dkbd. spacing	11.862	5.528	0.026	2.83	0.0611
by pallet type					
nail splits	4.923	2.520	0.189	8.83	0.0001
protruding nail heads	0.731	1.417	0.136	5.98	0.0001
protruding nail points	0.189	0.484	0.1412	6.23	0.0001
missing nails	0.051	0.276	0.084	3.47	0.0008
uniformity of dkbd. spacing	11.573	4.054	0.188	7.27	0.0001

s = standard deviation; R^2, F-value,and PR>F = statistical analysis, dkbd. = deckboard.

Table 18. The effect of manufacturing on workmanship quality variations by as pallet mills.

	1		2		3		4	
	mean	s	mean	s	mean	s	mean	s
number of nail splits	1.795	2.117	0.579	0.769	2.133	2.000	11.740	6.505
protruding nail heads	0.333	1.108	0.053	0.229	4.467	4.486	0.220	0.764
protruding nail points	1.128	1.151	0	0	0.333	0.900	0	0
missing nails	0	0	0	0	0.533	0.743	0	0
deckboard spacing (%)	15.93%	4.602	9.39%	2.966	10.16%	4.751	9.78%	5.038

	5		6		7		8	
	mean	s	mean	s	mean	s	mean	s
number of nail splits	5.700	6.891	5.080	4.521	4.571	4.344	0.265	1.260
protruding nail heads	0.283	1.209	1.620	2.329	0.306	0.895	0.410	1.344
protruding nail points	0.033	0.181	0.160	0.650	0	0	0	0
missing nails	0.033	0.181	0.060	0.240	0.041	0.200	0.157	0.455
deckboard spacing (%)	10.16%	4.751	9.78%	5.038	13.66%	3.312	12.49%	6.709

s = standard deviation

Table 19. The effect of manufacturing on workmanship quality variations by nailer types for pallet mills.

	Viking		Campbell		Morgan	
	mean	s	mean	s	mean	s
number of nail splits	5.742	6.435	4.400	4.253	0.265	1.260
protruding nail heads	0.263	0.967	2.277	3.165	0.410	1.344
protruding nail points	0.212	0.653	0.200	0.711	0	0
missing nails	0.018	0.135	0.169	0.453	0.157	0.455
deckboard spacing (%)	12.13%	4.838	9.78%	5.038	12.49%	6.709

s = standard deviation

Table 20. The effect of manufacturing on workmanship quality variations by pallet types.

	1		2		3		4	
	mean	s	mean	s	mean	s	mean	s
number of nail splits	6.037	6.380	0.182	0.405	1.205	1.746	1.000	1.054
protruding nail heads	0.279	1.093	1.000	3.000	1.455	2.183	0.100	0.316
protruding nail points	0	0	0	0	0.568	0.998	0.100	0.316
missing nails	0.015	0.121	0.091	0.302	0	0	0	0
deckboard spacing (%)	11.12%	3.992	-	-	14.77%	5.451	10.55%	3.218

	5		6		7		8		9	
	mean	s	mean	s	mean	s	mean	s	mean	sd
number of nail splits	0	0	4.600	4.005	9.100	4.095	6.075	7.744	11.000	3.464
protruding nail heads	0.222	0.441	2.150	3.431	1.500	2.718	0.225	0.620	0.167	0.577
protruding nail points	0	0	0.300	0.883	0	0	0.525	0.933	0	0
missing nails	0	0	0.225	0.530	0.100	0.316	0.050	0.221	0.083	0.289
deckboard spacing (%)	4.64%	2.435	10.59%	4.866	15.13%	2.900	11.59%	5.456	-	-

s = standard deviation, - = not available

Very few missing nails were observed. This is partly due to the automation of nailing machines which inputs a constant flow of fasteners to the guns. Also such problems are easily rectified with a hammer and nail.

Therefore, during assembly, the major quality problem in pallets are the number of nail splits and deckboard spacing. However, the R-square. values were low and the F-values were high, indicating that the samples of the 5 defects cannot provide information about the population (Table 17).

4.5 Conclusions

There are three categories of quality variation to summarize:

1. The variation in raw material lumber sizing between sources of supply ranged from 1.6% to 39%. While within sources of supply has a low variations (0.72% to 7.6%).

2. There was no significant difference in size variation of hardwood cut-stock sampled in 1983 and that of 1986. The variations range from 0.43% to 7.25% in 1983 and 0.67% to 4.86% in 1986. In addition, the between board variation was similar to the within. The variations range from 0.92% to 2.12% for within board variation and 0.79% to 4.83% for between board variation. There was also similar size variation in thickness and width (0.43% to 7.25%, 0.67% to 6.53%, respectively). The 1986 cut-stock width and thickness variation was within the NWPCA published tolerances. The variation in cut-stock sizing results in a 11% predicted change in racking strength and 9% change in durability of pallets.

3. Out of squareness is not a quality problem in the pallet industry when automatic nailers are used. Nail splits and uniformity of deckboard spacing are a quality problem. Missing nails, protruding nail heads and protruding nail points are not a significant quality problem, because they are easy to detect and corrected.

5.0 Pallet Nails

5.1 *Introduction*

Pallets are subjected to dynamic and static forces of various levels from many directions. Wooden pallets fail either in the stringers, decks, or blocks, or at the connections. According to Wallin (1983) 65% of the observed pallet damage was at pallet joints. The pallet joints separate as a result of axial withdrawal of the nail shank or staple legs, pull-through of the fastener head or crown, shear deformation associated with bending of the fastener, or combinations of these modes. Wood density, lumber size, and moisture content during assembly and use influence joint performance. The fastener characteristics which influence joint performance are (1) wire diameter, (2) length and depth of penetration, (3) head diameter, (4) thread type, (5) thread crest diameter, (6) thread angle, (7) number of flutes, (8) wire toughness and brittleness. Any changes in these fastener characteristics affect the joint and pallet performance. An objective of this study is to determine the existing levels of pallet fastener quality variation.

5.2 *Literature Review*

Hundreds of fastener types are available for the assembly of the many different products in which they are used. Federal Specification FF-N-105B (1971) lists 408 fastener types. Wooden pallets in the U.S. are typically assembled with helically threaded, annularly threaded, twisted square wire, fluted, and plain shank nails. These pallet nails are commonly made of wire of 0.105-in. to 0.135-in. diameter (12 to 10 gauges), as shown in Table 21 (ASME, 1988). Staples are made of round or rectangular 0.062 to 0.080-in. (16 to 14 gauge) wire as shown in Table 22 (ASME, 1988).

Plain-shank nails of 0.086 to 0.105-in. diameter and staples of 0.052 to 0.80-inch wire are generally used when they are to be clinched for the assemble of block-pallet mats as shown in Table 23 (ASME, 1988). During clinching, the nail and staple points are bent over. Clinched fasteners provide higher withdrawal resistance than unclinched fasteners.

To improve the holding power or withdrawal resistance, the shanks are mechanically formed or deformed (ASTM, 1977). The process used includes etching, barbing, serrating, fluting, annular threading (ring shank), and helical threading (spiral or drive screw nails). Annularly threaded nails may have as much as a 40% greater withdrawal resistance then a plain-shank nail of the same size (Wood Handbook, 1987). When the nailed wood shrinks during its seasoning, the annually and helically threaded nails have as much as four times higher withdrawal resistance than the plain-shank nail of the same size (Wood Handbook, 1987). When moisture conditions change, the annularly and helically threaded fasteners have as much as 4 times more withdrawal resistance than the common nail (Wood Handbook, 1987).

According to Stern (1968) another way to improve the withdrawal resistance of driven fasteners is to apply surface coatings: 1) Cement coating is a finishing with natural resin applied to the fastener to decrease its driving resistance, to increase its withdrawal resistance

Table 21. Standard, helically threaded, stiff-stock and hardened stiff-stock steel nails in imperial units (ASME, 1988).

Code	Length (in)	Wire Diam. (in)	Crest-Diameter Stand. (in) A	Crest-Diameter Min. (in) B	Thread Angle Stand. (in) A	Thread Angle Min. (in) B	Head Diam. (in)	FWI	Quality Index, FBI, with Respect to Shear Resistance for Given MIBANT Angle (deg): Stiff-Stock 29	Stiff-Stock 34	Stiff-Stock 40	Stiff-Stock 46	Hardened 8	Hardened 12	Hardened 16	Hardened 20	Hardened 24	Hardened 28
150x105 AA	1.5	0.105	0.124	---	60	--	0.25	94	70	63	56	50	140	118	102	90	80	72
AB			0.124	---	--	67	0.25	76	70	63	56	50	140	118	102	90	80	72
BA			---	0.120	60	--	0.25	81	70	63	56	50	140	118	102	90	80	72
BB			---	0.120	--	67	0.25	66	70	63	56	50	140	118	102	90	80	72
175x105 AA	1.75	0.105	0.124	---	60	--	0.25	94	70	63	56	50	140	118	102	90	80	72
AB			0.124	---	--	67	0.25	76	70	63	56	50	140	118	102	90	80	72
BA			---	0.120	60	--	0.25	81	70	63	56	50	140	118	102	90	80	72
BB			---	0.120	--	67	0.25	66	70	63	56	50	140	118	102	90	80	72
175x112 AA	1.75	0.112	0.132	---	60	--	0.28	100*	78	70	62	55	154	130	112	99	88	80
AB			0.132	---	--	67	0.28	80	78	70	62	55	154	130	112	99	88	80
BA			---	0.128	60	--	0.28	87	78	70	62	55	154	130	112	99	88	80
BB			---	0.128	--	67	0.28	70	78	70	62	55	154	130	112	99	88	80
200x105 AA	2	0.105	0.124	---	60	--	0.25	94	70	63	56	50	140	118	102	90	80	72
AB			0.124	---	--	67	0.25	76	70	63	56	50	140	118	102	90	80	72
BA			---	0.120	60	--	0.25	81	70	63	56	50	140	118	102	90	80	72
BB			---	0.120	--	67	0.25	66	70	63	56	50	140	118	102	90	80	72
200x112 AA	2	0.112	0.132	---	60	--	0.28	100*	78	70	62	55	154	130	112	99	88	80
AB			0.132	---	--	67	0.28	80	78	70	62	55	154	130	112	99	88	80
BA			---	0.128	60	--	0.28	87	78	70	62	55	154	130	112	99	88	80
BB			---	0.128	--	67	0.28	[illegible]	78	70	62	55	154	130	112	99	88	80
200x120 AA	2	0.120	0.142	---	60	--	0.28	108	86	77	68	62	171	144	124	109	98	88
AB			0.142	---	--	67	0.28	87	86	77	68	62	171	144	124	109	98	88
BA			---	0.137	60	--	0.28	92	86	77	68	62	171	144	124	109	98	88
BB			---	0.137	--	67	0.28	75	86	77	68	62	171	144	124	109	98	88
225x112 AA	2.25	0.112	0.132	---	60	--	0.28	100*	78	70	62	55	154	130	112	99	98	80
AB			0.132	---	--	67	0.28	80	78	70	62	55	154	130	112	99	98	80
BA			---	0.128	60	--	0.28	87	78	70	62	55	154	130	112	99	98	80
BB			---	0.128	--	67	0.28	70	78	70	62	55	154	130	112	99	98	80
225x120 AA	2.25	0.120	0.142	---	60	--	0.28	108	86	77	68	62	171	144	124	109	98	88
AB			0.142	---	--	67	0.28	87	86	77	68	62	171	144	124	109	98	88
BA			---	0.137	60	--	0.28	92	86	77	68	62	171	144	124	109	98	88
BB			---	0.137	--	67	0.28	75	86	77	68	62	171	144	124	109	98	88
250x112 AA	2.5	0.112	0.132	---	60	--	0.28	100*	78	70	62	55	154	130	112	99	98	80
AB			0.132	---	--	67	0.28	90	78	70	62	55	154	130	112	99	98	80
BA			---	0.128	60	--	0.28	87	78	70	62	55	154	130	112	99	98	80
BB			---	0.128	--	67	0.28	70	78	70	62	55	154	130	112	99	98	80
250x120 AA	2.5	0.120	0.142	---	60	--	0.28	108	86	77	68	62	171	144	124	109	98	88
AB			0.142	---	--	67	0.28	87	86	77	68	62	171	144	124	109	98	88
BA			---	0.137	60	--	0.28	92	86	77	68	62	171	144	124	109	98	88
BB			---	0.137	--	67	0.28	75	86	77	68	62	171	144	124	109	98	88
250x135 AA	2.5	0.135	0.159	---	60	--	0.30	120	103	92	82	73	204	172	148	130	117	105
AB			0.159	---	--	67	0.30	96	103	92	82	73	204	172	148	130	117	105
BA			---	0.154	60	--	0.30	103	103	92	82	73	204	172	148	130	117	105
BB			---	0.154	--	67	0.30	84	103	92	82	73	204	172	148	130	117	105
275x120 AA	2.75	0.120	0.142	---	60	--	0.28	108	86	77	68	62	171	144	124	109	98	88
AB			0.142	---	--	67	0.28	87	86	77	68	62	171	144	124	109	98	88
BA			---	0.137	60	--	0.28	92	86	77	68	62	171	144	124	109	98	88
BB			---	0.137	--	67	0.28	75	86	77	68	62	171	144	124	109	98	88
275x135 AA	2.75	0.135	0.159	---	60	--	0.30	120	103	92	82	73	204	172	148	130	117	105
AB			0.159	---	--	67	0.30	96	103	92	82	73	204	172	148	130	117	105
BA			---	0.154	60	--	0.30	103	103	92	82	73	204	172	148	130	117	105
BB			---	0.154	--	67	0.30	84	103	92	82	73	204	172	148	130	117	105
300x120 AA	3	0.120	0.142	---	60	--	0.28	108	86	77	68	62	171	144	124	109	98	88
AB			0.142	---	--	67	0.28	87	86	77	68	62	171	144	124	109	98	88
BA			---	0.137	60	--	0.28	92	86	77	68	62	171	144	124	109	98	88
BB			---	0.137	--	67	0.28	75	86	77	68	62	171	144	124	109	98	88
300x135 AA	3	0.135	0.159	---	60	--	0.30	120	103	92	82	73	204	172	148	130	117	105
AB			0.159	---	--	67	0.30	96	103	92	82	73	204	172	148	130	117	105
BA			---	0.154	60	--	0.30	103	103	92	82	73	204	172	148	130	117	105
BB			---	0.154	--	67	0.30	84	103	92	82	73	204	172	148	130	117	105
350x135 AA	3.5	0.135	0.159	---	60	--	0.30	120	103	92	82	73	204	172	148	130	117	105
AB			0.159	---	--	67	0.30	96	103	92	82	73	204	172	148	130	117	105
BA			---	0.154	60	--	0.30	103	103	92	82	73	204	172	148	130	117	105
BB			---	0.154	--	67	0.30	84	103	92	82	73	204	172	148	130	117	105

* Basis of comparison
Table reproduced from ASME, 1988

Table 22. Standard, bright and coated, plain-shank, regular-stock steel, staples in imperial units (ASME, 1988).

Length (in)	Nominal Wire Diam. (in)	Cross-Section		Finish		FWI with Respect to Withdrawal Resistance		FSI with Respect to Shear Resistance for Given MIBANT Angle, Deg. for Bright or Coated fasteners		
		Thickn. (in)	Width (in)	Bright	Coated *	Bright	Coated *	85	115	150
2.00	0.062	0.055	0.061	x	-	33	--	-	-	33
	0.072	0.067	0.073	-	x	--	50	-	x	--
	0.080	0.075	0.080	x	-	39	--	x	-	39
2.25	0.062	0.055	0.061	-	x	--	59	-	x	--
	0.072	0.067	0.073	x	-	44	--	x	-	44
	0.080	0.075	0.080	-	x	--	65	-	x	--
2.50	0.072	0.067	0.073	x	-	33	--	x	-	33
	0.080	0.075	0.080	-	x	--	50	-	x	--
3.00	0.072	0.067	0.073	x	-	39	--	x	-	39
	0.080	0.075	0.080	-	x	--	59	-	x	--
3.75	0.072	0.067	0.073	x	-	44	--	x	-	44
	0.080	0.075	0.080	-	x	--	65	-	x	--

* increase in delayed withdrawal resistance of coated staples, driven into green wood and tested after its seasoning to 12-pct. moisture content, shall be at least 33 pct. above that of identical bright staples. If the coating is more effective, its benefit can be prorated in determining its FWI.

Table reproduced from ASME, 1988

Table 23. Standard, and coated, plain-shank, regular-stock steel, nails and staples format assembly in imperial units (ASME, 1988)

NAILS				STAPLES		
Code	Length In.	Wire Diameter In.	Head Diameter In.	Code	Length In.	Nominal Wire Diameter In.
100x086	1.00	0.086	0.19	100x062	1.00	0.062
100x091	1.00	0.091	0.22	100x072	1.00	0.072
100x099	1.00	0.099	0.25	100x080	1.00	0.080
100x105	1.00	0.105	0.25	125x062	1.25	0.062
125x086	1.25	0.086	0.19	125x072	1.25	0.072
125x091	1.25	0.091	0.22	125x080	1.25	0.080
125x099	1.25	0.099	0.25	150x062	1.50	0.062
125x105	1.25	0.105	0.25	150x072	1.50	0.072
150x086	1.50	0.086	0.19	150x080	1.50	0.080
150x091	1.50	0.091	0.22	175x062	1.75	0.062
150x099	1.50	0.099	0.25	175x072	1.75	0.072
150x105	1.50	0.105	0.25	175x080	1.75	0.080
175x086	1.75	0.086	0.19	200x062	2.00	0.062
175x091	1.75	0.091	0.22	200x072	2.00	0.072
175x099	1.75	0.099	0.25	200x080	2.00	0.080
175x105	1.75	0.105	0.25			
200x086	2.00	0.086	0.19			
200x091	2.00	0.091	0.22			
200x099	2.00	0.099	0.25			
200x105	2.00	0.105	0.25			

Table reproduced from ASME, 1988

by bonding the nail to the surrounding wood, and to provide limited corrosion resistance. However, the increase in withdrawal resistance of cement coated nails decrease with time. This coating is, therefore, used primarily for the assembly of expandable containers used during rough handling over a limited period of time, when immediate withdrawal resistance is a criterion. 2) Zinc coating and coatings of other metals, such as copper clad, and aluminum galvanized, are used when corrosion and staining is a problem. Such coatings do not increase the withdrawal resistance of the nails. 3) Plastic-coated fasteners may have reduced driving resistance, increased holding power, limited protection against corrosion, and chemical deterioration, and limited bond to the surrounding wood, thereby reducing moisture penetration Some of these coatings may be stripped during driving into denser woods and will not necessarily improve the withdrawal resistance of the fastener.

The fastener point influences the holding power of the nail. Long points cause the wood to split, which reduces the withdrawal resistance of the fastener. Blunt or short points and no points may reduce splitting, but cut some of the wood fibers during driving, which lowers the withdrawal resistance of the fastener to less than that of the fasteners with the common diamond point.

Nail heads may be flat, oval, countersunk, deep-countersunk, or brad, to mention a few (ASTM, 1977). The Wood Handbook (1974) states that "nails with all types of heads, except the deep countersunk, brad, and some thin flat head nails, are sufficiently strong to withstand the force required to pull them from most woods in direct withdrawal." The deep countersunk and brad nails driven below the wood surface are not intended to carry large withdrawal loads, since they could fail in head pull-through. In general, thickness and diameter of head increases as the size of the nail increases.

The density of the wood used also affects the withdrawal resistance of the fasteners. The Wood Handbook (1974) defines the empirical formula for the maximum withdrawal load is:

Equation 7 $p = 7850 \times G^{\frac{5}{2}} \times DL$

where:

p = maximum load, in pounds;
L = depth, in inches of penetration of the nail in the fastener member
G = specific gravity of the wood based on ovendry weight and volume at 12% moisture content
D = diameter of the nail, in inches

Therefore, the greater the wood density, the greater with separation resistance of a joint. (ASME, 1988) The Fastener Withdrawal Index (FWI) is another way to measure the withdrawal resistance of the fasteners. FWI is a relative measure of the estimated withdrawal performance of a given fastener which is dependent on the characteristics of the fastener and independent of the wood material in which it is to be used. The FWI for any given fastener is described as a percentage of the performance of the "base nail". That is, a fastener with an FWI of 75 has 75 percent of the holding power of the base nail. The equation for computing FWI is as follows:

Equation 8 $FWI = 221.24 \times WD\left[1 + 27.15(TD - WD)(\frac{H}{TL})\right]$

where:

WD = wire diameter (measured or computed)
TD = average thread-crest diameter, in inches
H = number of helixes along thread length of a nail with the average thread diameter
TL= thread length, in inches

Lateral resistance is also affected by the wood density. The Wood Handbook provides an empirical formula for lateral resistance as:

Equation 9 $p = KD^{\frac{3}{2}}$

where:

p = is the lateral load, in pounds per nail at a joint slip of 0.015 inches

K = is a coefficient based on the specific gravity of woods
D = is the diameter of the nail, in inches.

Therefore, the greater the wood density, the greater the resistance of joint slippage and load-carrying capacity. However, less dense species tend to split less. Increasing the diameter, length and number of nails can offset the lower withdrawal resistance lateral load transmission in low-density wood species (Scholten, 1965 and ASME, 1988).

In addition to lateral resistance, the fastener shearness can be measured with the Fastener Shear Index (FSI). It is a relative measure of fastener shear-transmission performance which is independent of the wood material in which the fastener is to be used. The FSI for any given fastener is described as a percentage of the performance of the "base nail". A fastener with a FSI of 75 is 75 percent as stiff as the base nail. The equation for computing FSI is as follows:

Equation 10 $$FSI = \frac{263{,}260 \times (WD)^{1.5}}{M + 40}$$

where:

WD = wire diameter (measured or computed)
M = average MIBANT bend angle

The hardness values of fasteners are related to the carbon content and, thus, the bending or yield strengths of the material of which the fasteners are made. (Padla, 1983). ASTM F547-77 (The Standard Definition of Terms Relating to Nails for Use with Wood and Wood-Base Materials) contains a classification of steel grades by carbon content: 1) a low-carbon steel where the maximum of the carbon range is up to and including 0.15%, 2) a medium low-carbon steel where the maximum of the carbon range exceeds 0.15% up to and including 0.23%, 3) a medium high-carbon steel where the maximum of the carbon range exceeds 0.23% up to and including 0.44%, and 4) a high-carbon steel where the maximum of the carbon range exceeds 0.44%.

ASTM F680-80 (Standard Methods for Testing Nails) contains three tests for evaluating the quality of steel in fasteners:

1. Rockwell Hardness Test
2. Conventional Bend Test
3. Impact Bend Test

Pallet fastener standards usually refer to the Impact Bend Test. Figure 3 is a photograph of the Model TE-154 MIBANT (Morgan Impact Bend-Angle Nail Tester). According to Stern (1971), "a single test performance with this tool may provide information on the bending resistance of the nail during lateral load transmission, and under certain conditions, its buckling resistance during nail driving." The National Wooden Pallet and Container Association (NWPCA) adopted the device and bend angle criterion as part of the evaluation of pallet fastener quality (Stern, 1977). The NWPCA pallet standards contain fastener quality classes: A MIBANT angle of 8 to 28 degrees designates a hardened fastener, 29 to 46 degrees as stiff-stock fastener, and 46 degrees and above a soft-steel fastener. Stern (1974) further defines hardened-steel nails as "heat-treated and, subsequently, tempered, medium or medium-high carbon-steel nails, providing at least the stiffness of bright low-carbon-steel nails of larger diameter at high flexure loads, with the treating process resulting in toughened nails and with the tempering process resulting in increased toughness and ductility and decreased brittleness of the nails." He also defined stiff-stock nails as "bright, nonhardened, medium or medium-high carbon steel nails, often made of SA-1039 steel, providing a higher yield point and greater stiffness to the assembled pallets than bright, low-carbon-steel nails of same wire diameter at high flexure loads."

Wallin and Whitenack (1982) indicated that the MIBANT angle ranged from 8 to 81 degrees when 5946 pallet nails of various sizes were tested from 223 sample lots provided by various manufacturers. Wallin (1978) defines a high-quality pallet nail as a medium-carbon steel wire nail of 0.110-inch diameter, which bends no more than 20 during the MIBANT test without breaking or fracturing. A high quality nail must also have at least a 0.020-inches thread-crest

Figure 3. Photograph showing the Model TE-154 MIBANT device.

press-out and a thread angle of 60 degrees to the perpendicular to the nail axis. Both the thread angle and the thread-crest press-out diameter affect the contact area between the nail shank and the wood. The thread-crest press-out is the distance from crest to crest of the fastener threads in a direction perpendicular to the axis of the nail as shown in Figure 4. This area is related to the fastener withdrawal resistance. Thus, the contact area between the nail and surrounding wood can increase at a compounded rate of 0.65% per degree of increase in thread angle (Wallin, 1978).

5.3 Materials and Methods

Over the years, the William Sardo Jr. Pallet and Container Laboratory of the Virginia Polytechnic Institute and State University (VPI&SU) has offered the pallet and container industry a fastener-quality analysis program. The physical characteristics and MIBANT angle of over 2800 different types of pallet fasteners have been measured. To reflect fasteners currently in use, data collected between 1980 and 1988 was studied. Helically threaded nails only were studied due to the predominance of these nails in the laboratory records, and since this nail type is the most commonly used for pallet assembly. Figure 4 schematically indicates how the physical characteristics of a helically threaded nails are measured. For additional details on these meaning procedures, consult Osborn (1986). The MIBANT angle was measured according to ASTM F680-87 (1987). Frequency distributions were plotted for the different wire diameters and levels of variability were calculated where sample size permitted. Wire diameters are typically 0.135, 0.128, 0.1205, 0.113, 0.1055, and 0.099 inches. These wire diameters correspond to the following gauges of 10, 10.5, 11, 11.5, 12, and 12.5, respectively The Federal Specifications, now under revision, permit ±0.004 inches variation within each gauge. The National Wooden Pallet and Container Association (NWPCA) permits ±0.002 inches vari-

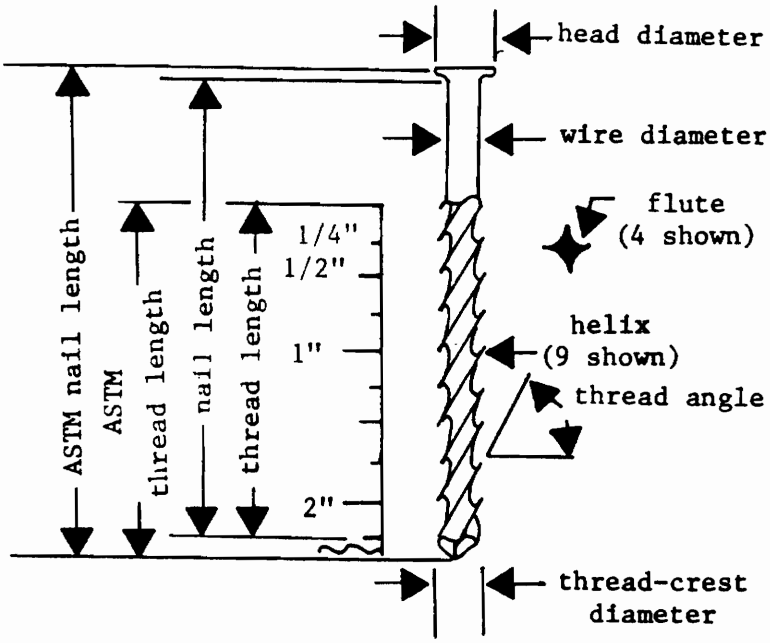

Figure 4. A diagram showing the physical characteristics of a helically threaded nail.

ation (NWPCA, 1982; NWPMA, 1974; NWPMA, 1960). For the purpose of this study, the gauges are defined in the following manner:

0.097″ to 0.101″ = 12.5 gauge
0.103″ to 0.107″ = 12 gauge
0.111″ to 0.115″ = 11.5 gauge
0.118″ to 0.122″ = 11 gauge
0.126″ to 0.130″ = 10.5 gauge
0.133″ to 0.137″ = 10 gauge

The length of helically threaded pallet nails, shown in Figure 4, ranges from 1.5 to 3.5 inches in 1/4 or 1/2-inch increments. Length variations of ±1/16-in. are acceptable by NWPCA (1982). These criteria are used to define fastener length classes. A total of 334 different helically threaded nails, each represented by 25 replicates, were evaluated and are used as a basis of the following analyses. The nails originated from 26 or more fastener vendor sources.

5.4 Results

5.4.1 Wire Diameters

Figures 5 and 6 are frequency distributions of the wire diameters. Superimposed are the FF-N-105B and NWPCA acceptance levels. The FF-N-105B standard tolerances of ±0.004 inches overlap between the 12 and 12.5, 11 and 11.5, and 10 and 10.5 gauges as defined in FF-N-105B. Reliable gauge classification for pallet nails purchased on the 1/2 gauge using these standards is impossible. The acceptance criteria of NWPCA in Figure 6 include most of the wire-diameter frequency peaks. For helically threaded pallet nails, the NWPCA acceptance levels of ±0.002 inches better reflect the diameter variations in pallet nails and better permit discrimination between gauges than FF-N-105B. The NWPCA criteria are used to define the tolerances in this thesis.

There are a number of fasteners that do not fall within the NWPCA acceptance levels. Evidently there are fasteners that are being manufactured and sold which cannot be classified by gauge. According to Equation 1, a plain shank nail of 0.114 diameter will be 90% less in withdrawal resistance than a nail of 0.110 inches from an oak board. Purchasing pallet nails by gauge is therefore not reliable. This is one of the reasons why the industry should disregard gauge sizes and use the actual wire diameters, in inches. Of all the pallet nails tested, the 0.113 in. and 0.120 in. sizes were the most common and are, therefore, the most common helically threaded nail, used for pallet assembly. The 0.099, 0.105, 0.113, 0.120, 0.128 modes in Figures 5 and 6 correspond very closely to the average diameters specified for each gauge in both the NWPCA and the FF-N-105B standards. Table 24 contains the within gauge variation of wire diameters. These are less than 1% for all but the 10 gauge. The high variation in wire diameter in the 10 gauge class may be attributed to the small sample size and not manufacturing variations.

5.4.2 Average Thread-Crest Diameters

Considering the relatively small variations in wire diameters, shown in Table 24, and the fact that, within wire diameter variations in thread-crest diameters affect joint and pallet performance, it appears that, for these most popular wire sizes, two thread-crest diameters and thread qualities predominant, hence, manufactured.

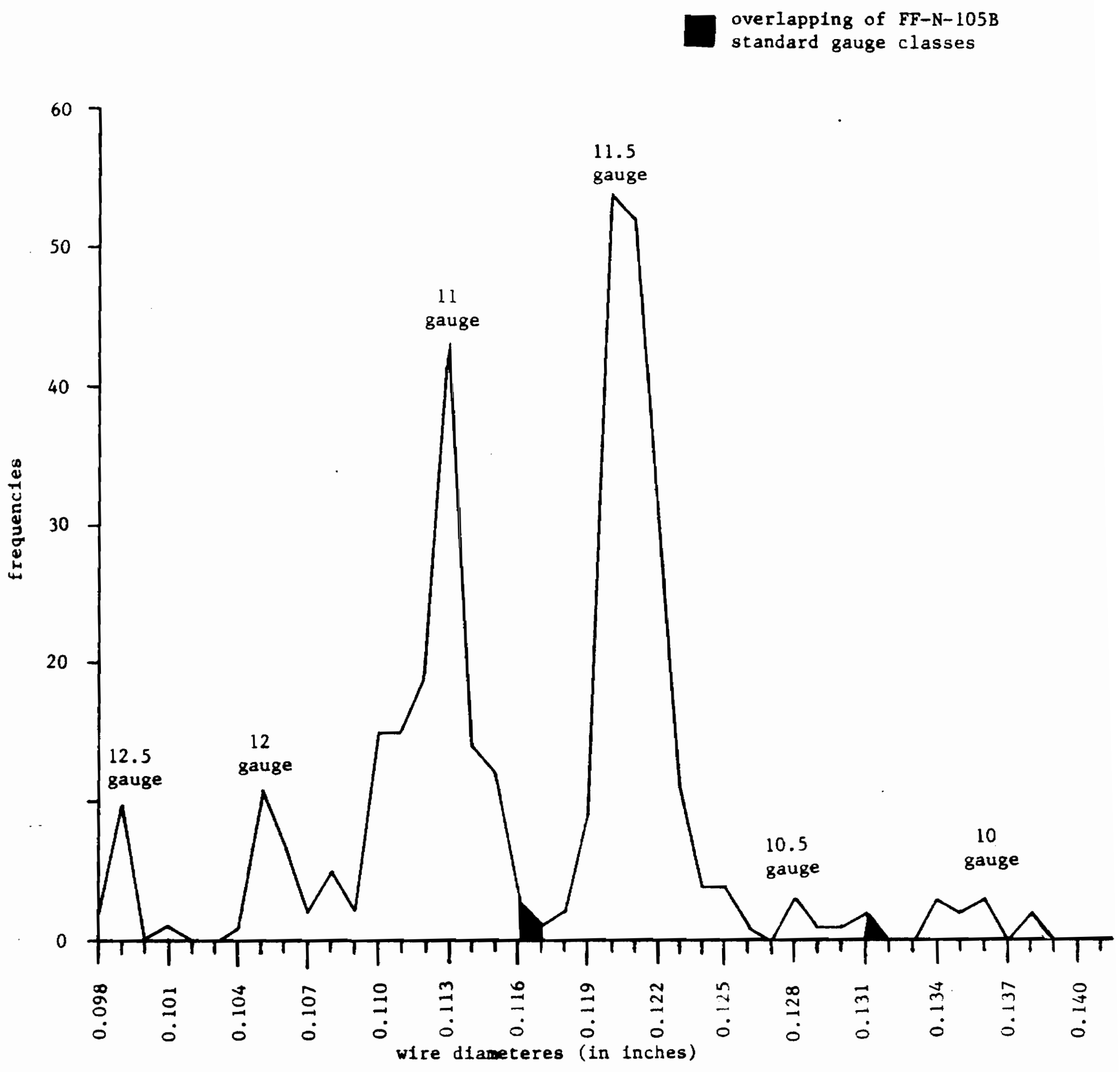

Figure 5. Frequency distribution wire diameters for helically threaded pallet nails with FF-N-105B standard gauge definitions marked.

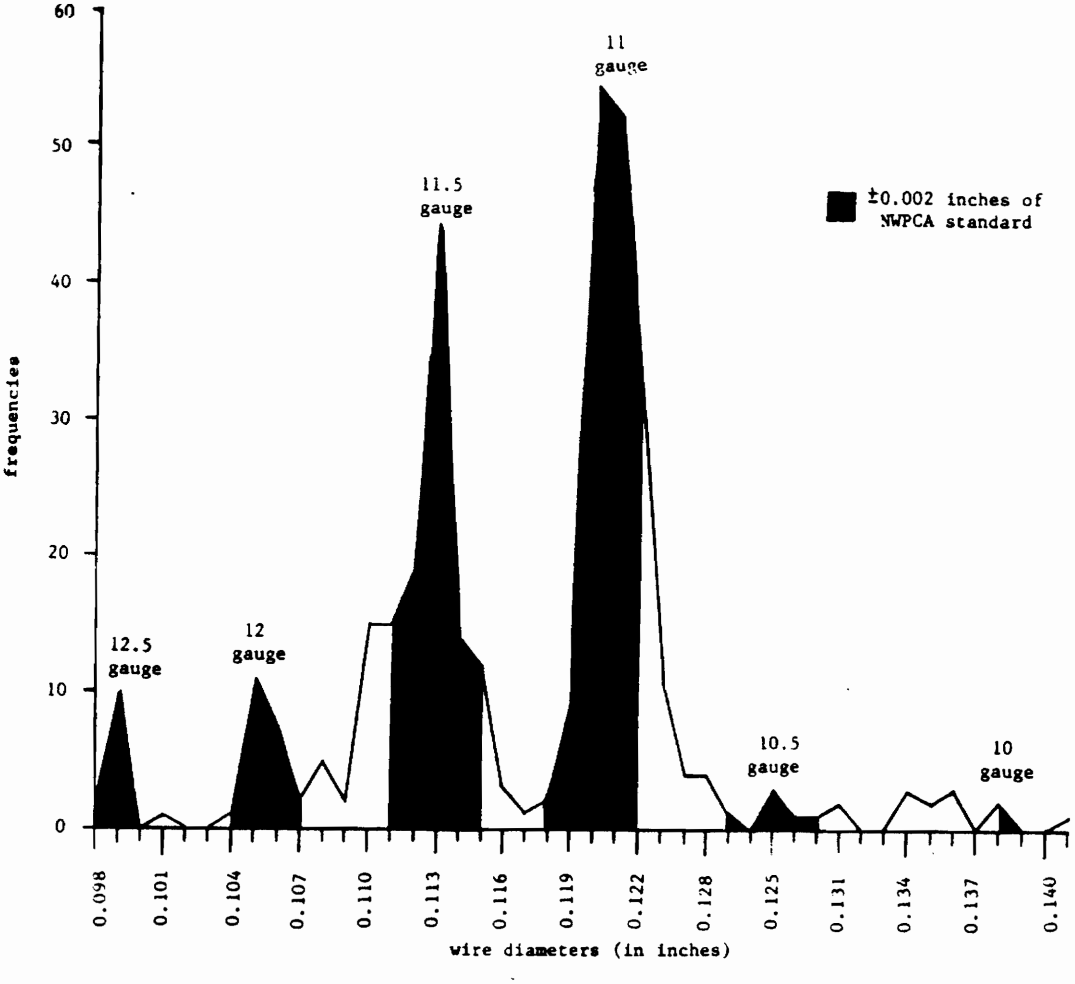

Figure 6. Frequency distribution of wire diameters for helically threaded pallet nails with NWPCA standard gauge definition marked.

Table 24. Variation in wire diameter within gauges of helically threaded pallet nails.

gauges	n	mean (in)	s (in)	COV (%)
10	8	0.135	0.0293	21.0
10.5	6	0.128	0.0013	0.8
11	140	0.121	0.0009	0.8
11.5	118	0.113	0.0012	0.9
12	22	0.106	0.0007	0.9

n = sample size, s = standard deviation,
COV = coefficient of variation, in = inches

Table 25 indicates the levels of variation for selected nail properties for each gauge. The variability of thread-crest diameter is relatively large within gauge, ie within 12 gauge = 3.9%, within 11.5 gauge = 54.8%, within 11 gauge = 11.8%.

Table 26 indicates the variations in average thread-crest diameters within the wire diameters of given nail sizes. Variation of 2.6% to 5.8% represents an estimated 40% to 123% difference in estimated withdrawal resistance of all other fastener characteristics.

Table 27 indicates the variations in average thread crest-diameter for nails from different vendors by gauge, wire classification, and nail length. The variability is also relatively small, ranging from 1.2 to 2.7%. This indicates that within lots and vendors, the variations in thread-crest diameters is small. Therefore, when purchasing fasteners by wire classifications, wire sizes, and lengths, from different vendors, relatively high levels of variations in thread-crest diameters can be expected. It is evident from this that wire diameter and thread-crest diameters should be indicated in a descriptive specification and purchase agreement.

Table 28 contains the average thread-crest diameters for the 0.105-in to 0.122-in nail sizes. These are quite variable. In the 0.107 wire-diameter size, the fasteners measured were 100% outside the NWPCA specification limits. The thread-crest diameter of the 0.105 wire diameter nails were all within these limits. The majority of the 11 and 11.5 gauge nails were below the NWPCA specification requirements. These threaded nails have less surface area, and therefore, less contact area between the nail shank and the surrounding wood. The withdrawal resistance will therefore be lower than that for nails specified in the NWPCA standard.

5.4.3 Head Diameter

Figure 7 indicates the frequency distribution of the head diameters within the three predominant nail sizes used for pallet assembly. The head diameter for the 11 and 11.5 gauge nails

Table 25. The within gauge variation of selected characteristics of helically threaded pallet nails.

properities	gauges	n	mean	s	COV (%)
average thread-crest diameter (inches)	11 11½ 12	127 111 23	0.136 0.126 0.119	0.016 0.069 0.005	11.8 54.8 3.9
average head diameter (inches)	11 11½ 12	73 82 10	0.280 0.274 0.256	0.089 0.127 0.120	31.8 46.3 46.9
average thread angle (degrees)	11 11½ 12	127 109 15	67 67 67	1.90 2.10 2.42	2.84 3.13 3.61
average MIBANT angle (degrees)	11 11½ 12	125 114 22	33 39 56	16.47 12.13 15.20	49.9 31.1 27.1

n = sample size, s = standard deviation, COV = coefficient of variation

Table 26. Variation in average thread-crest diameters for each wire diameter size of helically threaded pallet nails.

Gauge	Wire Dia. (inches)	n	Min. (in)	Mean (in)	Max. (in)	s (in)	COV. (%)
12.5	0.099	9	0.105	0.108	0.115	0.003	2.8
12	0.105	9	0.113	0.116	0.120	0.003	2.6
	0.106	9	0.115	0.120	0.127	0.004	3.3
11.5	0.110	15	0.120	0.126	0.133	0.005	4.0
	0.111	14	0.117	0.125	0.135	0.007	5.6
	0.112	17	0.118	0.127	0.135	0.005	3.9
	0.113	43	0.117	0.127	0.139	0.005	3.9
	0.114	29	0.121	0.127	0.154	0.007	5.5
11	0.119	9	0.122	0.131	0.140	0.005	3.8
	0.120	49	0.127	0.135	0.145	0.005	3.7
	0.121	50	0.127	0.135	0.147	0.005	3.7
	0.122	22	0.129	0.133	0.143	0.004	3.1

n = sample size, Min. = minimum, Max. = maximum, s = standard deviation, COV = coefficient of variation, in = inches

Table 27. Variation in average thread-crest diameters within vendors by gauges, nail classification and length.

Gauge	nail class.	Length (in)	n	s (in)	mean (in)	COV %
11	stiffstock	2.25	19	0.002	0.133	1.7
11	hardened	3.00	8	0.002	0.142	1.7
11	hardened	2.50	6	0.002	0.135	1.6
11.5	stiffstock	2.25	13	0.001	0.125	1.2
11.5	stiffstock	2.00	13	0.003	0.126	2.7
11.5	hardened	2.25	15	0.003	0.130	2.4
11.5	soft	2.25	7	0.003	0.126	2.2

n = sample size, s = standard deviation, COV = coefficient of variation

Table 28. The percentage of measurements above and below the NWPCA criteria for helically threaded pallet nails of a given wire dia.

	thread angle		thread-crest diameter					
	NWPCA specs. by thr. angle		NWPCA specifications limits by wire diameter					
	all gauges		11 g.		11.5 g.		12 g.	
	60-68°		0.132 to 0.142		0.125 to 0.135		0.112 to 0.122	
wire dia.	over (o) %	under (u)	o %	u	o %	u	o %	u
0.105	+33	-0					+ 0	-11
0.106	+25	-0					+22	- 0
0.107	+ 0	-0					100	- 0
0.111	+15	-0			+ 0	-43		
0.112	+35	-0			+ 0	-12		
0.113	+36	-2			+ 5	-44		
0.114	+50	-7			+11	-54		
0.115	+22	-0			+ 0	-27		
0.119	+13	-13	+16	-29				
0.120	+24	- 0	+10	-22				
0.121	+27	- 0	+ 5	-32				
0.122	+38	- 0	+ 9	- 0				

g. = gauge

range from 0.270 to 0.285 inches. Within the range, the distribution is conspicuously bimodal for both gauges. Indicating two quality levels are being produced.

Figure 8 is a plot of average head diameter as a function of wire diameter. The regression analysis reveals that predicted head diameter decreases 0.0011 inches per 0.001 inch decrease of wire diameter and a R-square value of 0.27. Nail head diameters significantly affect head pull-through resistance of the nail in a joint. Allowing for the effect of wood properties, a nail should be used such that the head pull-through resistance is comparable to the shank-withdrawal resistance. Because the head diameter is dependent on the wire diameter, the bearing area of the nail is important to use to analysis the head diameter characteristic. Assuming a round nail head, the bearing area can be represented by the difference between the head diameter and wire diameter. For the 0.113 inch and 0.120 inch wire diameters the average difference or bearing distance is 0.1613 and 0.1573 inches, respectively. The lowest bearing distance is exhibited by the 12 gauge nails at 0.1500 inches. The head pull-through resistance for round head nails with 3/4 inch thick nailed member can be estimated from equation 11 (Wallin and Whitenack, 1982):

Equation 11
$$HP = \frac{K(HD^2 - WD^2) \times T \times G^{2.25}}{(MC - 3)}$$

where:

G = ovendry specific gravity
MC = moisture content, may vary from 28% for green wood to 12% for dry wood
K = 1,250,000 constant
HD = head diameter, in inches
WD = wire diameter, in inches
T = thickness of the deckboard, in inches ($\leq$ 0.75 inches)
HP = head pull-through resistance

Assuming a wood specific gravity of 0.60, the estimated average head pull-through resistance for the 0.113 and 0.120 inch nails is 581 pounds and 346 pounds, respectively. This indicates that the 0.113 wire diameter nail head is nearly 235 pounds (40%) more resistant pull-through nail than the average the 0.120 inch wire diameter nail.

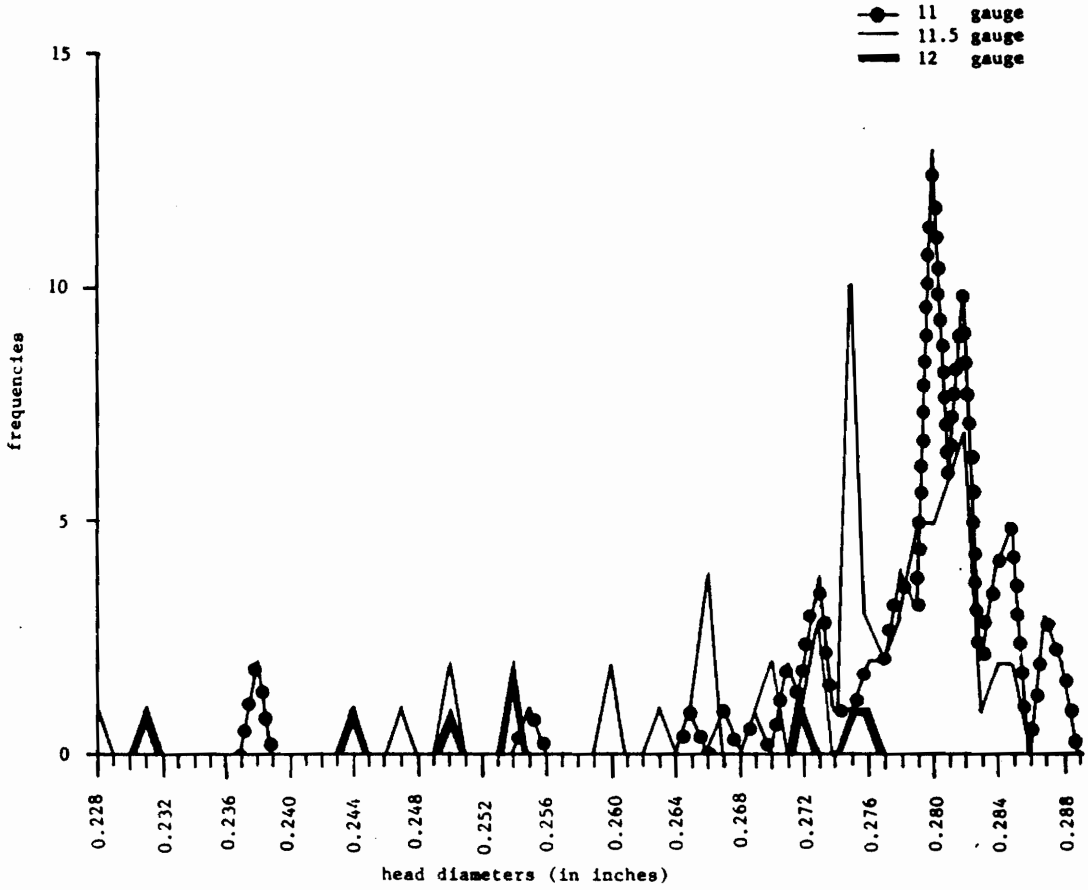

Figure 7. Frequency distribution of nail head diameter within three pallet nail gauges.

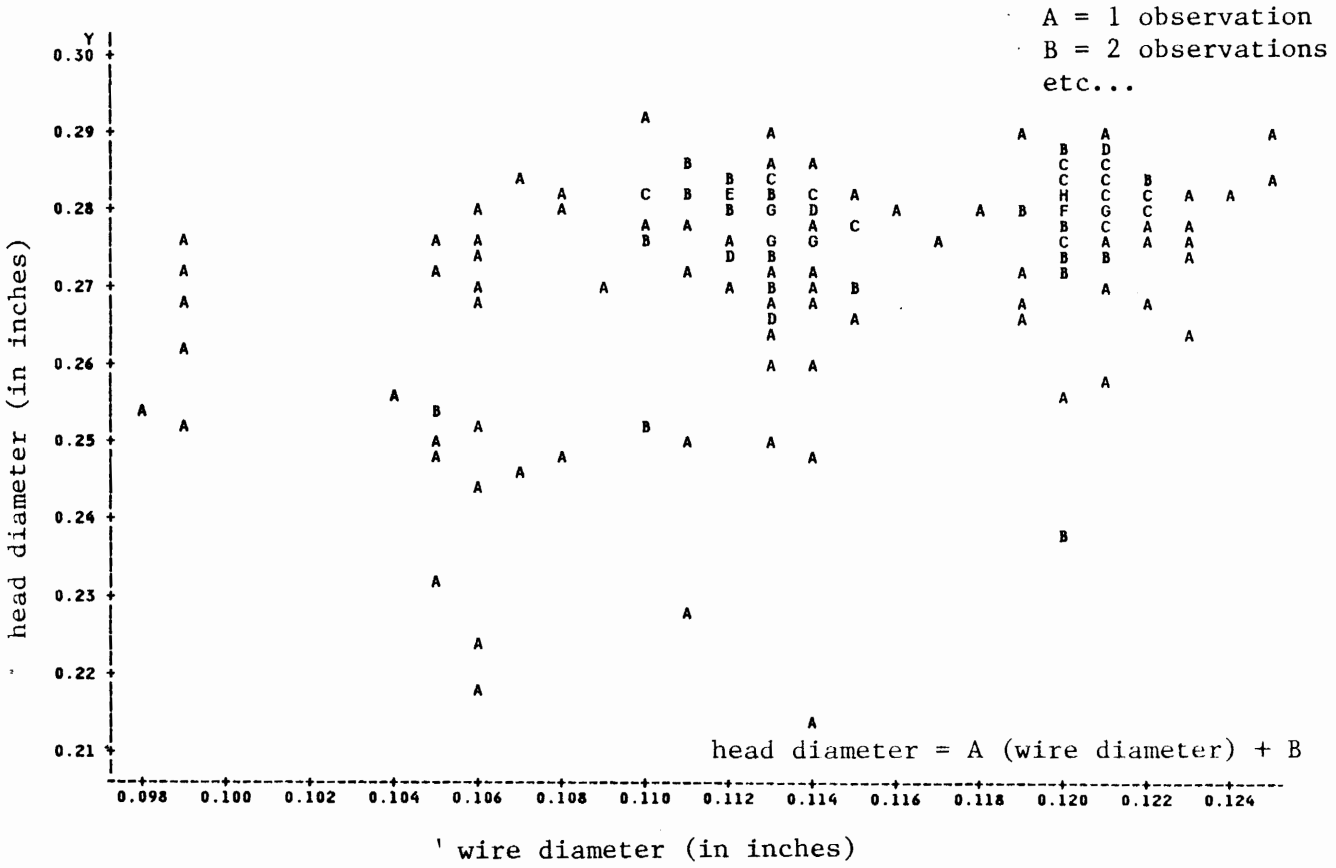

Figure 8. Regression analysis for helically threaded nails of head diameters as a function of wire diameter.

Table 29 indicates the head diameter variations for different wire diameters. The coefficient variations range from 1.8% to 9.0%. The diameter of nail heads within and between wire diameters are the most variable of the nail characteristics and result in a 44% difference in head pull-through resistance. Therefore in a properly designed joint, the nail head characteristic should not be ingored.

5.4.4. Thread Angle and Number of Flutes

According to Wallin (1983), the lower the thread angle measured with respect to the perpendicular of the fastener axis for helically threaded nails, the greater will be the widthdrawal resistance. Figure 9 is the distribution of thread angle as a function of fastener gauges. These distributions appear bimodal within the same range. The 11 gauge modes are 62° and 68° within a range of 57° to 77° , and the 11.5 gauge modes are 62° and 70° within a range of 58° to 80°. This represents a significant variatin in estimated withdrawal resistance. If all other characteristics are the same in a fastener according to equation 8, then this represents a potential 110% difference in estimated withdrawal resistance assuming thread length is 1.5 inches, average thread-crest diameter is 0.135 inches and wire diameter is 0.112 inches. range of 58° to 80°. The mean thread angle of 67° is the same for all gauges studied (Table 30). The variability within gauge and wire diameter is relatively small. Although there are two quality levels being produced, the variation is not due to the variation in wire diameter. Table 28 contains the percentage of measurements over and under the NWPCA thread angle limits for fasteners. The thread angles of a significant number of fasteners studied exceeded the NWPCA thread angle acceptance limits of 60° - 68°. Figure 10 contains the frequency of number of flutes. The most common is 4.

Table 29. **Variations in head diameter and bearin distance for each wire diameter for helically threaded pallet nails.**

Gauge	Wire Dia. (inches)	n	Min. (in)	Mean (in)	Max. (in)	s (in)	COV. (%)	Bearing Distance (in)
12.5	0.099	8	0.231	0.264	0.276	0.012	4.5	0.1662
12	0.105	7	0.231	0.255	0.275	0.015	5.9	0.1499
	0.106	9	0.217	0.256	0.280	0.023	9.0	0.1500
11.5	0.110	10	0.251	0.273	0.291	0.014	5.1	0.1639
	0.111	8	0.228	0.271	0.285	0.021	7.7	0.1593
	0.112	15	0.269	0.278	0.284	0.005	1.8	0.1661
	0.113	34	0.250	0.274	0.290	0.008	2.9	0.1613
	0.114	24	0.213	0.272	0.286	0.015	5.5	0.1580
11	0.119	6	0.265	0.275	0.289	0.009	3.3	0.1567
	0.120	33	0.238	0.277	0.297	0.012	4.3	0.1573
	0.121	32	0.257	0.273	0.289	0.007	2.6	0.1593
	0.122	9	0.267	0.279	0.284	0.005	1.8	0.1571
	0.123	5	0.263	0.274	0.282	0.007	2.6	0.1514

n = sample size, s = standard deviation, Min. = minimum,
Max. = Maximum, COV = coefficient of variation, in = inches

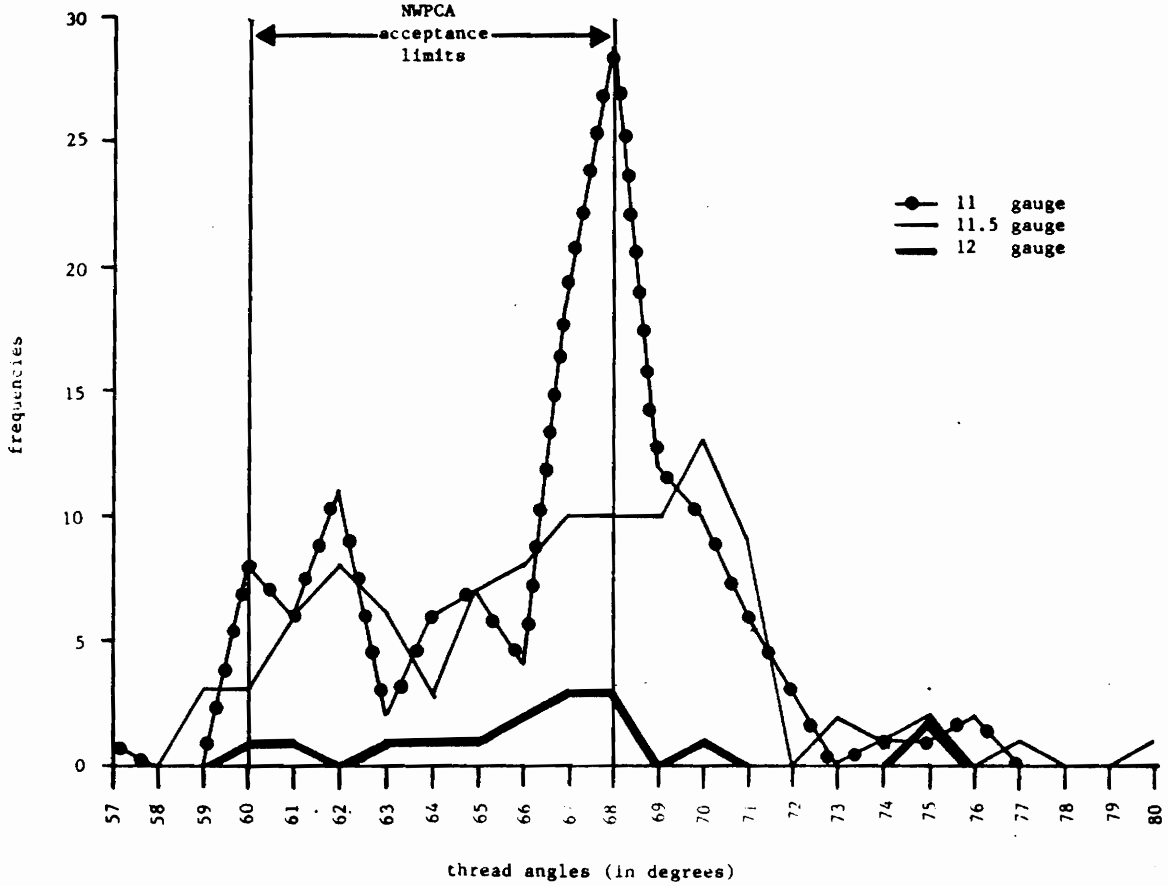

Figure 9. Frequency distribution of the thread angle of helically threaded nails within three pallet nails.

Table 30. Variations in thread angle for each wire diameter of helically threaded pallet nails.

Gauge	Wire dia. (inches)	n	Min. (deg)	Mean (deg)	Max. (deg)	s (deg)	COV. (%)
12.5	0.099	6	62	68	73	3.69	5.4
12	0.105	9	63	69	84	6.48	9.4
	0.106	9	60	66	78	6.13	9.3
11.5	0.110	14	61	67	74	4.47	6.7
	0.111	13	61	64	69	3.39	5.3
	0.112	17	61	66	73	4.03	6.1
	0.113	42	59	67	80	4.24	6.3
	0.114	29	59	67	77	6.24	9.3
11	0.119	8	57	65	69	4.02	6.2
	0.120	49	60	66	72	4.01	6.1
	0.121	49	60	67	75	3.97	5.9
	0.122	21	60	68	76	3.18	4.7

n = sample size, Min. = minimum, Max. = maximum, s = standard deviation, COV = coefficient of variation, deg = degrees

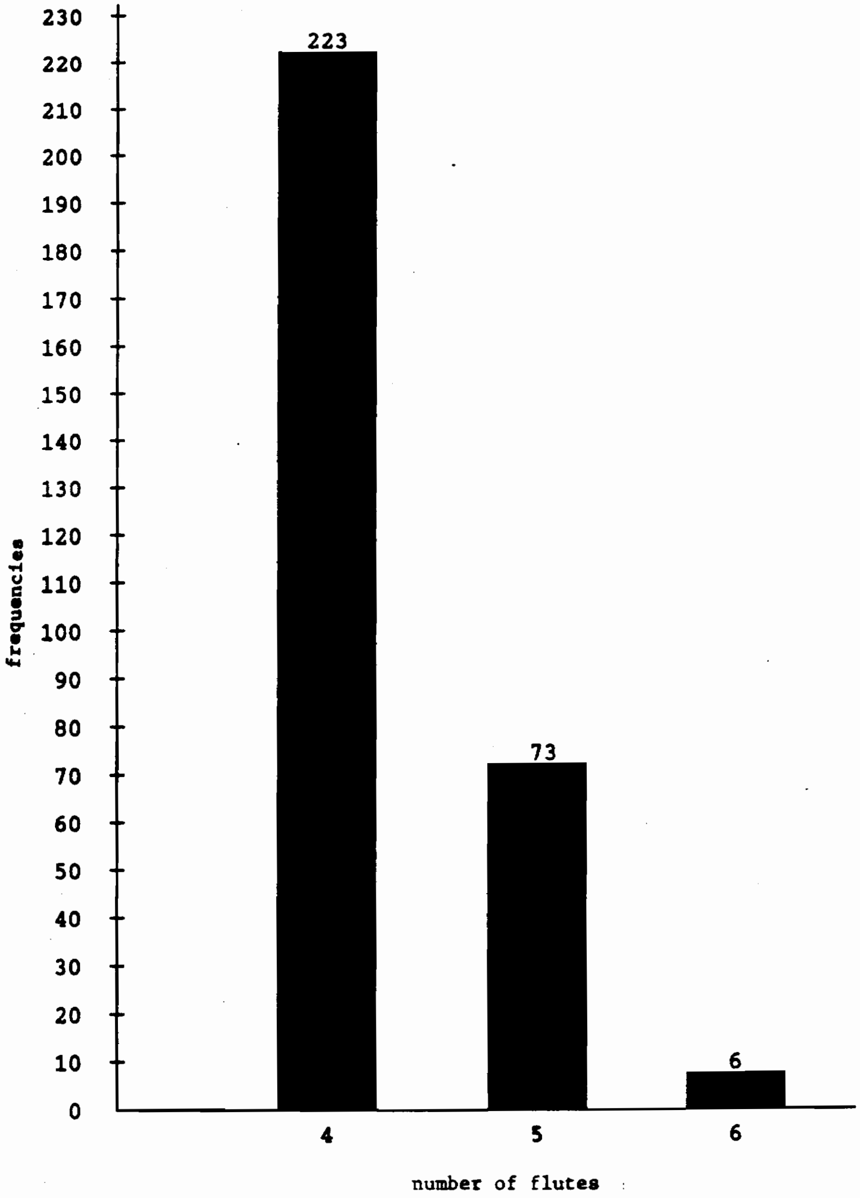

Figure 10. Frequency distribution of the number of flutes for helically threaded pallet nails.

5.4.5. MIBANT Angle

Figure 11 is a frequency distribution of the MIBANT angle for helically threaded nails in 3 gauges. The angles range from 9° to 83° with a distinct bimodal appearance within the 11 and 11.5 gauges. The NWPCA classifies pallet fasteners: 8° to 28° = hardened, 29° to 46° = stiff-stock, 47° and greater = soft. The term "hardened" in this case does not refer to the manufacturing process but merely a class name. Notice that no 12 gauge fasteners meet the "hardened" criterion. The majority of the fasteners fall within the stiff-stock and hardened classes. The "soft" range represents mostly 12 gauge nails. The correlation between wire diameter and MIBANT angle is obvious in Table 25. Notice as the gauge increases so does the MIBANT angle. As expected, the within gauge variation is quite high: 11 gauge = 49.9%, 11.5 gauge = 31.1%, and 12 gauge = 27.1%. The variation within wire diameters in Table 31 is also very high, ranging from 10.6 to 47.7% because of the bimodal distribution. This indicates considerable differences in wire chemistry work hardening or temper hardening during manufacture. Such variation is intentional since within lot texture variation is the 2 to 4% COV range. It is further obvious that nail vendors are manufacturing to the NWPCA classification of stiff-stock and hardened. Table 32 contains the MIBANT angle variation for different vendors by gauge, stiff-stock or hardened, length, and wire chemistry. The variation for the stiffstock helical nails were relatively high ranging from 2.264 to 4.77 as compared to the hardened nails ranging from 1.602 to 1.976. Since the bending resistance of a nail influences joint performance, when purchasing nails it is important to specify wire chemistry or preferably MIBANT angle in addition to gauge or wire diameter.

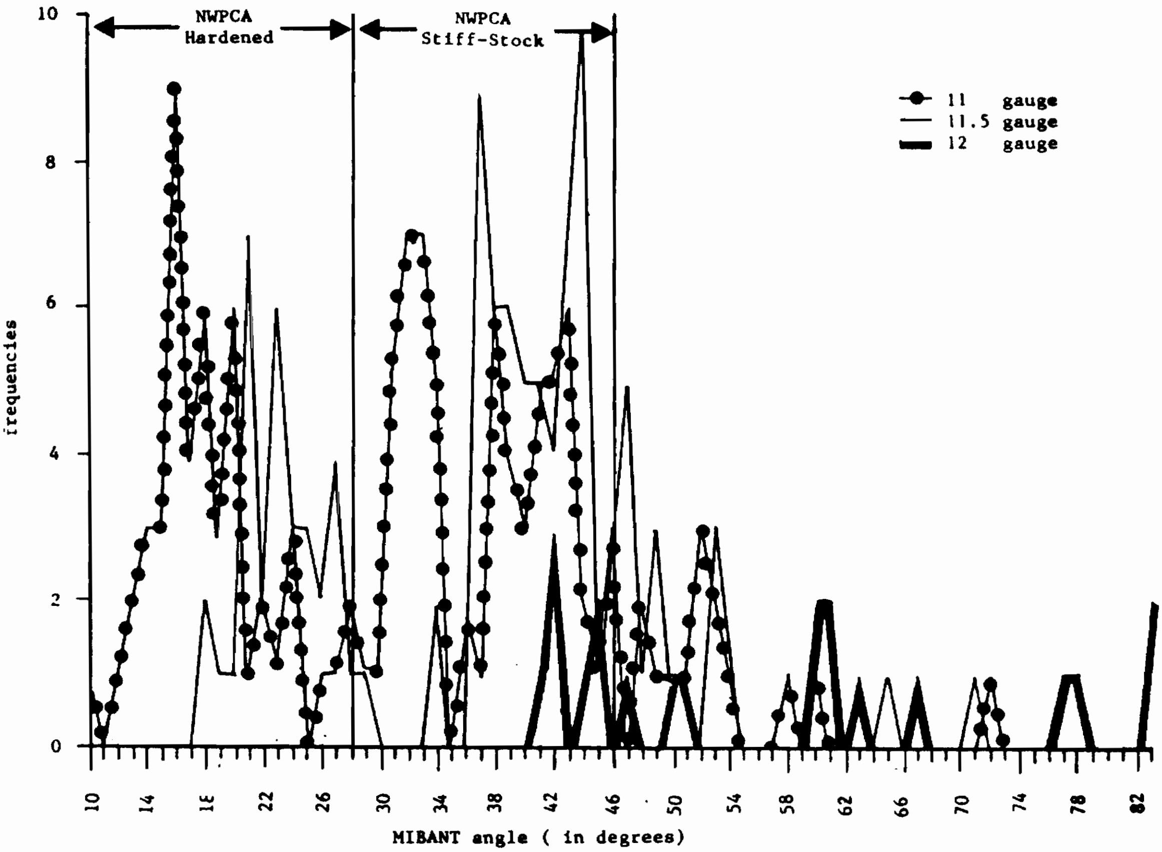

Figure 11. Frequency distribution of the average MIBANT angle of helically threaded pallet nails for three nail gauges.

Table 31. Variation in average MIBANT angle for each wire diameter for helically threaded pallet nails.

Gauge	Wire Dia. (inches)	n	Min. (deg)	Mean (deg)	Max. (deg)	s (deg)	COV. (%)
12.5	0.099	9	58	70	79	7.42	10.6
12	0.105	9	45	60	83	13.98	23.3
	0.106	8	42	52	78	12.62	24.3
11.5	0.110	15	20	34	46	11.45	33.7
	0.111	14	18	33	71	15.71	47.7
	0.112	18	20	35	65	12.30	35.1
	0.113	42	18	38	60	10.24	26.9
	0.114	29	19	40	54	8.07	20.2
11	0.119	8	16	30	46	11.87	39.6
	0.120	48	10	31	72	14.21	45.8
	0.121	53	14	32	60	11.89	37.1
	0.122	22	13	35	53	10.83	30.9

n = sample size, Min. = minimum, Max. = maximum, s = standard deviation, COV = coefficient of variation, deg = degrees

Table 32. Variation of average MIBANT angles within vendors by gauges, nail classification, and length.

Gauge	nail class.	Length (in)	n	s (deg)	mean (deg)	COV %
11	stiffstock	2.25	20	4.770	34.55	13.8
11	hardened	2.25	8	1.602	18.12	8.8
11	hardened	2.50	6	1.826	19.17	9.5
11.5	stiffstock	2.25	13	3.358	41.00	8.2
11.5	stiffstock	2.00	13	2.264	40.00	5.7
11.5	hardened	2.25	15	1.976	21.87	9.0
11.5	soft	2.25	7	1.958	51.86	3.8

n = sample size, s = standard deviation, COV = coefficient of variation

5.4.6. Nail Length

Figure 12 is a distribution of the actual length of fastener. The most frequent length is 2.25 inches, implying that this is the most popular pallet nail length produced. Conspicuous peaks appear at 1.75, 2.00, 2.50 and 3.00 indicating other less frequently used lengths. We define length classes according to NWPCA as shown on Figure 12. There are a significant number of nails being manufactured that do not conform to these classes. Since length and subsequently depth of penetration into the nailing affect the performance, one must take care when ordering fasteners by length.

5.4.7. Thread Length

Ideally you want the entire portion of the nail shank in the nailing member to be threaded. That portion of the shank in the nailed member can be plain shank. Apparently this is often not the case in pallet assembly. Table 33 contains the variation of thread length for each length class. Notice in the most common 2.25 inch length 1/2 to 1 inch of the nail is plain. According to NWPCA criteria, 2 inch long nails are suitable for nailing up to a depth of 3/4 inches in a nailed member, therefore as much as 1/2 of the shank in the nailing member is nonfunctional in certain applications.

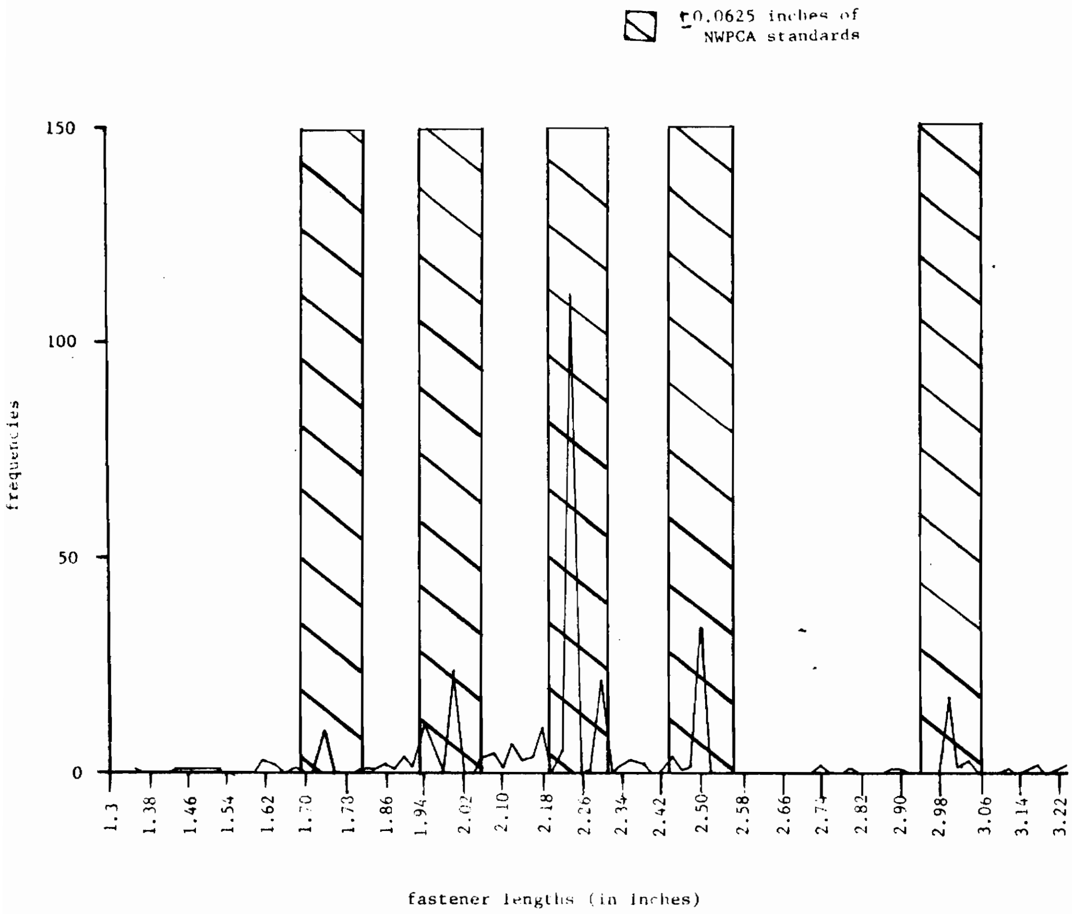

Figure 12. Distribution of fastener lengths of helically threaded pallet nails.

Table 33. Variations of thread length for helically threaded pallet nails.

Lengths (in)	n	Min. (in)	Mean (in)	Max. (in)	s (in)	COV (%)
1.625	7	0.875	1.005	1.190	0.1164	11.6
1.750	9	0.850	1.118	1.250	0.1154	10.3
2.000	54	0.875	1.315	1.470	0.1750	13.3
2.250	129	1.000	1.482	1.750	0.1602	10.8
2.500	48	1.340	1.770	2.375	0.2797	15.8
3.000	22	1.313	1.991	2.380	0.2635	13.2

n = sample size, Min. = minimum, Max. = maximum,
s = standard deviation, COV=coefficient of variation
in = inches

5.5 Conclusions

Pallet nails are manufactured in a wide variety of shapes and sizes today. The quality of the fasteners directly affects the durability of the pallet. Standards have been set to insure nail and pallet quality.

1. The FF-N-105B standard tolerances of ±0.004 inches for nail length overlap between the 10 and 10.5, 11 and 11.5, and the 12 and 12.5 gauges. Therefore, it is difficult to distinguish between the gauges using this standard. The NWPCA standard of ±0.002 inches of variation in wire diameter is a better classification for pallet nails. There are a significant number of nails manufactured outside the NWPCA gauge class limits. As a result, there are fasteners that are being manufactured and classified within a gauge which in fact do not meet the NWPCA standards.

2. Wire Diameter Within Gauge: The most popular gauges used by the pallet industry in the U.S. are 11 and 11.5. The variation within gauges is small within lot and vendor, however, the variation between lot and vendor is quite large for the wire diameters. Therefore, when purchasing fasteners by gauges from different vendors, high levels of variation in wire diameter can be expected 0.8% to 21%.

3. Average Thread-Crest Diameter: The variations were similar and small for the hardened and stiffstock nail classification (1.2% to 2.7%) within the different suppliers. Therefore, when purchasing fasteners by thread-crest diameter, the fasteners being produced do not vary significantly within lot and vendor.

4. Head Diameter: Head diameter within and between the gauges are the most variable fastener charateristic. Range in bearing distance observed was 0.0163 inches, representing a 15% difference in an estimated head pull-through resistance.

5. Thread Angle: The distribution of thread angles is bimodal at 62° and 68°. The average angle is 67° for all gauges. The range in thread angle is 57°to 84°, representing an estimated 65% difference in withdrawal resistance.

6. MIBANT Angle: The variation in MIBANT angle is high within and between gauges. When the MIBANT angle is partitioned according to producer, gauge, length, and MIBANT classifications, the variation in MIBANT angle for hardened fasteners is 8.8% to 9.5%. Compared to the stiffstock fasteners 5.7% to 13.8%.

7. Length: The most popular length produced for the pallet industry is the 2.25 inches. There are a number of fasteners that are being produced that do not fall within the NWPCA length classes.

8. Thread Length: The range of the thread length for a 2.25 inch nail is 1.00 to 1.75 inches.

9. Considering all fasteners affecting the quality of helically threaded pallet nails, the variation exhibited by the fastener studied resulted in a total variation of an estimated withdrawal resistance of 60% and shear resistance of 82% and head pull-througth resistance of 15%.

6.0 S.P.C. Handbook for the Pallet Industry

6.1 *Introduction*

There are 3 words that are fast becoming a part of all manufacturers' vocabulary. They are 1) quality control (QC), 2) quality assurance (QA), and 3) statistical process control (SPC). QC is the "regulatory process through which we measure actual quality performance, compare it with standards, and act on the differences." QA is the "activity of providing, to all concerned, the evidence to establish confidence that the quality function is still being performed adequately" (Juran, 1979). However, SPC is a QC/QA method, which "... is the use of statistical methods, such as control charts, to analyze a process or its output over time, so as to take appropriate actions to achieve and maintain a state of stability/predictability and improve the capacity of the product" (Ford, 1984). In other words, QC is the total program where material is evaluated and a decision is made about the material. QA is the evidence that the program works, such as evaluating machine performance based on data collected.

SPC not only assures a product quality, but through the monitoring of equipment functions can result in improving the overall efficiency of an operation.

QC/QA/SPC concepts were originated by Dr. W.A. Shewhart and his colleagues at the Bell Labs in the 1920's. However, it was the Japanese who made it successful. Before 1950, Japanese consumer goods had the reputation of being cheap and shoddy. By 1954, Japan had captured markets all over the world. The five forces behind the success were 1) the implementation of statistics, 2) the education of management, engineers and production workers, 3) teaching of QC/QA techniques, 4) conferences with top management, and 5) the use of QC-circles. The QC-circles was comprised of small groups of workers discussing ways to eliminate special causes of variability, and improve the system through changes in tools, changes in design and scheduling (Deming, 1982).

Today, the popularity of QC/QA/SPC methods is partly due to the pressure customers are putting on their vendors-suppliers to provide evidence of product quality and is partly due to the vendors interest in reducing production costs. Many companies today are instituting vendor ratings. These ratings help them determine which vendors to purchase from and the relative quality of product they can expect when purchases are made. These ratings are based on certain aspects of the management and production technique. Many companies today will require all vendors and suppliers to have a SPC program in place. SPC can be used as an integral part of the supplier's process to provide continuous evidence of product quality. Customers of the pallet and container industry are requesting they implement SPC programs. At present the majority of the wood pallet industry has not implemented such programs. The pallet manufacturer can also benefit from an SPC program. Pallet companies can reduce the cost of rework, improve yields, reduce labor costs, improve product quality and reduce maintenance costs (Brown, 1979). Further SPC programs include the use of the Pallet Design System (PDS). PDS is a structural design procedure for the wood pallets. The system accurately predicts the performance levels of wood pallets. It is sensitive to very small changes in quality of pallet construction. Once an appropriate design is selected and a sale agreement is reached, the manufacturer must produce the pallet design according to the required specifications. Failure to do so can result in great risk to life, higher cost from damage to goods being shipped, slower handling rates, increased rework costs, and a violation of the sale agreement. It is, therefore, important for the manufacturer to know whether his process is in control or not... ie., the pallet is manufactured according to quality required by the customer.

To achieve a successful QC/QA/SPC program, the entire plant must support it. Management commitment and involvement is the key to any QC program. Without it, the program will fail. Management needs to get actively involved and also set standards for measuring success. The employees need to understand, through education, what management is trying to accomplish with the use of a QC/QA/SPC program. Communication between all personnel will help indicate when problems occur (Brown, 1982).

This handbook is designed to assist the Wood Pallet and Container manufacturers in implementing an SPC program.

6.2 A TYPICAL Pallet Mill

A TYPICAL pallet manufacturing process is described and referred to throughout the handbook. While it is felt this example is representative of the pallet industry, it may not accurately describe all operations. The example is used only to assist in describing the SPC procedure as it applies to the pallet mill. Figure 13 depicts the step by step procedure for the manufacturing of pallets.

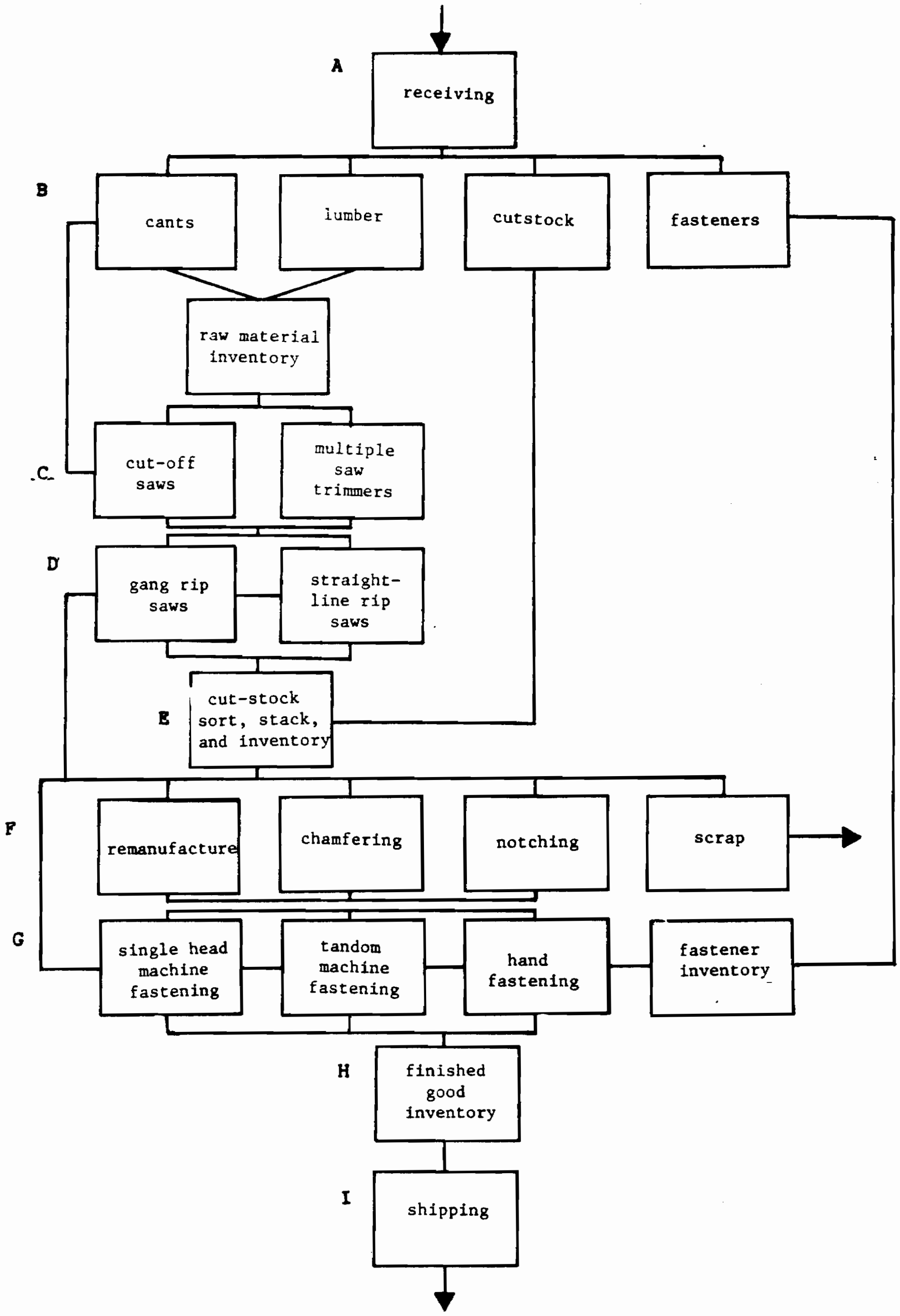

Figure 13. Flow chart for a TYPICAL pallet mill.

Typically, raw material arrives (A) and is inventoried (B). However, when needed, the forklift operator may transfer a delivery directly to the infeed conveyor. Cants or lumber are cut to length (C) and then ripped (D). Rejected material is scrapped or remanufactured (F). Accepted material is either chamfered (in some deckboards), notched (in some stringers), or unaltered (F), depending on the requirement of the pallet at that time.

As needed, cut-stock is transferred to an assembly area. Pallets are typically assembled manually using hand held pneumatic tools, and/or machine assembled with single head or tandem type nailers (G). Assembled pallets are stored in finished good inventory (H) and then shipped (I). According to McCurdy et al.,(1985) the typical pallet assembly operation has 19 employees. Of these, 10 to 15 are direct labor.

In pallet manufacturing, the SPC program should provide continuous supplementary assessment of raw material, cut-stock, fasteners, and workmanship quality. This is accomplished by monitoring and measuring certain quality characteristics at each stage of the operation A through I.

The SPC program is based on two procedures applied when appropriate: 1) acceptance sampling and 2) control charts.

Acceptance Sampling

When a company receives a shipment, a decision can be made to accept or reject it based on the conforming standards set by the buyer. Inspection can also occur at various stages in manufacturing such as 1) incoming material and parts, 2) process inspection at various points in the manufacturing operation, 3) final inspection by a manufacturer of his own product, or 4) final inspection of the finished product by one or more purchasers. However, the purpose of acceptance sampling is to determine a course of action, not to estimate the lot quality or to control quality. Acceptance sampling prescribes a procedure that will give a specified risk of accepting lots of a given quality. In other words, acceptance sampling yields quality assurance, and an acceptance sampling plan merely accepts or rejects lots. There are two types of acceptance sampling employed in statistical quality control: attributes and variables. These methods are dependent on how the characteristics under evaluation are measured. The attributes can be separated into two groups: good or bad. The variables can be evaluated based on a numeric or a scale of measure such as 6.000 or 3.56.

All manufacturing processes are subject to performance variations. Therefore, in any production process, some variation in quality is unavoidable. Shewhart (Duncan, 1986) defined two types of variations: random and assignable. Certain variations in quality are due to causes over which we have some degree of control such as the use of a new unskilled worker. This type of variation is called assignable. Random variation is the normal variation that occurs solely due to chance.

Control charts are used to separate the assignable causes from the random causes of quality variation using statistic procedures. Two types of charts are employed. The first chart is called an X-bar chart, which involves the plotting of sample averages. The second chart is called a R chart, which is based on sample ranges. Control limits for the X-bar and R charts are the boundaries that separate the assignable causes from the random causes. When a point occurs outside of these limits then an assignable cause is affecting the process. Steps are then taken to reduce or eliminate this cause such as change saw blades. An example of how to use control charts can be found in Appendix C.

It is important to remember that control charts are used to monitor a process. Every chart is unique to each operation by showing when that process is out of control. For example, a control chart for machine X cannot be used for machine Y. In a pallet mill the only process to which control charts are applicable is the sizing of cut-stock produced. The quality of fasteners and raw material usually received from suppliers are monitored using acceptance sampling techniques. Acceptance sampling is also applied to the workmanship reflected in the finished product. Table 34 is a summary of the characteristics to be measured and the SPC technique to be used.

6.3 Monitoring Raw Material Quality

Raw material quality impacts on production costs by affecting yields and handling rates. Monitoring raw material quality will also assist the pallet manufacturers in identifying quality suppliers. Quality will be based on measures of thickness, width, length, grade, moisture content, and species. The SPC program may include other measures such as load configuration, odor, etc.

1. Sample Size - Size of sample, randomly selected for raw material, depends on:

    a. Standard deviation for each type of measure.
    b. A desired target mean such as a standard green or dry lumber from the National Hardwood Lumber Association (NHLA) (1986) grading rules.
    c. Specification limits such as an acceptance range for lumber by NWPCA.
    d. Acceptance level in which the lot is accepted 95% of the time.
    e. Rejection level in which the material is rejected per lot 10% of the time.
    f. The calculation for sample size as found in Appendix A.

    However from a study (Gales, 1988), the standard deviation in hardwood cants and lumber was evaluated based on a number of saw mills. Sample sizes have been calculated using the standard deviation of this data, the target as the desired means, and specification limits set at ±0.25 inches. A 95% acceptance lèvel and a 10% rejection level is the recommended levels to calculate sample sizes. The sample sizes are as follows:

Table 34. The summary of characteristics to be measured in the pallet and container industry for an SPC program.

Raw Material measure:	a) thickness b) width c) length	acc. sampling plan by variables	sample mean per load after unloading
	d) grade e) species f) moisture c.	acc. sampling plan by attributes	MIL. Std. 105D per load after unloading
Cut Stock measure:	a) thickness b) width c) length	control charts	X-bar and R charts 5/hour after cut
	d) grade e) species f) moisture c.	acc. sampling plan by attributes	MIL. Std. 105D per load after unloading
Fasteners measure:	a) wire diameter b) thread-crest diameter c) head diameter d) thread angle e) nail length f) thread length	acc. sampling plan by variables	sample mean per box after received
	g) MIBANT angle	NWPCA criteria	12 per box after received
Workmanship measure:	a) "out of squareness" b) uniformity of deckboard spacing	acc. sampling plan by variables	sample mean per shippment after assembly
	c) no. nail splits d) no. protruding nail heads e) no. protruding nail points f) no. missing nails	acc. sampling plan by attributes	MIL. Std. 105D per shippment after assembly

Table 35. Raw material sample size data based on the standard deviation by Gales (1988), 95% acceptance and 10% rejection levels.

thickness (in)	s (in)	sample size	width (in)	s (in)	sample size
2"	0.248	11	4"	0.243	10
4"	0.337	20	6"	0.385	25
6"	0.244	11	8"	0.198	7

s=total board standard deviation
at ±0.25"

2. Sample Frequency - The raw material is to be evaluated for every truck load or lot that enters the plant.

3. Location of Sampling - Since a random sample is taken based on the entire load, the material has to be sampled after unloading.

4. Tools - To evaluate the characteristics of the raw material a tape measure and data sheets are needed.

5. Data Collection:

   a. To measure cants, a tape measure is used and read to the nearest 1/16-inch. If lumber is being measured then a caliper is recommended and read to the nearest 0.01-inch.
   b. Measurements are taken at 3 places along the length of the boards and cants in the width and thickness dimensions and two locations along the length (see Figure 14).
   c. Lumber grading is left to the sales agreement between the sawmill and the pallet company.
   d. Moisture content is measured using electric resistance meter where appropriate.
   e. Measurements are recorded on a data sheet such as data sheet A of Figure 15.

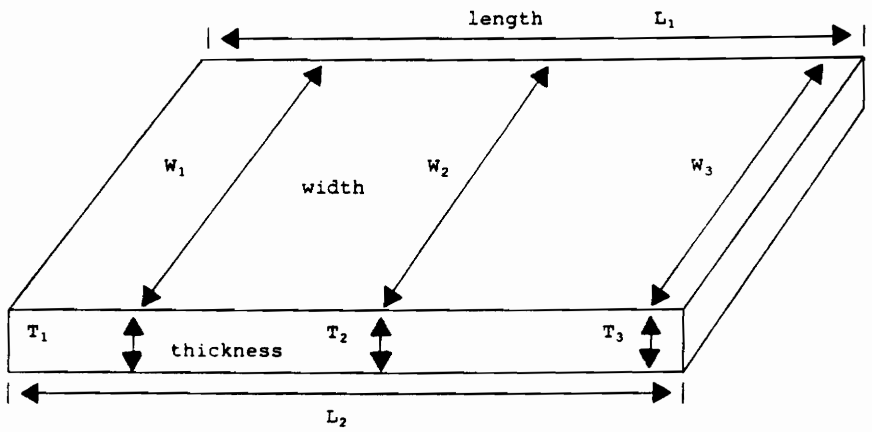

Figure 14. Location of measurement for monitoring lumber size variation.

SHEET A **DATA FOR RAW MATERIAL**

SOURCE: DESCRIPTION:

DATE: TIME: INSPECTOR:

SAMPLE SIZE: MANUFACTURER:

Sample	WIDTH			THICKNESS			LENGTH				PDS
number	W1	W2	W3	T1	T2	T3	L1	L2	grade	M.C.	species
1											
2											
3											
4											
5											
6											
7											
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Figure 15. Data Sheet A - An example data sheet to record raw material quality data.

6.4 Monitoring Cut-Stock Quality

Cut-stock is the pallet part ready for assembly and can be manufactured on site or off. The cut-stock processed on site is evaluated statistically by the use of control charts as follows. Purchased cut-stock will be treated as raw material.

1. Sample Size - Before control charts can be implemented, an initial sample size of 25 is taken directly after the material is cut to set the control limits. When working a control chart a subgroup sample size of 5 shall be taken. A subgroup is the material sampled in sequential order when manufacturing like materials, such as widths of deckboards.

2. Sample Frequency - Samples are taken every hour or when ever a process changes, such as a blade replacement, setworks adjustment, operator change, etc.

3. Location of Sampling - Samples are to be measured after each machine in the ---- cut "C" and ripping operation "D" in Figure 13.

4. Data Collection:

   a. Three measurements are taken of the width and thickness to the nearest 0.01″ and two measurements of the length to the nearest 1/16″ as step 2 of raw material (see Figure 14).
   b. Data is recorded on data sheets, such as sheet B in Figure 16.
   c. Calculate and plot control limits as shown in Appendix A. Examples are displayed in Figures 17 and 18. The charts are now ready to be used. For every constant time interval (1 hour), a subgroup size of 5 is measured and recorded. The mean and ranges are calculated for each subgroup and drawn on the X-bar and R chart, respectively. The data below is plotted on Figures 17 and 18 as an example.

SHEET B An example data sheet to record CUTSTOCK DATA

SOURCE:
DESCRIPTION:
DATE:
TIME:
INSPECTOR:
SAMPLE SIZE/FREQUENCY:
SHIFT:

Sample number	WIDTHS					THICKNESS					LENGTH				grade	M.C.	PDS species
	W1	W2	W3	mean	range	T1	T2	T3	mean	range	L1	L2	mean	range			
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	
			TOTAL					TOTAL				TOTAL					
			AVERAGE					AVERAGE				AVERAGE					

Figure 16. Data Sheet B - An example data sheet to record cut-stock quality data.

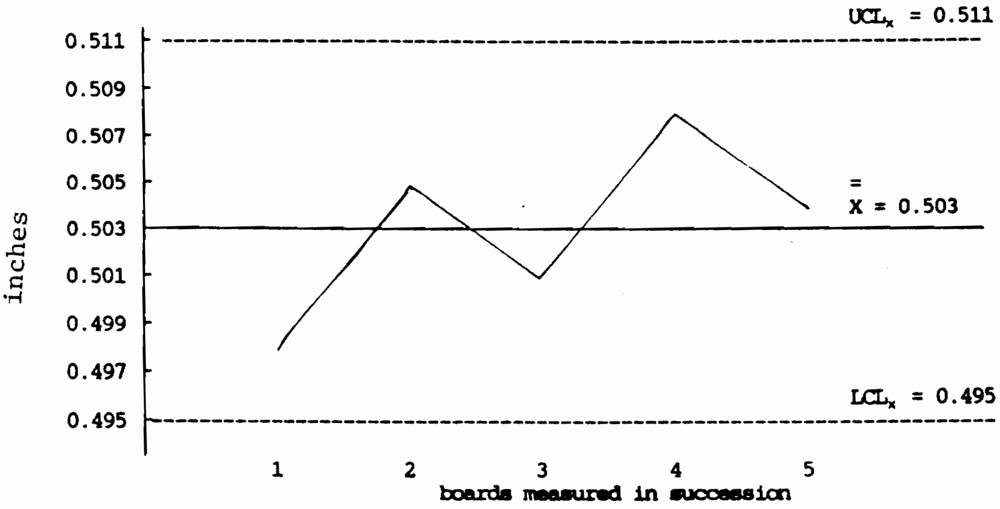


Figure 17. A typical X-bar control chart for the pallet cut-stock.

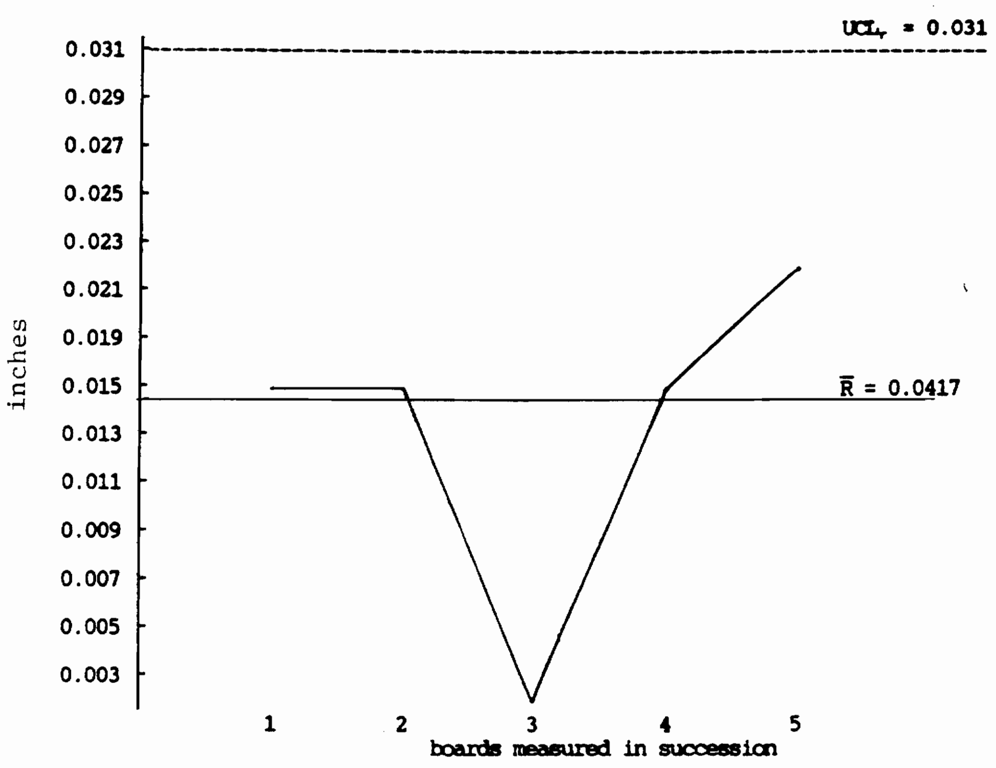


Figure 18. A typical R control chart for the pallet cut-stock.

Table 36. An example of cut-stock thickness data collected for the use of control charts.

measurement (inches)						
n	X1	X2	X3	X4	mean	range
1	0.498	0.500	0.505	0.490	0.498	0.015
2	0.500	0.515	0.505	0.510	0.505	0.015
3	0.500	0.502	0.502	0.502	0.501	0.002
4	0.510	0.515	0.500	0.508	0.508	0.015
5	0.500	0.515	0.493	0.510	0.504	0.022
			X=	0.503		

n = sample size, X1, X2, X3, X4 = measurements along a sample.

If only between board variation is of interest, one measurement for each board sample is needed. The average and range between boards is determined for the 5 boards and is plotted on a graph where the limits were set for between board variation data. If within board variation is of interest, three measurements for each 5 boards is needed. In other words, a separate control limits need to be calculated for within and between boards. The within board variations are a cause of the movement of the saw or saw setworks in relation to the board. The between board variation is a cause of a change in the process, such as the change of the blade, or a change in the shift of personnel.

d. Cut-stock samples may be graded according to any of the rules found in Appendix E. Note that acceptance sampling by attribute will be used to monitor grade of cut-stock.

e. Moisture content will be measured using the resistance meter.

As control charts are implemented over time, the control limits will become narrower because the sawing variations have decreased with continual adjustments of the control limits. This results in improved performance and lumber yields. If something changes the process then the control chart limits has to be recalculated with the initial 25 measurements.

Interpretation of Control Charts

When any point falls outside the limits for the X-bar, it is evidence that a general change affecting all pieces has occurred between samples. This could be due to changes in materials, processes, or other factors which might account for the point out of control. And if any point falls outside the limits of a R-chart, then there is evidence that the uniformity of the process has changed. This could mean a change in either man, machine, or material factors (Juran, 1979). These changes are due to what is known as assignable causes. However, when no points fall out of the limits, we cannot say that there are no assignable causes of variation present, but rather that the process is in control. In the example, Figure 17 and 18, no points fall outside of the control limits. Therefore, the process is in control, and product sizing is satisfactory.

It is also important to look at the randomness of the data, which indicates if the process is biased or if there is some factor that is preventing the charts from performing and giving information about the process. Controlled processing should exhibit no bias. This determination can be made by counting the points that run in succession of the same class on the control charts. A point above the average may be considered belonging to one class and a point below the average belonging to the other class (not including the points exactly on the average). This is considered as the runs above the average and the runs below the average. There are two key characteristics to look for to determine the randomness of the data. 1) to count the total number of runs of any given class. 2) to note the length of the longest run of a given type. Tables 37 and 38 give various probability points of randomness as they appear in an ordered series. Table 39 give the probabilities purely random series. In using these Tables 1) it is important to note the total number of runs in each class of elements, 2) look at the total number of points above the average and the total number below the average and assign the smallest of these totals to the value "r" and the largest to the value "s" (Duncan, 1986 and Juran, 1979). For example to check the randomness of the data, it is important to look at the runs. On the control chart in Figure 19 the results are:

Above the line the number of runs is:

runs of 1 = 3
runs of 2 = 2
runs of 3 = 1
runs of 4 = 1
----
total runs above = 7

Below the line the number of runs is:

runs of 1 = 4
runs of 2 = 3
----
total runs below = 7

Runs above + Runs below = total runs = 7 + 7 = 14. The total points above the mean is 14 and total points below the mean is 10. Therefore, r = 10 and s = 14. From Tables 37 and 38 the values of 6 and 8 are from the corresponding r and s values. Since the total runs of 14 is larger than 6 or 8 of the r and s, then it is assumed to be random. If it was concluded that it is not random, then there is something else which has a direct affect on the process that needs to be corrected before the control charts are further implemented.

It is important to remember that control charts are used to monitor a process. Every chart is unique to each operation by showing when that process is out of control. For example, A control chart for mill X cannot be used for mill Y. Therefore, in a pallet mill the only process the manufacturer can directly control is the lumber sizing or cut-stock produced. The fasteners and raw material are usually received from suppliers. In this case, the material can be tested by what is known as acceptance sampling by variables.

Moisture content, species and grades can be tested according to the procedures in Appendix B of acceptance sampling by attributes. The moisture content is measured with a resistant meter. The species is recorded according to Pallet Design System (PDS) species codes lo-

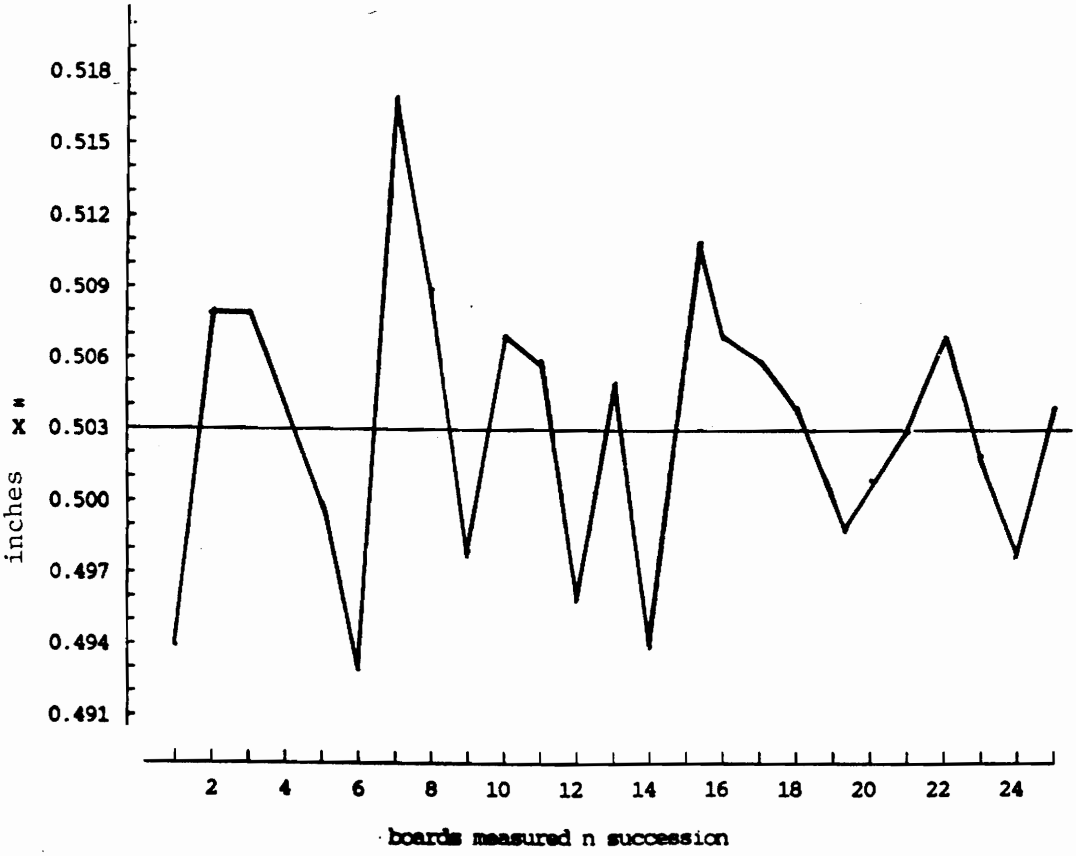


Figure 19. A X-bar chart showing for a 1/2 x 4 inch thick board with the initial 26 measurements for cut-stock data.

Table 37. Table for testing randomness of grouping in a sequence of alternatives.

Table for Testing Randomness of Grouping in a Sequence of Alternatives (probability of an equal smaller number number of runs than that listed is P = 0.005) (Duncan, 1986)

s = cases on one side of average

r = cases on other side of average

r always taken as the smaller number of cases; s the larger

s\r	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6	2														
7	2	3													
8	3	3	3												
9	3	3	3	4											
10	3	3	4	4	5										
11	3	4	4	5	5	5									
12	3	4	4	5	5	6	6								
13	3	4	5	5	5	6	6	7							
14	4	4	5	5	6	6	7	7	7						
15	4	4	5	6	6	7	7	7	8	8					
16	4	5	5	6	6	7	7	8	8	9	9				
17	4	5	5	6	7	7	8	8	8	9	9	10			
18	4	5	6	6	7	7	8	8	9	9	10	10	11		
19	4	5	6	6	7	8	8	9	9	10	10	10	11	11	
20	4	5	6	7	7	8	8	9	9	10	10	11	11	12	12

(Freda S. Swed and C. Eisenhart, "Tables for Testing Randomness of Grouping in a Sequence of Alternatives," Annals of Mathematical Statistics 14 (1943), pp. 68-87.)

Table 38. Table for testing randomness of grouping in a sequence of alternatives.

Table for Testing Randomness of Grouping in a Sequence of Alternatives (probability of an equal smaller number number of runs than that listed is P = 0.05) (Duncan, 1986)

s = cases on one side of average
r = cases on other side of averag3

r always taken as the smaller number of cases; s the larger

s\r	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6	3														
7	4	4													
8	4	4	5												
9	4	5	5	6											
10	5	5	6	6	6										
11	5	5	6	6	7	7									
12	5	6	6	7	7	8	8								
13	5	6	6	7	8	8	9	9							
14	5	6	7	7	8	8	9	9	10						
15	6	6	7	8	8	9	9	10	10	11					
16	6	6	7	8	8	9	10	10	11	11	11				
17	6	7	7	8	9	9	10	10	11	11	12	12			
18	6	7	8	8	9	10	10	11	11	12	12	13	13		
19	6	7	8	8	9	10	10	11	12	12	13	13	14	14	
20	6	7	8	9	9	10	11	11	12	12	13	13	14	14	15

(Freda S. Swed and C. Eisenhart, "Tables for Testing Randomness of Grouping in a Sequence of Alternatives," Annals of Mathematical Statistics 14 (1943), pp. 68-87.)

Table 39. A table displaying the limiting values for the total number of runs above and below the median of a set of values.

	Probability of an Equal or Smaller Value	
r s	0.005	0.05
10	4	6
11	5	7
12	6	8
13	7	9
14	7	10
15	8	11
16	9	11
17	10	12
18	10	13
19	11	14
20	12	15
21	13	16
22	14	17
23	14	17
24	15	18
25	16	19
26	17	20
27	18	21
28	18	22
29	19	23
30	20	24
31	21	25
32	22	25
33	23	26
34	23	27
35	24	28
36	25	29
37	26	30
38	27	31
39	28	32
40	29	33
41	29	34
42	30	35
43	31	35
44	32	36
45	33	37
46	34	38
47	35	39
48	35	40
49	36	41
50	37	42
51	38	43
52	39	44
53	40	45
55	42	46
56	42	47
57	43	48
58	44	49
59	45	50
60	46	51
61	47	52
62	48	53
63	49	54
64	49	55
65	50	56
66	51	57
67	52	58
68	53	58
69	54	59
70	55	60
71	56	61
72	57	62
73	57	63
74	58	64
75	59	65
76	60	66
77	61	67
78	62	68
79	63	69
80	64	70
81	65	71
82	66	71
83	66	72
84	67	73
85	68	74
86	69	75
87	70	76
88	71	77
89	72	78
90	73	79
91	74	80
92	75	81
93	75	82
94	76	83
95	77	84
96	78	85
97	79	86
98	80	87

(Freda S. Swed and C. Eisenhart, "Tables for Testing Randomness of Grouping in a Sequence of Alternatives," Annals of Mathematical Statistics 14 (1943), pp. 68-87.)

cated in Appendix E. The cut-stock grades are recorded according to the PDS rules located in Appendix E.

6.5 *Monitoring Fastener Quality*

The quality of a pallet fastener is a function of: fastener length, thread length, wire diameter, thread crest diameter, thread angle, MIBANT angle, head diameter, crown length, number of flutes, and type or shape of the point. All nail information can be measured and recorded in data sheets like Sheet C, the Fastener Quality Analysis (FQA) form in Figure 23.

1. Sample Size - size of sample, randomly for fasteners, depends on:
    a. Standard deviation for each fastener characteristic.
    b. A desired mean or target such as a standard value from the ASME standards.
    c. Specification limits such as an acceptance range for wire diameters defined by NWPCA of ±0.002 inches; nail length of ±1/16″; MIBANT angles of 29°-46° (stiffstock), 8°-28° (hardened steel); thread angle of 60°-68°; diamond point, chisel, blunt and no longer than 5/32″.
    d. Acceptance level such as accepting the lot 95% of the time.
    e. Rejection level such as rejecting the material of the lot 10% of the time.

    However from a study (Gales, 1988), the typical standard deviation within lot of fasteners are shown in Table 40.

SOURCE: ____

Fastener Identification: ____

____

Fastener Type:

a) helical nail ____
b) annular nail ____
c) square wire ____
d) plain shank nail ____
e) round wire square ____
f) sq. wire staple ____

Fastener Description:

a) avg. length ____
b) avg. thr. dia. ____
c) avg. thr. ang. ____
d) avg. no. helix ____
e) avg. no. rings ____
f) avg. MIBANT ang. ____
g) crown length ____
h) avg. thr. length ____
i) avg. wire dia. ____
j) flutes ____
k) wire width ____
l) wire thickness ____
m) head diameter ____

Fast No.	MIBANT Angle (deg)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
AVG	
MIN	
MAX	
C.V	

Date of Receipt: ____
Date of Test: ____
Report by: ____
General Appearance: ____

____

____

Comments: ____

____

____

____

____

____

____

Figure 20. Data Sheet C - An example Fastener Quality Analysis (FQA) data form used to record fastener quality information.

Table 40. The standard deviations within vendors from Gales (1988).

	gauges	s	NWPCA limits	sample size
Average Thread-Crest Diameter (inches)	11	0.016	±0.005″	108
	11.5	0.069	±0.005″	2002
	12	0.005	±0.005″	11
Average Head Diameter (inches)	11	0.089	±1/32″	82
	11.5	0.127	±1/32″	174
	12	0.120	±1/32″	155
Average Thread Thread (Degrees)	11	1.90	±5°	2
	11.5	2.10	±5°	2
	12	2.42	±5°	3

s = standard deviation

A sample size of 12 is recommended to test the fasteners. However, Appendix A shows how to calculate a sample size.

2. Sample Frequency - the fasteners are evaluated for every lot of fasteners. A lot is a manufacturing process in which the objects being produced are all manufactured in the same frame of time.

3. Location of sampling is at the arrival of the fasteners.

4. Tools to evaluate the characteristics of a fastener a micrometer or calipers to the nearest 0.001″, MIBANT device, protractor, and data sheets are needed.

5. Data Collection:

   a. To complete the FQA, record the "source" of the fastener. The original source of the fastener can be manufacturer, the importer or the distributor. Identify the fastener according to markings on the box, bill of lading, invoice, etc.

b. The fastener type in the data sheet contains several types of fasteners commonly used in the pallet construction illustrated in Figure 21. Mark the appropriate fastener type that is being evaluated.

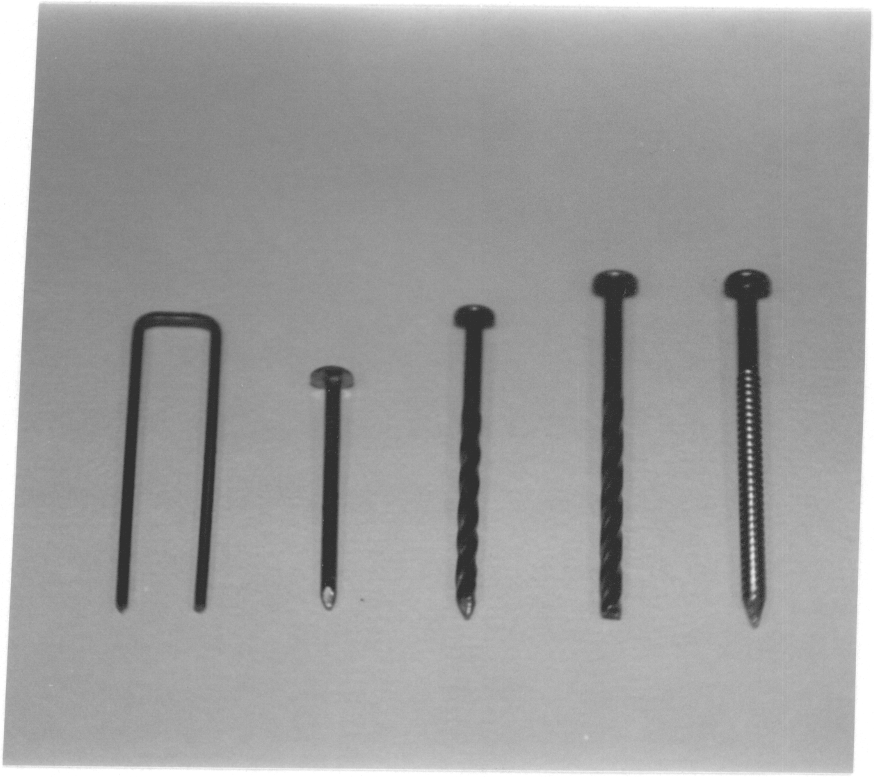
c. Fastener description is the actual measurement of several fastener characteristics. Measurements are performed with either a ruler accurate to 1/16-inch or a micrometer accurate to 0.001-inch. Record fractions as decimals to facilitate later computations using the calculator. For example, 2-1/4 should be recorded as 2.25. The following paragraphs are descriptions of how these measurements or computations should be made for each fastener characteristic.

1) Fastener Length

   - Nails: The distance from the top of the nail point to the bottom of the fillet under the nail head measured with a ruler to the nearest 1/16-inch. It is important to note that this definition differs from the proposed ASTM definition of nail length which includes the nail point as illustrated in Figure 22. Measure the length of at least 3 fasteners.
   - Staples: The distance between the top of the point to the bottom of the crown as shown in Figure 22 measured with a ruler to the nearest 1/16-inch. This definition differs from the proposed ASTM definition of staple length also illustrated in Figure 22. Measure the length in at least 3 fasteners.

2) Thread Length: The distance between the top of the point and the top of the threads (minus the length of any discontinuities) as shown in Figure 22, measured with a ruler to the nearest 1/16-inch. There is usually little thread length variation within a sample. Therefore, measurement of 3 fasteners is usually sufficient to obtain reliable average value. This definition differs from the proposed ASTM definition of thread length which is also illustrated in Figure 22.

3) Wire Diameter



left to right: staple, plain-shank nail, twisted square-wire nail, helically threaded nail, and annularly threaded nail.

Figure 21. A photograph showing the different fastener types used in pallet construction.

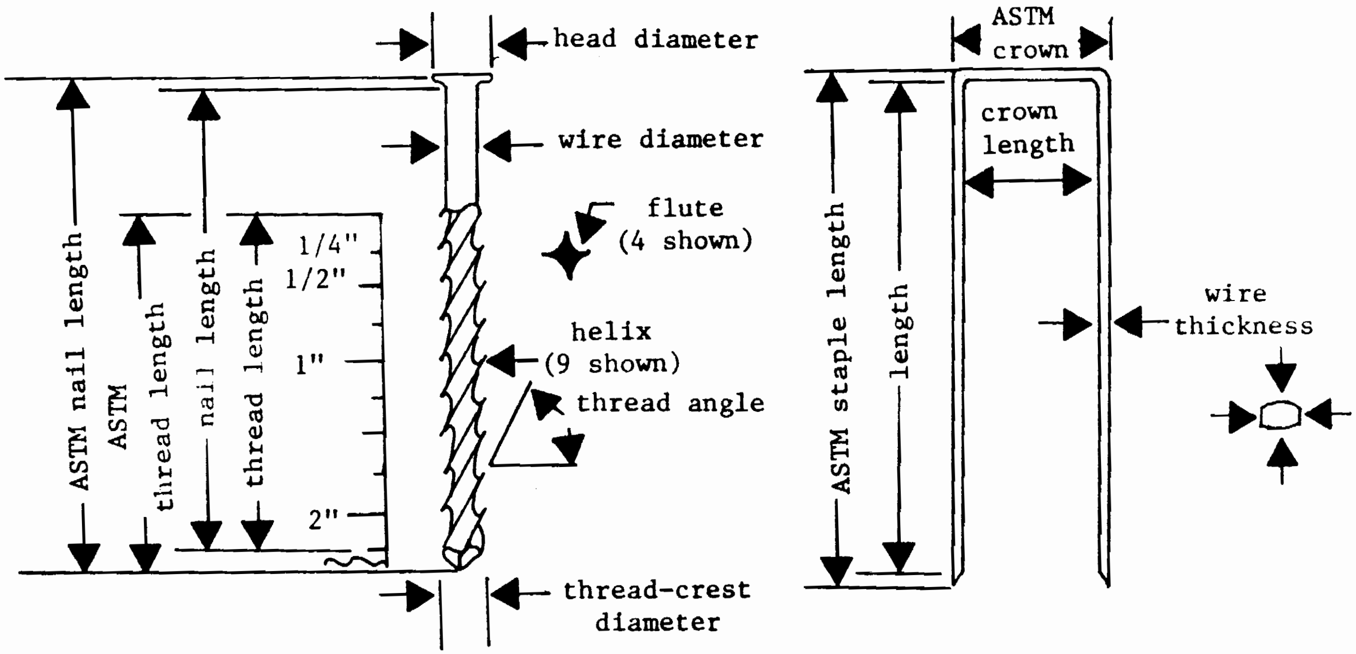


Figure 22. A diagram showing the physical characteristics of a threaded nail and a plain-shank staple.

- Helically threaded, annually threaded, or plain-shank nails: The distance across the unthreaded portion of the nail shank as illustrated in Figure 22. Measured with a micrometer to the nearest 0.001-inch. If the fastener is coated, the coating should be removed in the area where measurement is to be made. There is usually little wire diameter variation with a sample. Therefore, measurement of 3 fasteners is usually sufficient to obtain a reliable average value.
- Twisted square-wire nails: The wire diameter (WD) cannot be measured directly and must be approximated using the equation:

  $$WD = 0.9 \times TD$$

  for a limited range of TD, where TD is the average measured thread diameter for the sample.
- Staples: Measured across a single leg of a round wire staple, or across the widest dimension of a flattened wire "rectangular" staple as illustrated in Figure 22. Measurements should be made with a micrometer to the nearest 0.001-inch on the uncoated portion of the staple leg. There is usually little wire diameter variation within a sample. Therefore, measurement of 3 fasteners is usually sufficient to obtain a reliable average value.

4) Thread-Crest Diameter: The thread-crest diameter is the distance from crest to crest of the fastener threads in a direction perpendicular to the axis of the nail as shown in Figure 22. Measurment should be made with a micrometer to the nearest 0.001-inch. To account for any taper in the thread, measurements should be made at three locations along the length of the thread. An average from a sample size of 3 is recorded on the FQA form.
5) Helixes
   - Helically threaded or twisted square-wire nails: The number of helixes is defined as the number of helical thread crossings along the full length of the

nail thread. Using a nail with a thread diameter equal to the average thread diameter of the sample, place a ruler along the thread parallel to the axis of the nail as illustrated in Figure 22. The number of helixes is the number of points of contact between the straight edge and the nail thread. The fastener illustrated has nine (9) helixes. Randomly select 3 fasteners for the fastener sample. In cases where the thread extends beyond the last contact point or where discontinuities exist in the thread, a more accurate estimate can be obtained by dividing the number of contact points by the exact thread length over which they were counted and multiplying the resulting value by the total thread length. Round off to the nearest 0.1-helix.

- Annularly threaded nails: Annularly threaded nails have no helixes.

6) Flutes

- Helically threaded or twisted square-wire nails: Flutes are the number of helical flutes or depressions along the nail shank. These can be seen best in cross-section as illustrated in Figure 22. Looking at the pointed end of a nail, count the number of major depressions in the wire surface. A twisted square-wire nail always has 4 flutes. Pallet fasteners predominantly have 4,5, or 6 flutes. Some variation can be found within samples of helically threaded nails. Therefore all fasteners in a sample of helically threaded nails should be examined. For samples with 4 and 5 or with 5 and 6 flutes, the number of helixes must be counted and recorded for each number of flutes.
- Annularly threaded nails: Annularly threaded nails do not have any flutes along the nail shank. Annularly threaded nails are assumed to have 4 flutes for the purpose of computation.

7) Thread Angle

- Helically threaded or twisted square-wire nails: The thread angle is measured relative to a plane perpendicular to the axis of the nail as illustrated in

Figure 22. This value can be measured by rolling a nail over a piece of carbon paper and using a protractor. However, the most consistent results are obtained by computing an average thread angle (TA) using the following equation:

$$TA(degrees) = ARCTAN \times \left[\frac{F}{TD \times \pi \times (\frac{H}{TL})} \right]$$

where: F = the number of flutes along the nail shank
TD = the average thread diameter
H = the number of helixes along the nail shank
TL = The thread length
ARCTAN = arctangent
$\pi = 3.1428....$

Thread angle should be rounded off to the nearest degree. This equation can be stored in a programmable calculator such as a HP-41. If variation in the number of flutes is found within a sample a thread angle must be computed for each case by inputting the appropriate number of helixes for each number of flutes.

- Annularly threaded nails: Annularly threaded nails do not have a thread angle.

8) Rings per inch, For annularly threaded nails count the number of rings along the threaded portion of the nail and divide that number by the thread length. There is usually little variation within a sample of annularly threaded nails. Therefore, examination of three fasteners is sufficient to obtain a reliable average value.
9) MIBANT Angle: The average of the results of 12 fastener bend tests performed on a certified bend angle resistance testing device in accordance with the recommended operating instructions and ASTM F680-87. The results of each indi-

vidual bend test should be recorded in the column provided on the FQA form. If the fastener exhibits failure in bending (head failure, partial shank failure, or complete shank failure), record the failure rather than a bend angle using the appropriate abbreviation (HF, PSF, or CSF, respectively). A mean value, standard deviation, and coefficient of variation should be computed and recorded for those fasteners that did not exhibit any type of shank failure. Mean bend angle should be recorded to the nearest degree. The COV should be recorded to the nearest 0.01 percent.

10) Head Diameter: The distance measured across the nail head perpendicular to the nail axis as shown if Figure 22. Measured with a micrometer to the nearest 0.001-inch. Heads are often oval shaped so the average of two measurements, the largest and the smallest, is recommended. For collated nails with partial heads measure the maximum diameter of the nail head and multiply by 0.90. These definitions differ from the proposed ASTM definition of head diameter which is the maximum distance measured across the nail. Measure 3 randomly selected fasteners.

11) Wire Width: For flattened wire ("rectangular wire") staples, the distance across the staple leg measured in a direction perpendicular to the staple crown as illustrated in Figure 22. Measured with a micrometer to the nearest 0.001-inch on the uncoated portion of the staple leg. This is also equivalent to the diameter of a round wire staple leg. Perform this on 3 fasteners.

12) Wire Thickness: For flattened wire ("rectangular wire") staples, the distance across the staple leg measured in a direction parallel to the staple crown as illustrated in Figure 22. Measured with a micrometer to the nearest 0.001-inch on the uncoated portion of the staple leg. Perform this on 3 fasteners.

13) Crown Length: The distance measure along the crown of the staple between the staple legs as illustrated in Figure 22. Measured with a ruler to the nearest 1/16-inch. This measurement differs from the crown measurement commonly

used by staple manufacturers and proposed by ASTM in that it does not include the two staple leg thickness. Perform this on 3 fasteners.

d. The date the sample was delivered, the date of testing, the name of the person performing the test and the general appearance should also be noted and recorded on the FQA form. Refer to Figure 23, for an example of a completed FQA form.

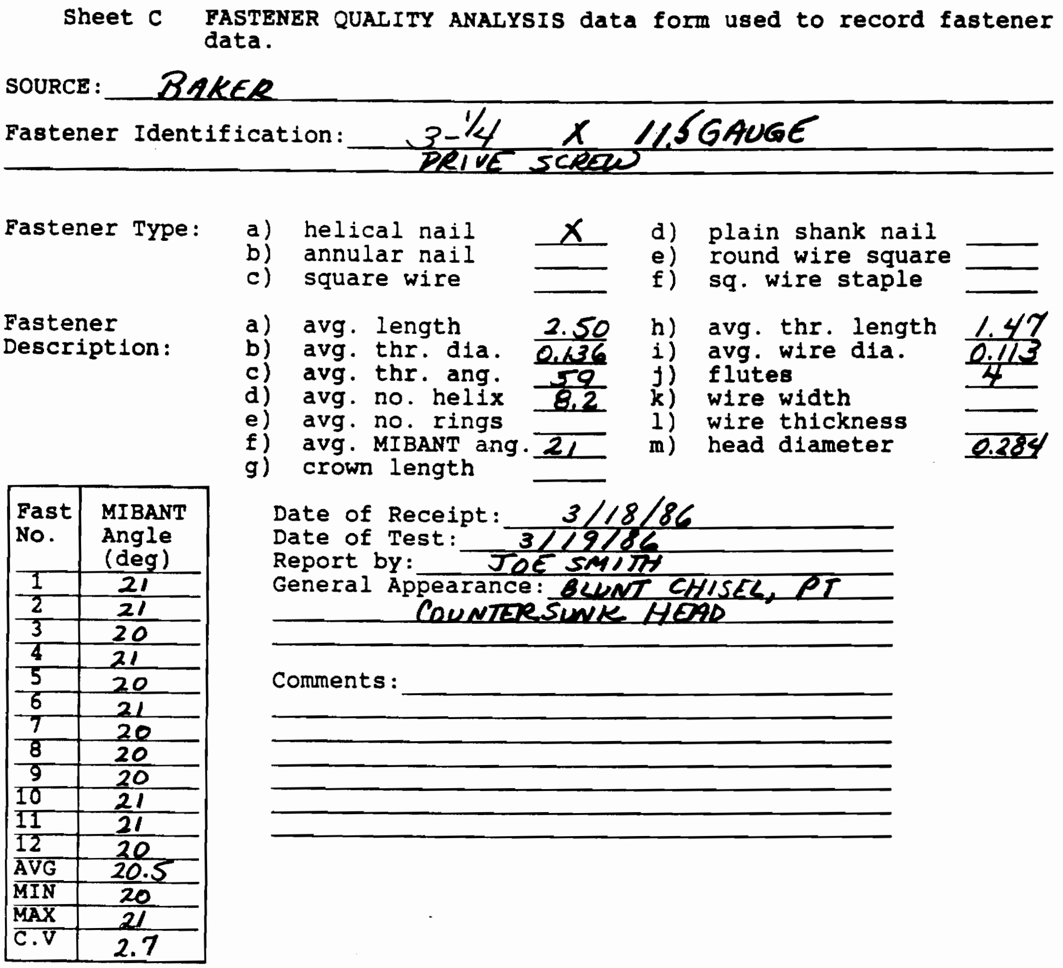
For further information on evaluating the fastener quality refer to Osborn (1986).

6.6 *Monitoring Pallet Workmanship*

Workmanship is the evaluation of the assembled pallet. Some of the quality concerns are indicated in Figure 24. A typical stringer and block pallet are shown schematically in Figures 25 and 26. The monitoring of workmanship is the final evaluation of the pallet before it is shipped. Defects at this stage are extremely critical, because if defects are not spotted the entire load can be rejected by the buyer based on a few bad pallets. Workmanship quality is based on: 1) "out of squareness", 2) deviation of pallet width and length, 3) uniformity of deckboard spacing, 4) number of nail splits, 5) number of protruding head and 6) points, and 7) number of missing nails. Example data sheets are found in sheet D of Figure 27. It is important for each manufacturer to have a listing of the type of pallets that are produced with a corresponding code to identify the pallet.

1. Sample Size - Size of sample, randomly selected for squareness and overall deviation in width and length of the pallet workmanship, depends on:

    a. Standard deviation for each pallet characteristic monitored.



Sheet C FASTENER QUALITY ANALYSIS data form used to record fastener data.

SOURCE: BAKER

Fastener Identification: 3-1/4 X 11.5 GAUGE DRIVE SCREW

Fastener Type:

a)	helical nail	X	d)	plain shank nail	
b)	annular nail		e)	round wire square	
c)	square wire		f)	sq. wire staple	

Fastener Description:

a)	avg. length	2.50	h)	avg. thr. length	1.47
b)	avg. thr. dia.	0.136	i)	avg. wire dia.	0.113
c)	avg. thr. ang.	59	j)	flutes	4
d)	avg. no. helix	8.2	k)	wire width	
e)	avg. no. rings		l)	wire thickness	
f)	avg. MIBANT ang.	21	m)	head diameter	0.284
g)	crown length				

Fast No.	MIBANT Angle (deg)
1	21
2	21
3	20
4	21
5	20
6	21
7	20
8	20
9	20
10	21
11	21
12	20
AVG	20.5
MIN	20
MAX	21
C.V	2.7

Date of Receipt: 3/18/86
Date of Test: 3/19/86
Report by: JOE SMITH
General Appearance: BLUNT CHISEL, PT COUNTERSUNK HEAD

Comments:

Figure 23. Showing how to fill out a Sheet C-FQA form .

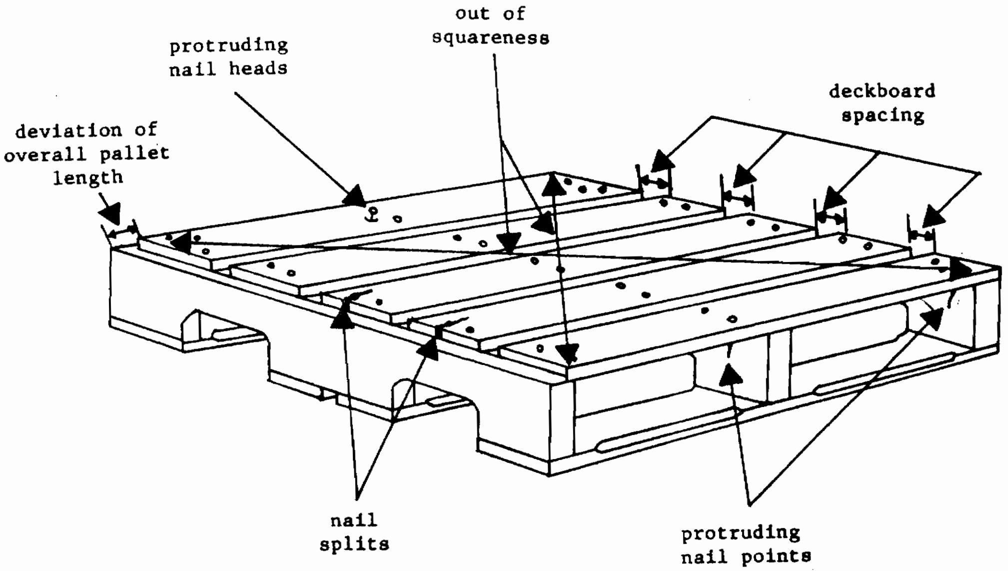


Figure 24. A diagram showing a typical stringer pallet with workmanship defects and nomenclature.

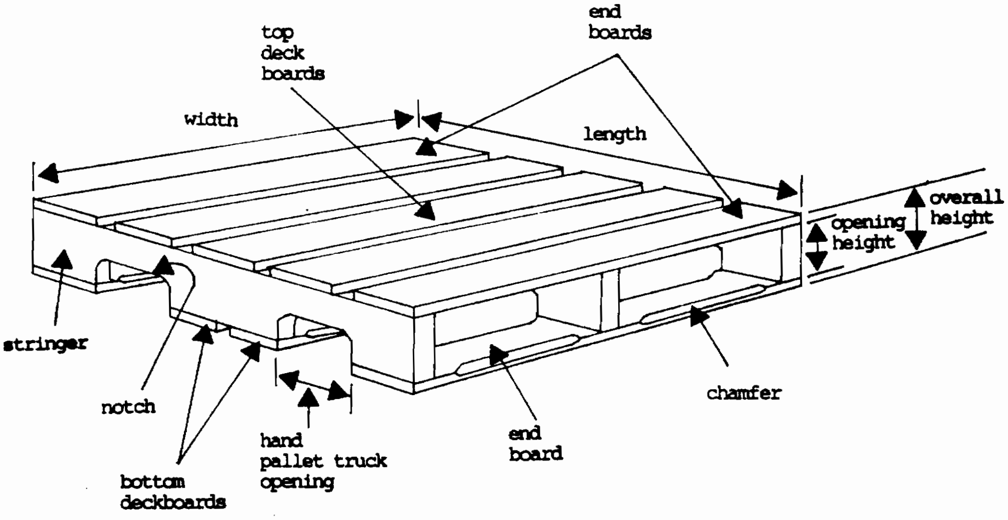


Figure 25. A diagram showing a typical stringer pallet nomenclature.

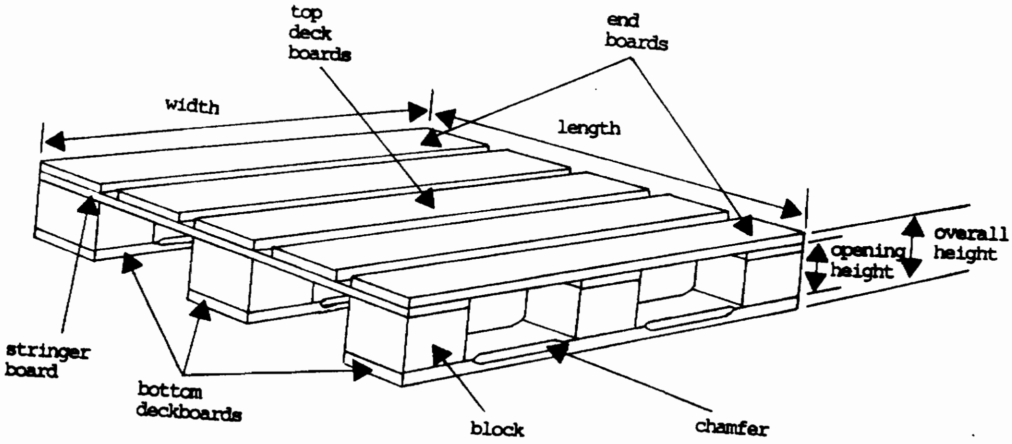


Figure 26. A diagram showing a typical block pallet nomenclature.

DATE:		INSPECTOR:					PALLET CODE:					
MACHINE NO.:			SHIFT:			OPERATOR:						
	1	2	3	4	5	6	7	8	9	10	11	12
DIMENSIONS: out of squareness												
deviation of overall pallet len.												
deviation of overall pallet wid.												
spacing (1)												
(2)												
(3)												
(4)												
(5)												
(6)												
(7)												
(8)												
No. nail splits												
No. protruding nail heads												
No. protruding nail points												
No. missing nails												

Figure 27. Sheet D - An example data sheet used to record workmanship data.

  b. A desired mean or target such as a standard value from the NWPCA standards of 1.5% of the length of the longest dimension or 1", which ever is greater for the squareness; deviation of the overall pallet size limited to ±1/4" width and ±1/4" length.
  c. Specification limits such as an acceptance range for "out of squareness" is 1 inch or 1.5% deviation by the NWPCA.
  d. Acceptance level such as accepting the lot 95% of the time.
  e. Rejection level such as rejecting the material of the lot 10% of the time.

  A procedure for calculating sample size can be found in Appendix A together with an example.

2. Sample Frequency - every assembly run of a given pallet style.

3. Location of sampling is in the storage area before shipment or at the unit feed of the assembly machine or table.

4. Tools to evaluate the characteristics of a pallet are a tape measure and data sheets.

5. Data Collection:

  a. Date measurements are taken, location, machine number, and pallet code while indicates customer and style are recorded.
  b. Dimensions: a) out of squareness is the measure to the diagonals (alternate corners) with a tape measure to the nearest 1/16-inch see Figure 24. b) deviation of overall pallet length is the amount of variation from lead board to lead board. It is measured with a tape measure to the nearest 1/16-inch. c) deviation of overall pallet width is the amount of variation from stringer to stringer of the pallet. It is measured with a tape measure to the nearest 1/16-inch.

c. Assembly: a) uniformity of deck spacing is the spacing in between each deckboard. This is measured with a tape measure to the nearest 1/16-inch. The nominal deckboard spacing is calculated by subtracting the overall pallet length from the total deckboard widths divided by the number of spaces. The percent of deckboard spacing is calculated from summation of the nominal space subtracted from the actual space divided by the nominal space times 100%. b) the uniformity of stringer spacing is the spacing between the stingers of either winged, 3- 4-, or 5-stringer pallets. The percent of stringer spacing is calculated in the same manner as step a) above. This is measured with a tape measure to the nearest 1/16-inch. c) parallelism deviation of deckboards is the measure of the deviation the deckboard spacing from a parallel plane. It is also measured with a tape measure to the nearest 1/16-inch. d) nail splits is the number of splits from the nail to the edge of the deckboard. e) protruding nail heads is the number of nail heads that are not flushed with the wood surface. f) protruding nail points is the number of nail points not in the wood. g) number of nails missing is the number of nails that are not present when the pallet is finally assembled.

6.7 Record Keeping

After the data have been utilized to monitor the quality of materials and products, parts of the data should be kept in weekly summaries for future references. This is important for the company to make comparisons of the changes in the operation or perhaps as a service to your existing or future customers.

1. Raw Material: keep weekly summaries of the average sawing variations (within, between and total board or cant variations), along with the percent of rejected material and comments on the operation and the material received from the saw mills.

2. Cut-Stock: keep weekly summaries of the control limits, X-bar and R values, and percent of out of control data.

3. Fasteners: keep lot summaries on the FSI, FWI and average nail values along with the percent of reject material.

4. Workmanship: keep weekly summaries of the average workmanship characteristics (number of nail splits, number of protruding nail heads and points, # of missing nails, and % of deckboard spacing) along with summaries of percent rejected material.

Appendix A. Sample Size Calculations for Acceptance Sampling by Variables

A.1. Equations Acceptance Sampling By Variables-Standard Dev. Known

In this testing method, only parts of the data recorded can be evaluated:

1. Raw Material: the width, thickness, and length of the lumber and cants can be evaluated.

2. Fasteners: all the physical characteristics, except for the MIBANT angle can be evaluated.

3. Workmanship: "out of squareness" and % of deckboard spacing

The supplier and buyer agree on an acceptance level. For instance, if the buyer wishes to accept 95 out of 100 lots, or reject 5% of the mean ($\overline{X}_1$), then $\alpha = 1 - \frac{95}{100} = 0.05$. In addition, the buyer decides he will not accept any of the material per lot above or below the specification limits (set by the buyer or a published standard) 10% of the time, then $\beta = 0.10$ of the means $\overline{X}_{u2}$ and $\overline{X}_{l2}$. The equations to use to determine sample size are:

$$(1)\quad Z_\beta = \frac{\overline{X}_{ua} - \overline{X}_{u2}}{\frac{\sigma}{\sqrt{n}}}$$

$$(2)\quad Z_\beta = \frac{\overline{X}_{la} - \overline{X}_{l2}}{\frac{\sigma}{\sqrt{n}}}$$

$$(3)\quad Z_\alpha = \frac{\overline{X}_{la} - \overline{X}_{1}}{\frac{\sigma}{\sqrt{n}}}$$

$$(4)\quad Z_\alpha = \frac{\overline{X}_{ua} - \overline{X}_{1}}{\frac{\sigma}{\sqrt{n}}}$$

where $\overline{X}_{ua}$ and $\overline{X}_{la}$ are the acceptance limits for the quality characteristic, σ is the known standard deviation, n is the sample size, and Z_α and Z_β are the Cumulative Normal Probability Distribution or Z-Table value for the $\alpha = 0.05$ and $\beta = 0.10$ values found in Appendix Table A-1. The known standard deviation is taken from past data. The unknowns in these equations are n, $\overline{X}_{ua}$, and $\overline{X}_{la}$. To solve for these, the equations need to be solved simultaneously:

1. using equations (1) and (2), solve for ($\overline{X}_{ua} + \overline{X}_{la}$) where $\overline{X}_{ua} + \overline{X}_{la} = \overline{X}_{u2} + \overline{X}_{l2}$

2. using equations (1) and (3), solve for n, where $n = \sigma^2 \left[\frac{Z_\beta - Z_\alpha}{\overline{X}_{u2} - \overline{X}_1} \right]^2$

3. substitute n into equation (1) to solve for $\overline{X}_{ua}$

4. solve for $\overline{X}_{la}$ where $\overline{X}_{la}$ = step 1. - step 3. This method solves for the sample size and readjusts the value with a constant a value ($\overline{X}_{la}$ and $\overline{X}_{ua}$).

Table A-1. The cumulative probabilities of the normal probability distribution.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9750	.9756	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9893	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9974	.9975	.9976	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9993	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

z	1.282	1.645	1.960	2.326	2.576	3.090	3.291	3.891	4.417
F(z)	.90	.95	.975	.99	.995	.999	.9995	.99995	.999995
2(1-F(z))	.20	.10	.05	.02	.01	.002	.001	.0001	.00001

(A.M. Mood, Introduction to the Theory of Statistics, New York: McGraw-Hill, 1950, p.423.)

A.1.1 Raw Material Example

The pallet mill has received a shipment of cants. The buyer wants some assurance that the all the loads of cants will be accepted 95% of the time or $\alpha = 0.05$ within the means ($\bar{X}_1$) of 3.50 inches thick for 4x6 cants. He also wants to reject the a lot if the cants are above 3.75 or below 3.25, 10% per lot. The 3.75 and 3.25 are the specification limits that are set by the company as being the maximum limits the 4x6 can deviate. The standard deviation is 0.243 inches based on past data of the company. Therefore; $\bar{X}_1 = 3.5$, $\alpha = 0.05$, $\bar{X}_{la} = 3.25$, $\bar{X}_{ua} = 3.75$, $Z_\alpha = 1.960$, $Z_\beta = 1.282$ (the z-values come from a Z-table for the values of α and β in Table A-1.

$$(1) \quad \frac{\bar{X}_{ua} - 3.75}{\frac{0.243}{\sqrt{n}}} = -1.282$$

$$(2) \quad \frac{\bar{X}_{la} - 3.25}{\frac{0.243}{\sqrt{n}}} = 1.282$$

$$(3) \quad \frac{\bar{X}_{ua} - 3.5}{\frac{0.243}{\sqrt{n}}} = 1.960$$

$$(4) \quad \frac{\bar{X}_{ua} - 3.5}{\frac{0.243}{\sqrt{n}}} = -1.960$$

1. solve equations (1) and (2) for ($\bar{X}_{ua} + \bar{X}_{la}$). In this case $\bar{X}_{ua} + \bar{X}_{la} = 7.0$.

2. solve equations (1) and (3) for n. In this case $n = 9.93$ or approximately 10.

3. substitute n into equation (1) to find $\bar{X}_{ua}$. In this case $\bar{X}_{ua} = 3.65$.

4. subtract step 3. from step 1. to find $\bar{X}_{la}$. In this case $\bar{X}_{la} = 3.35$.

Therefore, the acceptance limits for the upper and lower limits are 3.65 and 3.35, respectively, for the 10% allowable rejection limit when a sample size of 10 is taken will give the buyer statistical assurance of the material received. However, if the buyer does not want to change the specification limits ($\bar{X}_{ua}$ and $\bar{X}_{la}$) he can change the α and β values and re-evaluate the equations and follow steps 1 through 4.

A.1.2 Fastener Example

Before the fasteners are measured and recorded, a sample size for each characteristic of interest needs be determined. For example, the wire diameter of a 12 gauge fastener is 0.105 according to Federal Specifications (1977) with a ±0.002 of an inch tolerance set by NWPCA (1982). The buyer wants some assurance that the wire diameter lots received will be accepted 95% of the time or $\alpha = 0.05$ within the mean inches ($\bar{X}_1$) of 0.105 inches for a 12 gauge fastener. He also wants to reject the lot if it is above 0.107 or below 0.103 inches, 10% of the time. The 0.107 and 0.103 are the ±0.002 inch standard from the NWPCA (1982). The standard deviation is 0.0074. Therefore, $\bar{X}_1 = 0.105$, $\alpha = 0.05$, $\bar{X}_{la} = 0.103$, $\bar{X}_{ua} = 0.107$, $\beta = 0.10$, $Z_\alpha = 1.960$, and $Z_\beta = 1.282$.

$$(1)\quad \frac{\bar{X}_{ua} - 0.107}{\frac{0.0074}{\sqrt{n}}} = -1.282$$

$$(2)\quad \frac{\bar{X}_{la} - 0.103}{\frac{0.0074}{\sqrt{n}}} = 1.282$$

$$(3)\quad \frac{\bar{X}_{ua} - 0.105}{\frac{0.0074}{\sqrt{n}}} = 1.960$$

$$(4) \quad \frac{\bar{X}_{ua} - 0.105}{\frac{0.0074}{\sqrt{n}}} = -1.960$$

1. solve equations (1) and (2) for $(\bar{X}_{ua} + \bar{X}_{la})$. In this case $\bar{X}_{ua} + \bar{X}_{la} = 0.210$.
2. solve equations (1) and (3) for n. In this case $n = 3.46$ or approximately 4.
3. substitute n into equation (1) to find $\bar{X}_{ua}$. In this case $\bar{X}_{ua} = 0.102$.
4. subtract step 3. from step 1. to find $\bar{X}_{la}$. In this case $\bar{X}_{la} = 0.108$.

Therefore, the acceptance limits for the upper and lower limits are 0.102 and 0.108, respectively, for the 10% allowable rejection limit when a sample size of 4 is taken will give the buyer statistical assurance of the material received. However, if the buyer does not want to change the specification limits ($\bar{X}_{ua}$ and $\bar{X}_{la}$) he can change the α and β values and re-evaluate the equations and steps. re-evaluate the equations and steps.

A.1.3 Workmanship Example

Before the workmanship can be evaluated, a sample size for each characteristic of interest must be calculated. For example, the out of squareness (or diagonals) is one characteristic and is evaluated separately from another characteristic such as the number of nail splits. Lets′ assume the manufacturer wants some assurance that the assembled pallets are conforming to the standards he has set for all the lots, and will accept 95% of the time or $\alpha = 0.05$ within the mean $(\bar{X}_1)$ of 62 inches in length. He also wants to reject the lot if the pallets above 63 or below 61 under NWPCA standards, 1982), 10% per lot. The standard deviation is 0.5 from pass data. Therefore, $\overline{X}_1 = 62$, $\alpha = 0.05$, $\overline{X}_{la} = 61$, $\overline{X}_{ua} = 63$, $\beta = 0.10$, $Z_\alpha = 1.960$, $Z_\beta = 1.282$.

$$(1) \quad \frac{\overline{X}_{ua} - 63}{\frac{0.50}{\sqrt{n}}} = -1.282$$

$$(2) \quad \frac{\overline{X}_{la} - 61}{\frac{0.50}{\sqrt{n}}} = 1.282$$

$$(3) \quad \frac{\overline{X}_{ua} - 62}{\frac{0.50}{\sqrt{n}}} = 1.960$$

$$(4) \quad \frac{\overline{X}_{la} - 62}{\frac{0.50}{\sqrt{n}}} = -1.960$$

1. solve equations (1) and (2) for $(\overline{X}_{ua} + \overline{X}_{la})$. In this case $\overline{X}_{ua} + \overline{X}_{la} = 124$.

2. solve equations (1) and (3) for n. In this case $n = 2.6$ or approximately 3.

3. substitute n into equation (1) to find $\overline{X}_{ua}$. In this case $\overline{X}_{ua} = 62.63$.

4. subtract step 3. from step 1. to find $\overline{X}_{la}$. In this case $\overline{X}_{la} = 61.37$.

Therefore, the acceptance limits for the upper and lower limits are 62.63 and 61.37, respectively, for the 10% allowable rejection limit when a sample size of 3 is taken. This will give the manufacturer statistical assurance of the material received. However, if the buyer does not want to change the specification limits ($\overline{X}_{ua}$ and $\overline{X}_{la}$) he can change the α and β values and

A.2. Equations For Acceptance Sampling By Variables-Standard Dev. Unknown

When the standard deviation is unknown, the sample size is going to increase as a result. The t-test is used instead of the z-value. Consider the same cant example in the above z-test, except the standard deviation is unknown. In this case the buyer makes a rough estimate of what he would expect the standard deviation to be for the process or lot and call it "s".

1. compute $\lambda = \dfrac{\overline{X}_1 - (\overline{X}_{u2} \text{ or } \overline{X}_{l2})}{s}$

2. Find n by using Figure A-1 when Pa = 0.10 and computed λ from step 1.

3. compute the t-value when the sample mean is measured from a sample size n:

$$T = \frac{\overline{X} - \overline{X}_1}{\frac{s}{\sqrt{n}}}$$

4. if the t has a positive or negative value and is equal to or less than the t-Table value found in Appendix Table A-2, (where α and df = n-1 are used), the lot is accepted. If it has a negative value and numerically greater then the t-table value, then reject. If the lot is rejected, the buyer can retest the material, change the rough estimated of standard deviation, specify to the supplier size dimensions, or change the limits of $\overline{X}_{u2}$ and $\overline{X}_{l2}$.

Table A-2. Percentage points of the t-distribution.

	Probability (P)												
	.9	.8	.7	.6	.5	.4	.3	.2	.1	.05	.02	.01	.001
1	.158	.325	.510	.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.142	.289	.445	.617	.815	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.137	.277	.424	.584	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.134	.271	.414	.569	.741	.941	1.190	1.533	2.132	2.776	3.747	4.606	8.610
5	.132	.267	.408	.559	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	.131	.265	.404	.553	.718	.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	.130	.263	.402	.549	.711	.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	.130	.262	.399	.546	.706	.889	1.108	1.397	1.860	2.228	2.896	3.355	5.041
9	.129	.261	.398	.543	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.129	.260	.397	.542	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.129	.260	.396	.540	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.128	.259	.395	.539	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.128	.259	.394	.538	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.128	.258	.393	.536	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.128	.258	.393	.536	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.128	.258	.392	.535	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.128	.257	.392	.534	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.127	.257	.392	.534	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.127	.257	.391	.533	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.127	.257	.391	.533	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.127	.257	.391	.532	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.127	.256	.390	.532	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.127	.256	.390	.532	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.127	.256	.390	.531	.685	.857	1.059	1.318	1.711	2.064	2.482	2.797	3.745
25	.127	.256	.390	.531	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.127	.256	.390	.531	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.127	.256	.389	.531	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.127	.256	.389	.530	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.127	.256	.389	.530	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.127	.256	.389	.530	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.126	.255	.388	.529	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.126	.254	.387	.527	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.126	.254	.386	.526	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.126	.253	.385	.524	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

(R.A. Fisher and F. Yates, Statistical Tables for Biological, Agricultural and Medical Research, Edinburgh: Oliver & Boyd, Ltd, 1953, Table III.)

A.2.1 Raw Material Example

In this case, the company wants the same sampling plan, but the buyer estimates the unknown standard deviation to be s = 0.5. Therefore, $\overline{X}_1 = 3.5$, $\alpha = 0.05$, $\beta = 0.10$, $\overline{X}_{u2} = 3.75$ and $\overline{X}_{l2} = 3.25$.

1. $\lambda = \dfrac{\overline{X}_1 - (\overline{X}_{u2} \text{ or } \overline{X}_{l2})}{s} = \dfrac{3.5 - 3.75}{0.5} = 0.5$

2. n = 35 from Figure A-1 when Pa = 0.10 and $\lambda = 0.5$.

3. $t = \dfrac{\overline{X} - \overline{X}_1}{\frac{s}{\sqrt{n}}} = \dfrac{3.96 - 3.5}{\frac{0.5}{\sqrt{35}}} = 5.44$

4. t = 5.44 is greater than the 2.053 value from the t-Table, therefore the plan is rejected. The buyer can either make a price concessin with the supplier for receiving below standards, send back the material, or inform the supplier of the problem in his product in hopes he will adjust for it.

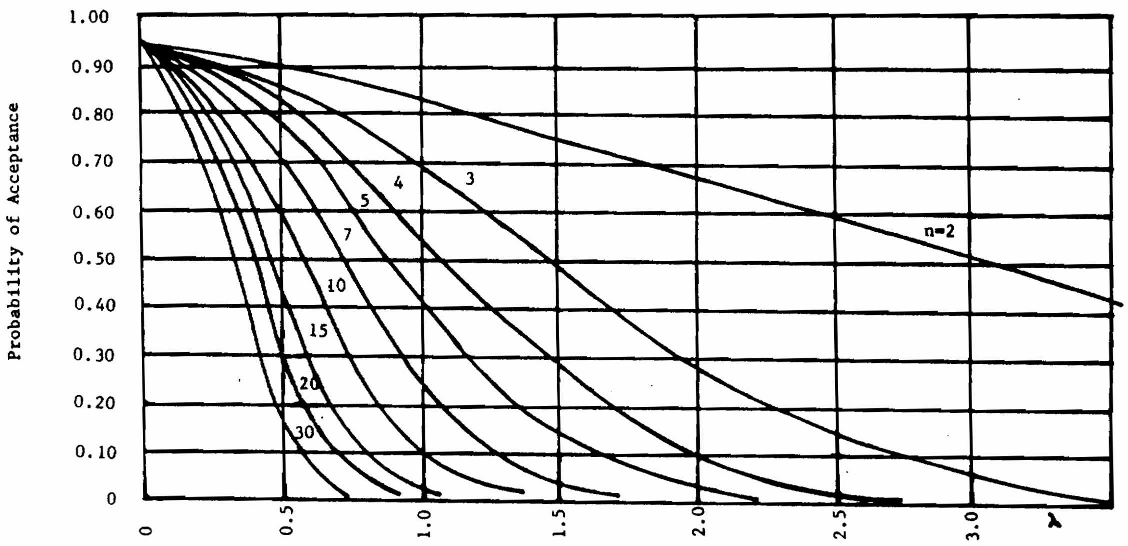
A.2.2 Fastener Example

In this case, the company wants the same sampling plan, but the buyer estimates the unknown standard deviation to be s = 0.001. Therefore, $\overline{X}_1 = 0.105$, $\alpha = 0.05$, $\beta = 0.10$, $\overline{X}_{u2} = 0.107$, and $\overline{X}_{l2} = 0.103$.

1. $\lambda = \dfrac{\overline{X}_1 - (\overline{X}_{u2} \text{ or } \overline{X}_{l2})}{s} = \dfrac{0.105 - 0.103}{0.001} = 2.0$

2. n = 4 from Figure A-1 when Pa = 0.10 and $\lambda = 2.0$.

3. $t = \dfrac{\overline{X} - \overline{X}_1}{\frac{s}{\sqrt{n}}} = \dfrac{0.109 - 0.105}{\frac{0.001}{\sqrt{4}}} = 8$ where 0.109 is the average from measuring 4 fasteners.



* In acceptance sampling, $\bar{X}'_1$ = the $\bar{X}'_1$ of the plan and $\bar{X}'$ any other lot or process quality, n = size of sample. The lot or process is assumed to be normally distributed or approximately nomally distributed. The sampling plan has only one acceptance limit. Source of original data: J. Neyman and B. Tobarska, "Errors of the Second Kind in Testing 'Student's Hypothesis,' Journal of the American Statistical Assoc. 31, pp. 318-26.

Figure A-1. A graphic display of an operation characteristic curves for single-limit sampling plans based on the statistic.

4. t = 8 is greater than the 3.182 value from the t-Table, therefore the plan is rejected

This is an example of how to implement acceptance sampling for 12 gauge wire diameters for one characteristic only. This would have to be performed on the other characteristic of the fastener of interest. However, the MIBANT angle test has set rules to follow that is not tested by acceptance sampling. The NWPCA has set an 8% failure criteria for the MIBANT angle, where the sample size of 12 can be used to test this criteria.

A.2.3 Workmanship Example

In this example, the company wants the same sampling plan, but the manufacturer estimates the unknown standard deviation to be s = 0.90. Therefore, $\overline{X}_1 = 62$, $\alpha = 0.05$, $\beta = 0\ .10$, $\overline{X}_{u2} = 61$, and $\overline{X}_{l2} = 63$.

1. $\dfrac{\overline{X}_1 - (\overline{X}_{u2} \text{ or } \overline{X}_{l2})}{s} = \dfrac{62 - 61}{0.90} = 1.11$

2. n = 9 from Figure A-1 when Pa = 0.10 and $\lambda = 1.11$.

3. $t = \dfrac{\overline{X} - \overline{X}_1}{\frac{s}{\sqrt{n}}} = \dfrac{62.06 - 62}{\frac{0.90}{\sqrt{9}}} = 0.20$

   where 62.06 is the average from measuring 9 fasteners.

4. t = 0.20 is less than 2.306, the value from the t-Table, therefore the plan is accepted.

This is only an example of how to implement acceptance sampling for pallet diagonals of 62 inch targets. The same test can be perform on any characteristic of the finished pallet.

Appendix B. Calculating Acceptance Sampling by Attributes with MIL STD 105D

The MIL STD 105D is used to test characteristics of materials that are attributes and variables:

1. Raw Material: the grade, species and moisture content can be evaluated by this plan.

2. Workmanship: the nail splits, protruding nail head and points, and missing nails can be tested.

In this example the pallet company wants to monitor the assembled pallet before it is shipped to his customer. The inspection level is II from Table B-1 and the lot or batch size of pallets to be shipped is 250. Therefore the sample size letter code is G from Table B-2. In addition the AQL is 1.0 when Pa = 0.10 and p = 5.35 from Table B-1. A single sampling plan for normal inspection is n = 50, acceptance criterum = 1, and the rejection criterum = 2. For a reduced sampling plan n = 20, acceptance criterum = 0, and rejection criterum = 2. For a tightened sampling plan n = 80, acceptance criterum = 1, and rejection criterum = 2. The sampling technique is carried out according to procedures 1 through 11 of the MIL STD 105D standards in this Appendix where normal inspection is instituted at this time. If acceptance of 10 consecutive lots is achieved, then the normal inspection is switched to reduced inspection. However, if any pallet is rejected under reduced inspection, the plan resorts back to normal inspection. This continues til the sample size "n" is tested. If under normal inspection 2 out of 5 consective lots are rejected then the testing switches to tightened inspection. Under this plan, if 5 consective lots are accepted then the sampling plan resorts back to normal inspection. However, if after 10 lots in tightened without returning to normal inspection occurs, then the testing is stopped and the material rejected.

The MIL STD 105D sampling plans are applicable to inspection of the following: 1) end items, 2) components and raw material, 3) operations, 4) materials in process, and 5) supplies in storage. These plans are intended for a continuous series of lots or batches. Definitions:

1. Classifying Defects and Defectives. Inspection by attributes is inspection whereby either the unit of produce is classified simply as defective or nondefective, or the number of defects in the unit of product is counted, with respect to a given requirement or set of requirements. Classification of defects is the enumeration of possible defects of the unit of product classified according to their seriousness. A defect is any nonconformance of the unit of product with specified requirements. Defects will normally be grouped into one or more of the following classes; how ever, defects may be grouped into other classes, or into subclasses within these classes. The extent of nonconformance of product shall be expressed either in terms of percent defective or in terms of defects per hundred units:

$$\textit{percent defective } (p) = \frac{\textit{number defectives}}{\textit{number units inspected}} \times 100$$

2. Acceptable Quality Level (AQL). The Acceptable Quality Level (AQL) is found by looking on Appendix Table B-1 when the Probability of Acceptance (Pa) and percent defective (p) for normal inspection is known. The AQL is the maximum percent defective (or the maximum number of defects per hundred units) that, for purposes of sampling inspection, can be considered satisfactory as a process average. When a consumer designates

Table B-1. Tabulated values for operating characteristic curves for single-sampling plans.

P_a	Acceptable Quality Levels (normal inspection)											
	0.10	0.40	0.65	1.0	1.5	2.5	--------	4.0	--------	6.5	--------	10
	p (in percent defective or defects per hundred units)											
99.0	0.0081	0.119	0.349	0.658	1.43	2.33	2.81	3.82	4.88	5.98	8.28	10.1
95.0	0.0410	0.284	0.654	1.09	2.09	3.19	3.76	4.92	6.15	7.40	9.95	11.9
90.0	0.0840	0.426	0.882	1.40	2.52	3.73	4.35	5.62	6.92	8.24	10.9	13.0
75.0	0.230	0.769	1.382	2.03	3.38	4.77	5.47	6.90	8.34	9.79	12.7	14.9
50.0	0.554	1.34	2.14	2.94	4.54	6.14	6.94	8.53	10.1	11.7	14.9	17.3
25.0	1.11	2.15	3.14	4.09	5.94	7.75	8.64	10.4	12.2	13.9	17.4	20.0
10.0	1.84	3.11	4.26	5.35	7.42	9.42	10.4	12.3	14.2	16.1	19.8	22.5
5.0	2.40	3.80	5.04	6.20	8.41	10.5	11.5	13.6	15.6	17.5	21.4	24.2
1.0	3.68	5.31	6.73	8.04	10.5	12.8	18.3	16.1	18.3	20.4	24.5	27.5
	0.15	0.65	1.0	1.5	2.5	--------	4.0	--------	6.5	--------	10	--------
	Acceptable Quality Levels (tightened inspection)											

(Mil. Std. 105D, Table I)

Table B-2. Sample size code letters.

Lot or Batch Size	Special Inspection Levels				General Inspection Levels		
	S-1	S-2	S-3	S-4	I	II	III
2 to 8	A	A	A	A	A	A	B
9 to 15	A	A	A	A	A	B	C
16 to 25	A	A	B	B	B	C	D
26 to 50	A	B	B	C	C	D	E
51 to 90	B	B	C	C	C	E	F
91 to 150	B	B	C	D	D	F	G
151 to 280	B	C	D	E	E	G	H
281 to 500	B	C	D	E	F	H	J
501 to 1,200	C	C	E	F	G	J	K
1,201 to 3,200	C	D	E	G	H	K	L
3,201 to 10,000	C	D	F	G	J	L	M
10,001 to 35,000	C	D	F	H	K	M	N
35,001 to 150,000	D	E	G	J	L	N	P
150,001 to 500,000	D	E	G	J	M	P	Q
500,001 and over	D	E	H	K	N	Q	R

(Mil. Std. 105D, Table X-K-1)

some specific value of AQL for a certain defect or group of defects, he indicates to the supplier that his (the consumer's) acceptance sampling plan will accept the great majority of the lots or batches that the supplier submits, provided the process average level of percent defective (p) in these lots or batches be no greater than the designated value of AQL.

3. Submission of Product. Lot or batch is a term that means "inspection lot" or "inspection batch," i.e., a collection of units of product from which a sample is to be drawn. The product shall be assembled into identifiable lots, sublots, batches, or in such other manner as may be prescribed. The lot or batch size is the number of units of product in a lot or batch.

4. Acceptance and Rejection. Acceptability of a lot or batch will be determined by the use of sampling plan or plans associated with the designated AQL or AQLs. Lots or batches found unacceptable shall be resubmitted for inspection only after all units are re-examined or retested and all defective units are removed or defects corrected.

5. Drawing of Samples. Samples consist of one or more units of product drawn from a batch or lot, the units of the sample being selected at random without regard to their quality. The number of units of product in the sample is the sample size. Samples may be drawn after all the units comprising the lot have been assembled, or samples may be drawn during assembly of the lot or batch.

6. Normal, Tightened and Reduced Inspection. These are types of sampling levels that take place in the MIL STD 105D. They will continue unchanged for each class of defects or defectives or successive lots or batches except where the switching procedures given below require change. The switching procedures shall be applied to each class of defects or defectives independently.

- Switching from one sampling level to another:

    a. Normal to Tightened. When normal inspection is in effect, tightened inspection shall be instituted when 2 out of 5 consecutive lots or batches have been rejected on original inspection.

    b. Tightened to Normal. When tightened inspection is in effect, normal inspection shall be instituted when 5 consecutive lots or batches have been considered acceptable on original inspection.

    c. Normal to Reduced. When normal inspection is in effect, reduced inspection shall be instituted providing that all of the following conditions are satisfied:

        1) The proceeding 10 lots or batches have been on normal inspection and none has been rejected on original inspection; and
        2) The total number of defectives (or defects) in the samples from the proceeding 10 lots or batches for such other number as was used for condition "a" above is equal to or less than the applicable number given in Appendix Table B-3; and
        3) Production is at a steady rate; and
        4) Reduced inspection is considered desirable by the responsible authority.

    d. Reduced to Normal. When reduced inspection is in effect, normal inspection shall be instituted if any of the following occur on original inspection:

        1) A lot or batch is rejected; or
        2) A lot or batch is considered acceptable under the

definition 3); or

3) Production becomes irregular or delayed; or

4) Other conditions warrant that normal inspection shall be instituted.

7. Discontinuation of Inspection. In the event that 10 consecutive lots or batches remain on tightened inspection, inspection under the provisions of this document shall be discontinued pending action to improve the quality of submitted material.

8. Inspection Level. The level determines the relationship between the lot or batch size and the sample size. Three inspection levels: I, II, and III, are given in Table B-1. Unless otherwise specified, inspection level II will be used.

9. Code Letters. Sample sizes are designated by code letters. Table B-2 shall be used to find the applicantable code letter for the particular lot or batch size and the prescribed inspection level.

10. Obtaining Sampling Plans. The AQL and the code letter shall be used to obtain the sampling plan from Tables B-3, B-4, and B-5. When no sampling plan is available for a given combination of AQL and code letter, the tables direct the user to a different letter. The sample size to be used is given by the new code letter not by the original letter. If this procedure leads to different sample sizes for different classes of defects, the code letter corresponding to the largest sample size derived may be used for all classed of defects. As an alternative to a single sampling plan with an acceptance number of 0, the plan with an acceptance number of 1 with its correspondingly larger sample size for a designated AQL.

11. Determination of Acceptability. The number of sample units inspected shall equal to the sample size given by the plan. If the number of defectives found in the sample is equal

Table B-3. Master table for normal inspection-single sampling.

Sample size code letter	Sample Size	Acceptable Quality Levels (normal inspection)																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑
E	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑	↑
F	20	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑
G	32	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑
H	50	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑
J	80	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	125	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	200	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	315	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	500	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	800	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	1250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	2000	↑	↑	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

↓ = use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection
↑ = use first sampling plan above arrow.

Ac = Acceptance number
Re = Rejection number

(Mil. Std. 105D, Table II-A)

Table B-4. Master table for tightened inspection-single sampling.

Sample size code letter	Sample Size	Acceptable Quality Levels (tightened inspection)																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	44 45	↑
D	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42	↑	↑
E	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42	↑	↑	↑
F	20	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑
G	32	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑
H	50	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑
J	80	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	125	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	200	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	315	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	500	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	800	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	1250	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	2000	0 1	↑	↓	1 2	2 3	3 4	5 6	8 9	12 13	18 19	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
S	3150		↑	1 2								↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

↓ = use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection
↑ = use first sampling plan above arrow.

Ac = Acceptance number
Re = Rejection number

(Mil. Std. 105D, Table II-B)

Table B-5. Master table for reduced inspection-single sampling.

Sample size code letter	Sample Size	Acceptable Quality Levels (reduced inspection)																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	2														0 1	↑		0 2	1 3	2 4	3 5	5 6	7 8	10 11	14 15	21 22	30 31
C	2													0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 24	↑
D	3												0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 24	↑	
E	5											0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 21	↑		
F	8										0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑	↑	↑			
G	13									0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑						
H	20								0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑							
J	32							0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑								
K	50						0 1	↓	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑									
L	80					0 1	↓		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑										
M	125				0 1	↑		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑											
N	200			0 1	↑	↓	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑												
P	315		0 1	↑		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑													
Q	500	0 1	↑		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑														
R	800	↑		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	↑															

↓ = use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection
↑ = use first sampling plan above arrow.

Ac = Acceptance number
Re = Rejection number

(Mil. Std. 105D, Table II-C)

to or less than the acceptance number, the lot or batch shall be considered acceptable. If the number of defectives is equal to or greater than the rejection number, the lot or batch shall be rejected.

The steps in the use of the standard may be summarized as follows:

1. decide on the AQL.
2. decide on inspection level
3. determine lot size
4. enter table to find sample size code letter
5. decide on type of sampling plan to be used.
6. enter proper table to find the plan to be used.
7. begin with normal inspection and follow the switching rules and the rule for discontinuance of inspection as called for.

Appendix C. Calculating Control Limits

1. The first step is to compute the average range ($\overline{R}$) of the entire set of subgroups. This involves the summation of all the ranges of the subgroups divided by the number of subgroups.

2. The limits for the ranges are computed using the D_3 and D_4 factors from Appendix Table C-1 when 3σ is used.

   $$\textit{upper control limit} \qquad UCL_r = D_4 \times \overline{R}$$

   $$\textit{lower control limit} \qquad LCL_r = D_3 \times \overline{R}$$

   and $D_4 = (1 + \frac{3d_3}{d_2}) \times \overline{R}$ and $D_3 = (1 - \frac{3d_3}{d_2}) \times \overline{R}$ if a value other than 3 in $\pm 3\sigma$. The values for d_3 and d_2 can be found in Appendix Table C-1.

3. The average of the means are computed when the means of each subgroup are summed together and divided by the number of subgroups.

4. The A_2 factor from Appendix Table C-1, is used in the calculation of X-bar control limits.

   $$\textit{upper control limit} \qquad UCL_x = \overline{X} + A_2 \times \overline{R}$$

Table C-1. Percentage points of the distribution of the relative range $w = R/\sigma'$, normal universe.

Chart for Ranges					Chart for averages
n	mean w or d_2	σw or d_3	D_3	D_4	A
2	1.128	0.8525	0	3.267	1.880
3	1.693	0.8884	0	2.575	1.023
4	2.059	0.8798	0	2.282	0.729
5	2.326	0.8641	0	2.115	0.577
6	2.534	0.8480	0	2.004	0.483
7	2.704	0.8330	0.076	1.924	0.419
8	2.847	0.8200	0.136	1.864	0.373
9	2.970	0.8080	0.184	1.816	0.337
10	3.078	0.7970	0.223	1.777	0.308
11	3.173	0.7870	0.256	1.744	0.285
12	3.258	0.7780	0.284	1.716	0.266
13	3.336	0.7700	0.308	1.692	0.249
14	3.407	0.7620	0.329	1.671	0.235
15	3.472	0.7550	0.348	1.652	0.223
16	3.532	0.7490	0.364	1.636	0.212
17	3.588	0.7430	0.379	1.621	0.203
18	3.640	0.7380	0.392	1.608	0.194
19	3.689	0.7330	0.404	1.592	0.187
20	3.735	0.7290	0.414	1.586	0.180
21	3.778	0.7240	0.425	1.575	0.173
22	3.819	0.7200	0.434	1.566	0.167
23	3.858	0.7160	0.443	1.557	0.162
24	3.895	0.7120	0.452	1.548	0.157
25	3.931	0.7090	0.459	1.541	0.153
over 25	$3/\sqrt{n}$	$3/\sqrt{n}$	.....	.....	.....

(E.S. Pearson, "The Probability Integral of the Range in Samples of n Observation from a Normal Population," Biometrika 32 (1941-42), pp.301-8. Mean and σ' reproduced from E.S. Pearson, "The Percentage Limits for the Distribution of Range in Samples from a Normal Population," Biometrika 24 (1932), pp. 404-17.)

$$\textit{lower control limit} \qquad LCL_X = \overline{X} - A_2 \times \overline{R}$$

Where $\overline{\overline{X}}$ = the means of the means and $A_2 = \frac{3}{d_2 \times n}$. When a different coefficient is used in place of 3 in the $\pm 3\sigma$. Note: X-bar and R chart limits can only be used if the subgroup size is constant.

5. Plotting the central line of the two control charts involves plotting the means of the ranges and the means of the means. See Figures 17 and 18 for examples of control charts.

6. Plotting the boundaries (upper and lower limits) for the X-bar and R charts involves plotting the limits solved in steps 2) and 4). See Figures 17 and 18 for examples of control charts.

7. After the limits are setup on both charts, data is collected in a subgroup size of 5, taken every hour. The data is record on data sheets such as sheet B in Figure 16.

8. Calculate the mean for the subgroups. The samples are summed together then divided by the number of samples taken in the subgroup.

$$\overline{X} = \frac{(X_1 + X_2 + X_3 + X_4 + X_5)}{n}$$

where X_1, X_2, X_3, X_4, and X_5 are the first, second, third, fourth, and fifth samples taken, respectively. This mean value can then be plotted on the X-bar control chart.

9. Calculate the range for each subgroup by subtracting the lowest measurement from the highest in the samples of a subgroup.

$$R = R_{\text{high}} - R_{\text{low}}$$

R value is then plotted on the R control chart.

C.1. Control Chart Cut-Stock Example

Before data is collected, it is important to know the characteristics that are being measured such as within board variations or between board variations where the machine performances are directly related the different variations. Within board variation can be caused by within blade variation, between board variation can be caused by the blade position fluctuation. Whichever variation is the most critical in that operation should be the one monitored.

Note: Any time something changes the process, a new control chart is constructed.

1. The means of the 25 subgroups evaluated in column X-bar are summed and divided by the total number of subgroups in solving for the means of the means or $\bar{\bar{X}}$. In this example, the total X value is 12.581 of between board variation from Table 36.

$$\bar{\bar{X}} = \frac{\overline{X}_{\text{total}}}{N} = \frac{12.581}{25} = 0.503$$

2. The ranges of each subgroup are computed by:

$$R = R_{high} - R_{low}$$

   The average range is computed by the summation of the Ranges divided by the total number of subgroups:

$$\bar{R} = \frac{R_{\text{total}}}{N} = \frac{0.367}{25} = 0.0147$$

3. The center line can be plotted on the Figure 19 for the X-bar and R control charts of the values in 1. and 2., respectively.

4. D_4 = 2.115 and D_3 = 0 from Appendix Table C-1 (assuming 3 and subgroup size of n = 5) for the R chart limits:

$$UCL_r = D_4 \times \overline{R} = 2.115 \times 0.0147 = 0.03109$$

$$LCL_r = D_3 \times \overline{R} = 0 \times 0.0147 = 0$$

5. For the X-bar chart limits, A_2 = 0.577 is from Appendix Table C-1.

$$UCL_x = \overline{\overline{X}} + A_2 \times \overline{R} = 0.503 + 0.577 \times (0.0147) = 0.5115$$

$$LCL_x = \overline{\overline{X}} - A_2 \times \overline{R} = 0.503 - 0.577 \times (0.0147) = 0.4945$$

Appendix D. Software Packages

Analysis of data and record keeping and reporting may be done manually. These companies having computers may consider leasing or purchasing software. Every year the Quality Progress magazine (Espeillac, 1987) publishes a QC/QA software directory. This guide is meant to serve as a year-round reference source for quality practioners and other uses of QA and QC software packages.

In searching for a compatible program, it is important to look at price, hardware configuration and capability, and multiprogram packages. The package must include X-bar and R charts, and some form of acceptance sampling analysis. It should allow the user to format reports using pallet nomenclature.

Some programs that are already on the market and include the QC/QA features mentioned above:

1) * SQC pack
Product-Quality Systems, Inc.
470 Windsor Park Drive
P.O. Box 633
Dayton, OH 45459
(800) 547-1565
(513) 435-9717

2) /SPC System and MAJIC
The Crosby Company
P.O. Box 2433
Glen Ellyn, IL 60138
(312) 790-1711

3) Quality Analyst
ASM International
Metals Park, OH 44073
(216) 338-5151

4) SS/SPQC
J.W. Loosemore
150 N. Bailey Drive
Porter, IN 46304
(219) 926-6825

5) MetriStat Real Time Plus
MetriStat Div., Business
Systems Design, Inc.
1205 Wall Street
P.O. Box 636
Oconomowoc, WI 53066
(800) 331-4332

* currently in use by some pallet companies

Appendix E. Grading and Species Classifications

Table E-1. The Pallet Design System (PDS) species classifications for hardwoods.

<table>
<tr><td colspan="5"><———— Increasing Strength <————</td></tr>
<tr><td>1</td><td>2</td><td>4</td><td>6</td><td>21</td></tr>
<tr><td rowspan="7">Hickories
Yellow Birch
Sweet Birch
Sugar Maple
Black Maple
Red Maple
Green Ash
White Ash
Beech
Rock Elm
Slippery Elm
Black Locust
Black Cherry
Eastern Oaks
Dogwood
Persimmon
Tanoak
Eucalyptus</td><td rowspan="2">Bigleaf Maple
Oregon Ash</td><td rowspan="4">Oregon White Oak
Ca. Black Oak
Cascara
Chinkapin
Myrtle
Madrone</td><td>Red Alder</td><td rowspan="2">VPI
Eastern Oak
File</td></tr>
<tr><td>7</td></tr>
<tr><td>3</td><td rowspan="3">Yellow Poplar
Eastern Cottonwood
Bigtooth Aspen
Quaking Aspen
Catalpa
Buckeye
Butternut
American Basswood</td><td>29</td></tr>
<tr><td rowspan="4">Sweet Gum
Black Tupelo
Water Tupelo
Cucumbertree
Southern Magnolia
Paper Birch</td><td rowspan="4">VPI
Yellow Poplar
File</td></tr>
<tr><td>5</td></tr>
<tr><td rowspan="2">Black Ash
Pumpkin Ash
Hackberry
Sycamore
Silver Maple
Striped Maple
Box Elder
Sassafras
Sugarberry</td><td>8</td></tr>
<tr><td>Black Cottonwood
Balsam Poplar</td></tr>
</table>

Table E-2. The Pallet Design System (PDS) species classifications for softwoods.

<——— Increasing Strength <———			
11	12	13	14
Douglas Fir Western Larch Loblolly Pine Longleaf Pine Shortleaf Pine Slash Pine	Western Hemlock Mountain Hemlock California Red Fir Grand Fir Noble Fir Pacific Silver Fir White Fir	White Spruce Black Spruce Red Spruce Englemann Spruce Sitka Spruce Sugar Pine Western White Pine Ponderosa Pine Monterey Pine Jack Pine Red Pine Eastern White Pine Pitch Pine Pond Pine Spruce Pine Virginia Pine Subalpine Fir Balsam Fir Baldcypress Eastern Hemlock Western Red Cedar	Alaska Yellow Cedar Incense-Cedar Port-Oxford-Cedar Atlantic White Cedar Northern White Cedar Eastern Red Cedar

Table E-3. The NWPCA grading classifications for cut-stock material.

PRECISION GRADE

Nominal Hardwood Lumber Dimension	Resultant Hardwood Surfaced Dimension
1x4	13/16" x 3-5/8"
1x6	13/16" x 5-5/8"
1x8	13/16" x 7-1/2"
2x4	1-5/8" x 3-5/8"
3x4	2-5/8" x 3-5/8"
4x4	3-5/8" x 3-5/8"

PREMIUM GRADE

Nominal Hardwood Lumber Dimension	Resultant Hardwood Surfaced Dimension
1x4	13/16" x 3-5/8"
1x6	13/16" x 5-5/8"
1x8	13/16" x 7-1/2"
2x4	1-5/8" x 3-5/8"
3x4	2-5/8" x 3-5/8"
4x4	3-5/8" x 3-5/8"

"AA" GRADE

Nominal Hardwood Lumber Dimension	Resultant Hardwood Surfaced Dimension
1x4	13/16" x 3-3/4"
1x5	13/16" x 4-3/4"
1x6	13/16" x 5-3/4"
1x7	13/16" x 6-5/8"
1x8	13/16" x 7-1/2"
2x4	1-3/4" x 3-3/4"
3x4	2-3/4" x 3-3/4"
4x4	3-3/4" x 3-3/4"

"A" GRADE

Nominal Hardwood Lumber Dimension	Resultant Hardwood Surfaced Dimension
1x4	7/8" x 3-3/4"
1x5	7/8" x 4-3/4"
1x6	7/8" x 5-3/4"
1x7	7/8" x 6-5/8"
1x8	7/8" x 7-1/2"
2x4	1-3/4" x 3-3/4"
3x4	2-3/4" x 3-3/4"
4x4	3-3/4" x 3-3/4"

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