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# Exploring Reliability of Oriented Strand Board's Tensile and Stiffness Strengths

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**Abstract.** In this paper, we apply insightful statistical reliability tools to manage and seek improvements in the strengths of Oriented Strand Board (OSB). As a part of the OSB manufacturing process, the product undergoes destructive testing at various intervals to determine compliance with customers' specifications. Workers perform these tests on sampled cross sections of the OSB panel to measure the tensile strength, also called internal bond (IB), in pounds per square inches until failure. Additional stiffness strength tests include parallel and perpendicular elasticity indices (EI), which are taken from cross sectional samples of the OSB panel in the parallel and perpendicular directions with respect to the orientation of the wood strands. We explore both graphically and statistically these "pressure-to-failures" of OSB. Also, we briefly comment on reducing sources of variability in the IB and EI of OSB.

***Key words:*** *exploring reliability graphically and statistically, reliability, internal bond, panel stiffness, elasticity index, Oriented Strand Board, lognormal, Weibull, loglogistic.*

# 1. INTRODUCTION

Oriented Strand Board (OSB) is a structural engineered wood composite panel consisting of mats formed from wood strands of approximately 0.030 inches in thickness, 2 inches in width and 4 inches in length. The mats are pressed under heat and pressure in both multi-opening and continuous presses. OSB is used in residential and non-residential construction for sheathing in walls, floors, and roofs (Figure 1.1). OSB is the most commonly used structural engineered wood panel in new residential housing construction in North America. It is the sheathing panel of choice in North America, since it is engineered with great uniformity and strength. See http://www.osbguide.com/faqs/faq1.html. The industry is currently experiencing unprecedented growth in North America in new mill startups and mill capacity expansion. Since 1990, new startups of mills have increased by 85% to 65 mills, while production capacity has increased by more than 100%, to a record 28 billion square feet per year (Adair 2005).

OSB is aggressively replacing plywood as the primary sheathing used in new construction in North America. Approximately 65% of the 43 billion square feet of construction sheathing used in 2005 consisted of OSB, while the remaining 35% consisted of plywood sheathing (Adair 2005). Plywood sheathing continues to decline in use for construction sheathing. Note 73% percent of all OSB sheathing produced is used in residential housing construction.

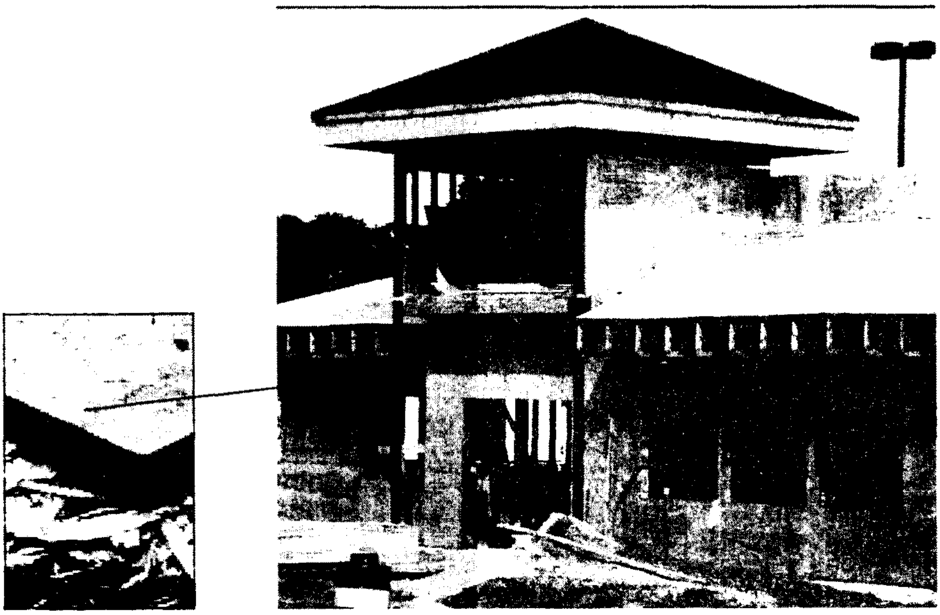


**Figure 1.1.** Illustration of OSB wood strands, panels and uses in construction.

Residential housing construction in the U.S.A. is predicted to decline from a record of almost 2.0 million annual new housing starts in 2005 to approximately 1.8 million housing starts by 2010 (Adair 2005). This projected 10% decline in housing starts, in conjunction with recent OSB capacity expansion, implies OSB producers will face tremendous downward pressure on pricing. These business pressures will require OSB manufacturers to maintain a strong focus on reliability, quality, and cost. The reliability methods outlined in this paper can be used to improve the quality of OSB sheathing, plus help lower manufacturing costs by reducing raw material inputs and by proactively preventing potential wasted OSB. See Guess and Proschan (1988), Guess, Hollander and Proschan (1986), Guess, Walker, and Gallant (1992), Young and Guess (1994), Young, and Guess (2002), Guess, León, Chen, and Young (2004), Guess, Zhang, Young, and León (2005) for discussions on various measures and approaches to understanding reliability.

Data quality is an important issue for modern manufacturers, especially OSB manufacturers, given current and future economic pressures in that sector. In most industrial settings, real-time and destructive data often will have outliers, missing values or require sorting for the final product type. Improved statistical analysis, and ultimately improved product quality, will result from improved data quality. For excellent guidance in this crucial area see these very helpful books (and their abundant references): English (1999), Huang, Lee and Wang (1999) and Redman (1996, 2001).

This paper explores reliability analysis via graphs, descriptive statistics, and assessments. Sections 2 and 3 study respectively OSB's tensile strength, called internal bond (IB), then OSB's stiffness strength (EI) by graphical and statistical analyses from S-PLUS and the add-on SPLIDA. For information on the statistical software S-PLUS, see http://www.insightful.com/products/default.asp. For information on the freeware add-on, SPLIDA, developed by Professor William Meeker, visit his web site: http://www.public.iastate.edu/~splida/. See the wonderful tome, Meeker and Escobar (1998). Additionally, we employ SAS's JMP, statistical discovery software, http://www.jmp.com. Tutorials on the use of these packages for reliability applications can be found at Professor Ramón León's course webpage at http://web.utk.edu/~leon/. Section 4 provides concluding comments.

## 2. EXPLORING GRAPHICALLY AND STATISTICALLY RELIABILITY OF TENSILE STRENGTH (IB) IN OSB

Our analysis begins with descriptive statistics of the internal bond strengths. The data set was obtained from a modern OSB manufacturer located in the southeastern United States. The OSB manufacturer uses southern pine species wood and phenol resin during the manufacturing process. Our first step is calculating means, medians, percentiles, etc; our second step is producing box plots and histograms of the OSB strength data. We want to first understand means, medians, percentiles, box plots, and histograms of the strengths of OSB. See, for example, Guess, Walker, and Gallant (1992) for how different measures of reliability can be used Compare, also, Guess, Edwards, Pickrell and Young (2003) for work on the modern engineered wood of medium density fiberboard.

Table 2.1 is a summary of descriptive statistics of internal bond that characterizes the location, variability, and shape of this data set. The mean and median are location statistics. The standard deviation, coefficient of variation, and interquartile range (IQR) are variability statistics. The shape of the data can be further characterized by skewness and kurtosis. Skewness measures the direction and degree of asymmetry. A positive value indicates skewness (long tailed) to the right while a negative value indicates skewness to the left. The value of 0.43 in this data suggests a mild positive skewness.

**Table 2.1.** OSB internal bond (IB) descriptive statistics.

| Statistics | IB (psi) |
|---|---|
| Mean | 49.7 |
| Median | 48.5 |
| Standard Deviation | 11.3 |
| Coefficient of Variation | 22.7 |
| IQR | 15.6 |
| Min | 15.3 |
| Max | 90.0 |
| Skewness | 0.43 |
| Kurtosis | 0.02 |

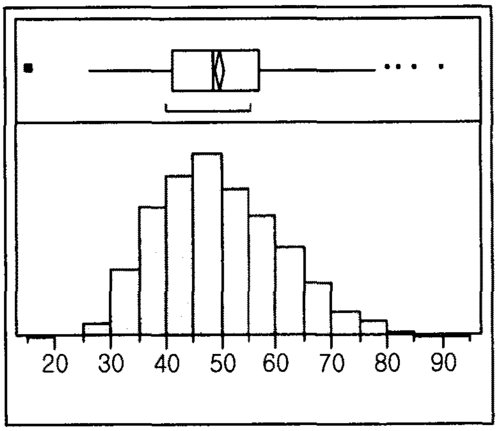


**Figure 2.1.** OSB internal bond histogram and boxplot from JMP.

The histogram is an effective graphical technique for showing both the skewness and kurtosis of the data set. The histogram in Figure 2.1 indicates that the internal bond is neither symmetrical nor normally distributed. Boxplots are one of the more used visual tools for summarizing a set of data measured on an interval scale. They are often utilized to show the shape of the distribution, its central value, variability, and outliers. In a boxplot graph, any points outside the whisker and the box are possible outliers. The boxplot in Figure 2.1 indicates a potential outlier that is far less than the other observations in the data. This possible outlier is highlighted as a thicker point to the left side of the box plot.

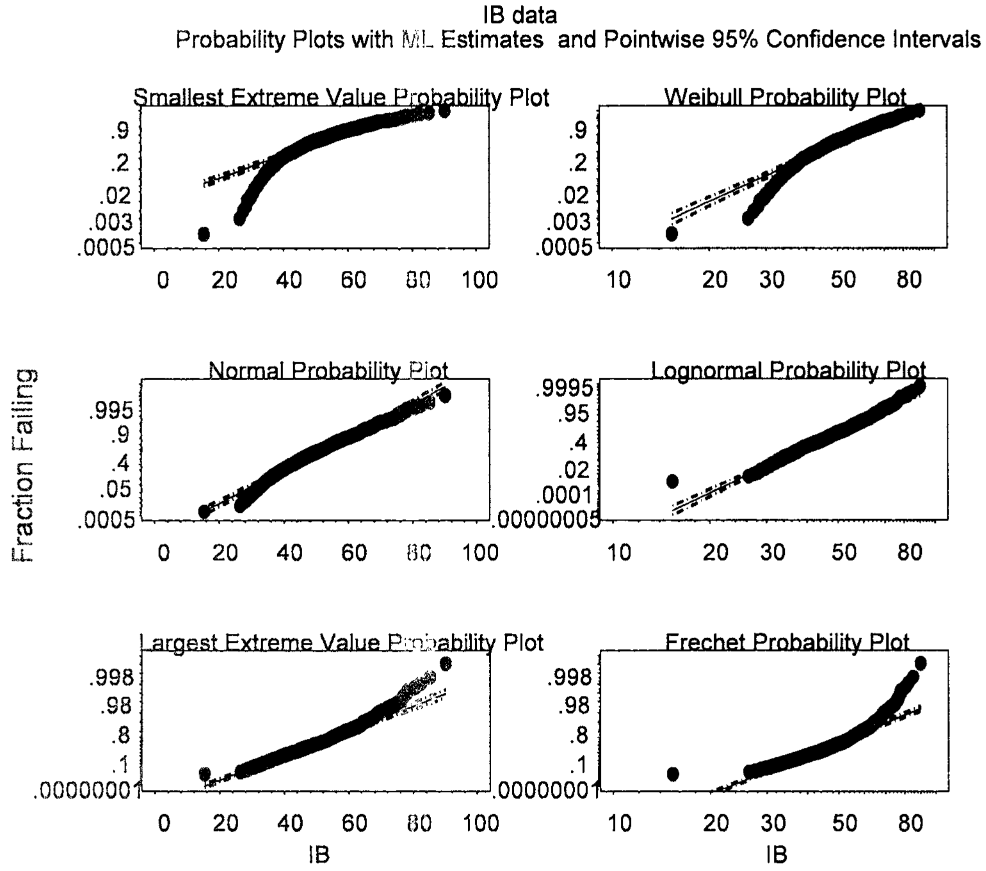


**Figure 2.2.** OSB internal bond probability plots from S-PLUS and SPLIDA.

Probability plots are one of the most commonly used graphical techniques in the analysis of reliability data, because they are powerful visual tools that clearly demonstrate how a particular data set fits a specific candidate probability distribution(s). The data are ordered and then plotted against the theoretical order statistics for a desired distribution. If the data set "conforms" to a particular distribution, the points will form a straight line. Simultaneous confidence bands, along with pointwise confidence intervals (see Meeker and Escobar, 1999) can provide objective assessments of deviation from the line. Data points outside the confidence bands are shown to deviate from the candidate probability distribution in question. See Chapter 6 of Meeker and Escobar (1998) for further information. Smallest extreme value (SEV), lognormal, largest extreme value (LEV), Frechet, normal, and Weibull probability plots were produced for this OSB internal bonding data using S-PLUS and SPLIDA.

From Figure 2.3, we see that, except for an outlier, the lognormal probability plot appears to fit the data best. The other probability plots have both outlier(s) plus departure in the lower or the upper tail. After the lognormal, according to Akaike's Information Criterion (AIC), the normal and loglogistic distributions fit the data best followed by the logistic, Weibull, Frechet, and SEV distributions. The probability plots provide a visual, subjective method for assessing the underlying distribution for the different product types. The lognormal distribution was determined to be a reasonable fit compared to Weibull, normal, plus five other distributions (we do not show all distributions here to save space).

Table 2.2 presents the log likelihood and AIC scores of select models. These serve as quantitative evidence of the best-fitting distribution model. The AIC for model selection (Akaike, 1973, Bozdogan, 2000) favors the model that minimizes AIC scores based on the same data. Therefore, the lognormal fit is the best approximating model for the data. The AIC scores from the data without the outlier are smaller than the complete data, which is more empirical evidence that observation number 144 is indeed an outlier.

**Table 2.2.** Selected model scores for the internal bond data, complete and excluding outliers.

| Model fit | Complete data | | Data with one outlier excluded | |
|---|---|---|---|---|
| | Log likelihood | AIC | Log likelihood | AIC |
| Lognormal | **-2026** | **4056** | **-2011** | **4026** |
| SEV | -2106 | 4216 | -2100 | 4204 |
| Normal | -2032 | 4068 | -2024 | 4052 |
| Weibull | -2047 | 4098 | -2040 | 4084 |
| Loglogistic | -2032 | 4068 | -2022 | 4048 |
| Logistic | -2038 | 4080 | -2031 | 4066 |
| LEV | -2035 | 4074 | -2017 | 4038 |
| Frechet | -2082 | 4168 | -2048 | 4100 |

The reliability/survival function assesses the probability that the product will survive beyond a specified "time" or "pressure." In our data, pressure to failure is measured. Kaplan-Meier plots (also called the Product Limit graphs) are one of the most popular survival plots. The Kaplan-Meier plot is a simple way of computing the survival curve in spite of troublesome data challenges, such as censored data. As we can see from the

Figure 2.3, survival of OSB declines as pressure increases. For example, the probability that IB will be greater than 50 psi is approximately 0.50, while the probability that IB is greater than 65 psi is approximately 0.10. Statistically, 5% of OSB failed before a pressure of 33 psi and 95% of OSB failed before a pressure of 68 psi. The Kaplan-Meier plot for this OSB data set indicates that pressure to failure decreases at increasing rates between 35 and 65 psi.

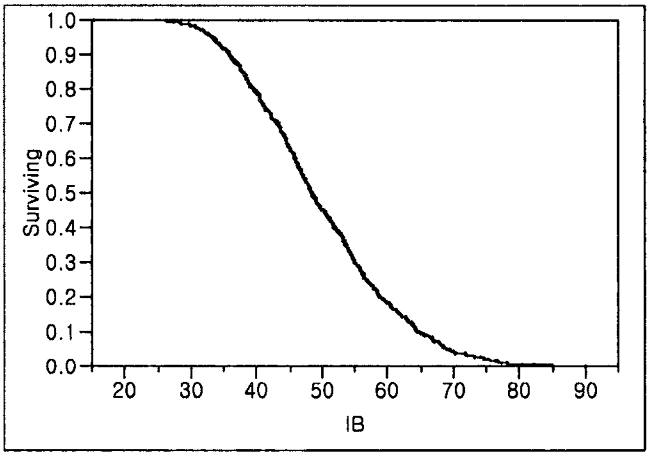


**Figure 2.3.** Reliability Kaplan-Meier Plot of internal bond of OSB.

The practitioner may use the Kaplan-Meier plots as an exploratory tool to estimate the effects of different wood and resin inputs for new product development, by comparing plots for the different rates. These comparisons may be very helpful for minimizing raw material inputs, while maintaining product reliability and reducing sources of variation.

## 3. EXPLORING GRAPHICALLY AND STATISTICALLY RELIABILITY OF STIFFNESS STRENGTH PARALLEL (EI) IN OSB

Table 3.1 is the summary of OSB parallel EI descriptive statistics. The skewness is 0.90, which indicates a positive skewness. The Kurtosis is 2.69, which indicates a "peaked" distribution.

The histogram and box plot are used to show the shape of the data. In Figure 3.1, the histogram appears slightly non-symmetrical, having an obvious right tail when compared to the normal distribution. The box plot is a graphic that displays the center portions of the data and some information about the range of the data. There are three points on the left side of the whisker plus more than 10 points on the right side of the whisker, with an obvious gap between points on the right side. The distance of this gap is almost the value of the IQR. Therefore, we consider the three points on the far right side of the whisker and the three points on the left side of the whisker as outliers. In the following probability plots, the data excluding these six outliers are used.

**Table 3.1.** OSB parallel EI descriptive statistics.

| Statistics | Parallel EI (psi) |
|---|---|
| Mean | 58212 |
| Median | 57860 |
| Standard Deviation | 4205.7 |
| Coefficient of Variation | 7.22 |
| IQR | 4831 |
| Min | 45903 |
| Max | 79499 |
| Skewness | 0.90 |
| Kurtosis | 2.69 |

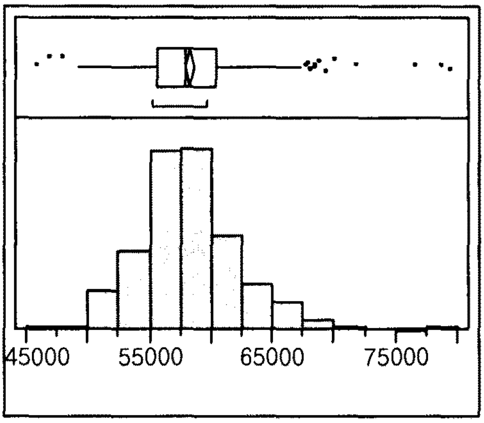
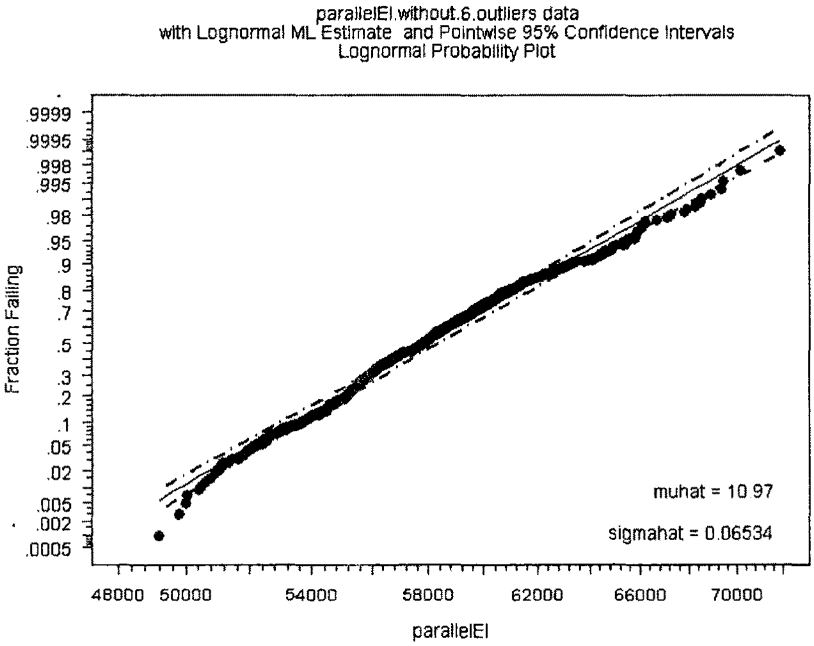
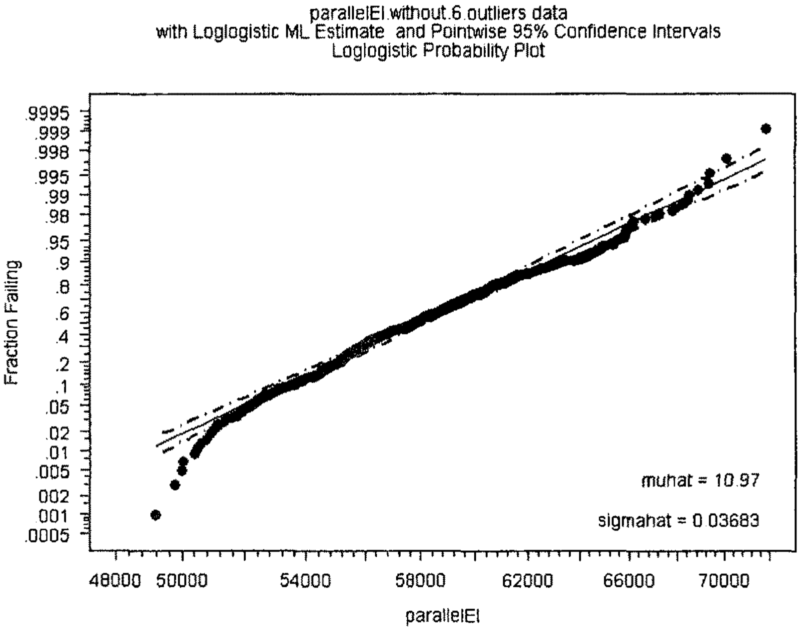


**Figure 3.1.** OSB parallel EI histogram and boxplot from JMP.

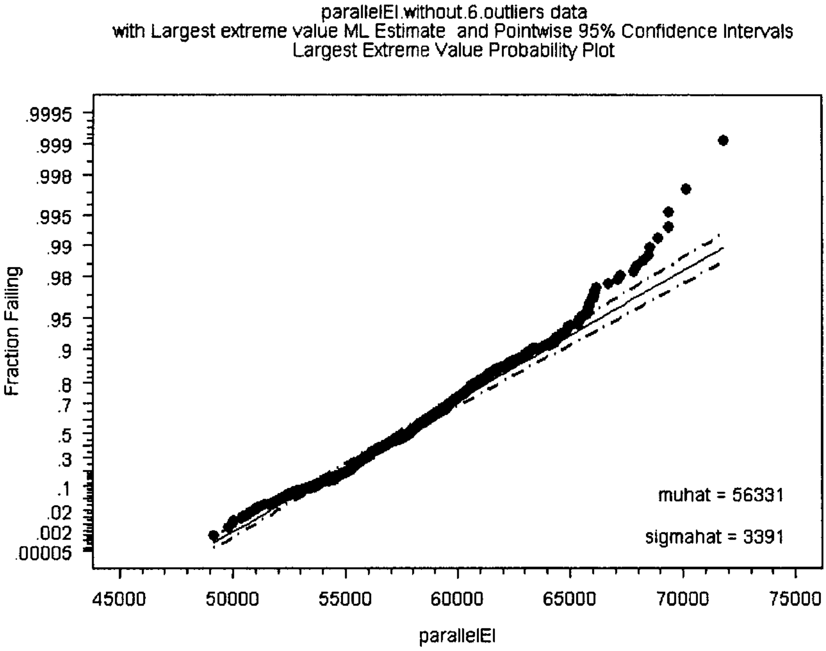
Probability plots for the lognormal, loglogistic, and largest extreme value distributions are shown in Figure 3.2. The lognormal distribution appears to be the best fit for the Parallel EI, followed by the loglogistic, and next the largest extreme value distributions, respectively. These probability plots are consistent with the AIC scores shown in Table 3.2 for the data with the six outliers excluded.



(a) Lognormal plot



(b) Loglogistic plot



(c) Largest extreme value plot

**Figure 3.2.** OSB parallel EI probability plots from S-PLUS and SPLIDA

Note that Table 3.2 illustrates the log likelihood and AIC scores of select models. These scores provide quantitative evidence for choosing the best distribution for the data. Before the six outliers are removed, the AIC score of loglogistic model had the lowest score, while the lognormal was third lowest among some of the most common models for reliability data. After the outliers were removed, the lognormal model of stiffness strength had the lowest AIC score, which is consistent with the AIC lognormal model selected for the IB data of the previous section. The overall AIC scores became smaller after the outliers were removed, providing additional evidence that these observations are indeed outliers.

**Table 3.2.** Selected model scores for the parallel EI data complete and excluding outliers.

| Model fit | Complete data | | Data with 6 outliers excluded | |
|---|---|---|---|---|
| | Log likelihood | AIC | Log likelihood | AIC |
| Lognormal | -5151 | 10306 | **-5052** | **10108** |
| SEV | -5301 | 10606 | -5143 | 10290 |
| Normal | -5164 | 10332 | -5059 | 10122 |
| Weibull | -5259 | 10522 | -5159 | 10322 |
| Loglogistic | **-5140** | **10284** | -5053 | 10110 |

| | | | | |
|---|---|---|---|---|
| Logistic | -5147 | 10298 | -5058 | 10120 |
| LEV | -5158 | 10320 | -5057 | 10118 |
| Frechet | -5173 | 10350 | -5066 | 10136 |

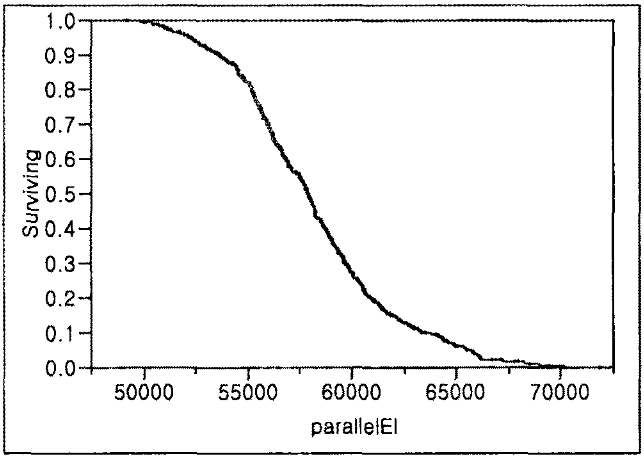


**Figure 3.3.** Reliability Kaplan-Meier plot of parallel EI of OSB.

Nonparametric plots and analysis are also important for reliability data analysis. Compare Walker and Guess (2003). The Kaplan-Meier plot is illustrated again in Figure 3.3 to capture the reliability function of Parallel EI of OSB.

From Kaplan-Meier estimates, 95% of the Parallel EI of OSB can survive at 52219 psi, while 5% of the Parallel EI of OSB can survive at 65435 psi. Half of the Parallel EI of OSB can survive at 57856 psi. This information is helpful for OSB manufacturers and end users. In addition, two different groups of Parallel EI of OSB can be plotted together. By comparing the Kaplan-Meier curves from different groups of OSB, manufacturers may improve product quality, while minimizing raw material inputs and reducing sources of variation.

## 4. CONCLUSIONS

In conclusion, we find that graphically and statistically exploring OSB reliability, as measured by IB and Parallel EI, provides valuable information about OSB. OSB is an important structural panel widely used in residential construction for roof, wall, and flooring sheathing. The reliability of a house is directly related to the reliability of the OSB sheathing that is used as part of its construction. The authors are not aware of any other published papers that study OSB reliability via Kaplan-Meier survival curves and related SPLIDA probability plots. The reliability results from this work may directly help OSB manufacturers understand the strength measures of the OSB product and facilitate the long term reduction in variation of the product. See Young and Guess 2003 for a similar study on medium density fiberboard. Parallel EI of OSB had six outliers, compared with one outlier for IB. This may suggest the need for process improvements in forming the mats of OSB, which greatly affect panel stiffness.

Observation number 144 had an extremely small IB of 15.3 psi. This outlier might be the result of a simple typo during data entry or may indicate a more serious problem, such as an infant mortality mode of failing strength of manufactured OSB, etc.

Descriptive statistics, graphs, and survival plots are powerful and insightful tools that may help us understand the reliability of the data, indicate sources of variation, and suggest opportunities for process improvement. Two software packages were used to validate this analysis from a vast suite of other statistical software packages; compare Deming (1986 and 1993). Future work will include estimating confidence intervals on the lower percentiles, plus exploring further sources of variation.

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