Final Report

AN INVESTIGATION OF ROUNDWOOD TRUCK TURN-TIME COST PENALTIES TO THE WOOD SUPPLY SYSTEM

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ABSTRACT

The purpose of this study is to examine the relative efficiency of roundwood delivery cycle-times at mill woodyards. Delivery process cycle-time data is collected for 10,244 loads of roundwood delivered to various mills in a 9 state study area including: AL, FL, GA, LA, ME, MS, SC, TX, and VA. Arrival time at the mill, key points through the unloading process, and departure time are recorded using a pencil-and-paper survey form during the actual delivery process by 254 individual truck drivers. Drivers record basic mill and load information including: mill name, wood/load form, truck/trailer type, and unloading equipment used. In addition, observations are made concerning delivery delay causes, if any.

Information from mills having the best average turn-times is split from the sample into what is termed the benchmark group (N = 2,561). The benchmark group consists of 25% of all loads sampled and delivered to the 28 mills having the best average turn-times. Benchmark mills comprise 20 percent of the 140 mills sampled in this study with a sample load count equal or greater than 30 loads. Statistical qualities of the benchmark group are compared to the rest-of-sample (ROS) (N = 7,683) in order to estimate the potential efficiency gains that would be realized if the ROS group could match delivery cycle-times of the benchmark group. Based on benchmarking results, excessive variance in truck turn-time adds significant system costs to roundwood delivered in the study area.

Benchmark turn-time values provide a yardstick that can be used to measure truck turn-time efficiency at various mills. Analysis of the benchmark data reveals the average delivery cycle-time is 20.49 minutes [99%CI, 19.83-21.14 minutes]. At benchmark mills, the process is completed in 33 minutes or less 90% of the time, 42 minutes or less 95% of the time, and 74 minutes or less 99% of the time. In comparison, the average ROS delivery cycle-time is 32.49 minutes [99%CI, 31.75-33.22 minutes]. At ROS mills, the delivery process is completed in 60 minutes or less 90% of the time, 80 minutes or less 95% of the time, and 135.3 minutes 99% of the time.

Comparing the ROS group to the benchmark group, 60.1% of all ROS loads or 4,683 loads are above the benchmark mean total turn-time of 20.49 minutes versus 30.1% or 770 benchmark group loads above the benchmark mean total turn-time. If the ROS group could match the benchmark group in turn-time performance, it would save a net 15.3 minutes per load for each of the 4,683 loads or 1,191.9 truck hours in the ROS group. Given a direct system cost (DSC) range of $41.67 to $69.44 per truck hour, this amounts to a potential reduction in ROS marginal DSC of $49,666 to $82,766 or from $10.61 to $17.69 per load for the 4,680 (60.1%) ROS loads above the benchmark mean. Expanding to the study area, marginal DSC estimates range from $35.1 to $58.5 million.

In addition to potential reductions in DSC, all ROS loads with total turn-time values greater than a pre-selected benchmark upper bound incur indirect system cost (IDSC) to account for the opportunity cost of lost logging production due to excessive variance in truck turn-times. IDSC percentiles provide a range of breakpoints where accounting for the opportunity cost of lost logging production kicks in. ROS IDSC values are estimated by subtracting the benchmark effects from the sample. IDSC per truck hour ($24.42-$77.70) is multiplied by the potentially recoverable excess idle-time hours at each percentile for the ROS group. Potentially recoverable ROS marginal IDSC estimates are: $8.05 to $25.61 per load for the 31.5% of all ROS loads that are above the

benchmark 90 percentile upper bound (33 minutes), $9.57 to $30.44 per load for the 19.9% of all ROS loads that are above the benchmark 95 percentile upper bound (42 minutes), and $12.39 to $39.44 per load for the 6.0% of all ROS loads that are above the benchmark 99 percentile upper bound (74 minutes). Expanding to the study area, marginal IDSC estimates are as follows: $14.0 to $44.4 million at the 90 percentile, $10.5 to $33.3 million at the 95 percentile, and $4.1 to $13.0 million at the 99 percentile.

Study area marginal system cost estimates, the sum of DSC and IDSC, range from $102.9 million at the 90 percentile to $71.5 million at the 99 percentile. To put things into perspective, the average benchmark mill consuming 1.5 million tons of roundwood per year contributes virtually zero marginal cost to the wood supply system. On the other hand, the average ROS mill consuming 1.5 million tons of roundwood per year contributes a marginal $14.15 per load for 60.1% of all loads delivered or $477,763 in marginal DSC (60.1% * 56,180 loads @ 26.7 tons per load) plus an additional $297,835 in marginal IDSC at the 90-percentile level, or an additional $223,708 at the 95-percentile level, or an additional $87,337 at the 99-percentile level. Hence, the average ROS mill consuming 1.5 million tons of roundwood annually contributes either $775,598 or $701,471 or $565,100 respectively, in marginal system cost, depending on where the line is drawn and the opportunity costs of lost logging production kick in.

Measured variables that have a statistically significant effect on total turn-time include: month of delivery, mill name, wood/load form, unloading equipment used, and truck/trailer type. Month of delivery was originally included as a proxy for weather. However, normal seasonal weather patterns were non-existent during the study period. Hence, there is no empirically supported interpretation of the variable. The mill name variable results provide conclusive empirical evidence that a portion of the variance in truck turn-time is related to mill-specific factors across the sample. A small portion of the variance in turn-time is captured by the interaction effects of wood/load form * unloading equipment. For tree-length loads, wheel loader mean unloading time is 5.82 minutes [95%CI, 5.49-6.15 minutes]. For double bunk loads, wheel loader mean unloading time is 6.34 minutes [95%CI, 5.88-6.90 minutes]. For piggy-back loads, OH crane mean unloading time is 10.62 minutes [95%CI, 9.44-11.80 minutes]. For short-wood bolts, OH crane mean unloading time is 6.22 minutes [95%CI, 2.35-10.09 minutes]. For the other category, wheel loader mean unloading time is 4.49 minutes [95%CI, 2.80-6.18 minutes]. Empirical evidence suggests tree-length loads can, on average, be unloaded faster than double bunk or piggy-back loads regardless of unloading equipment used. In terms of time efficiency alone, wheel loaders out perform other unloading equipment types for the tree-length and double bunk wood/load forms while OH cranes out perform other equipment types for piggy-back, and short-wood bolts.

Driver reported delays offer some insight with respect to the causes of excessive variance in truck turn-time. For all case values greater than the 90-percentile benchmark of 33 minutes (N=2,661), driver reported delays focus turn-time process improvement attention on unloading equipment systems capacity (53.2% of reported delays) and unloading equipment utilization rates. Delays caused by unscheduled crane/loader downtime are significant (6.9% of reported delays). Another potential area of opportunity is human resources utilization. For example, delays due to scales being closed are 7.3% of the reported delays. Unloading delays due to lack of space comprise 10.3% of reported delays.

ACNOWLEDGEMENTS

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Regular Members
Alabama Loggers Council
Champion International Corporation (now IP)
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International Paper Company
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Professional Logging Contractors of Maine
South Carolina Timber Producers Association
Southeastern Wood Producers Association (FL & GA)
Temple-Inland Corporation
Texas Logging Council
Westvaco
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Associate Members
Tigercat
Caterpillar
Forest Resources Association

The Final Report highlights key accomplishments of the 12-month Roundwood Truck Turn-Time Study designed to document the extent of variance in truck turn-time at the mill, establish an industry benchmark truck turn-time, present a valid methodology for assigning dollar values to the system "time penalty" due to excessive variance in truck turn-time, and identify factors contributing to excessive variation in truck turn-time.

This independent survey is financially supported by WSRI member companies and logging associations. However, the analyses and interpretations presented by the authors do not necessarily represent official WSRI positions.

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EXECUTIVE SUMMARY

The transport cost function of the wood supply value chain is an important area to consider in terms of potential system-wide efficiency gains. Obvious reasons for examining log truck delivery cycle-time in the contexts of operational and economic efficiency are: (i) to determine if opportunities exist to increase efficiency and decrease costs, and if so, (ii) to estimate the amount of capital that potentially can be appropriated to help alleviate the perceived problem of excessive variance in truck turn-times. It boils down to a marginal cost/marginal benefit analysis. This research examines only the marginal cost side of the equation. Analyses presented in this report document the extent of variance in roundwood truck turn-time at the mill, establish an industry benchmark truck turn-time, provide a range of marginal system cost estimates associated with excessive variance in truck turn-time, and attempt to identify causal variables. Based on benchmarking results, excessive variance in truck turn-time adds significant system costs to roundwood volume delivered in the study area.

Primary Data Collection

- A total of 10,244 valid turn-time cases were collected beginning in February 2000 and ending in October 2000. The sample data was collected by 254 participating drivers representing 131 logging contractors with deliveries to 290 mills in 9 states. The study area reflects states with corporate and logging association/ council membership in WSRI and guaranteed cooperators at the time the project was initiated. The study area includes Alabama, Florida, Georgia, Louisiana, Maine, Mississippi, South Carolina, Texas, and Virginia representing 5,105 logging firms with annual production equal to 195,717,975 tons or 7.33 million loads of roundwood. Some 312 loads were collected in February, 475 loads in March, 770 loads in April, 1,023 loads in May, 2,054 loads in June, 1,828 loads in July, 2,684 in August, 989 in September, and 109 loads in October.
- Geographic distribution of the sample is approximately proportional to output levels by state as outlined in the original sampling design. Reported sample data by state is as follows: Alabama = 1,580 loads, Florida = 865 loads, Georgia = 1,472 loads, Louisiana = 1,137 loads, Maine = 768 loads, Mississippi = 1,637 loads, South Carolina = 780 loads, Texas = 1,512 loads, and Virginia = 493 loads.
- Overall, data quality is surmised to be excellent. 9,999 cases or 97.6% of the total 10,244 are weight scaled as opposed to stick scaled. 9,553 cases or 95.5% of the weight scaled cases have scale tickets attached with at least one clock time stamped on the ticket. As a quality control check, driver reported scale-to-scale turn-times are compared to scale ticket time stamps for 1,000 randomly selected cases. The resulting Pearson bivariate correlation coefficient is .994 for the 1,000 case sub-set, indicating a sampling error of $\pm$ 0.6%.

Truck Turn-Times and Benchmarking Results

- Benchmark (BM) and rest-of-sample (ROS) turn-time values are presented at three different percentiles **(Figure 1)**. Benchmark values are based on a sub-set of 2,561 loads (25% of the sample) representing all reported deliveries to 28 mills. Benchmark mills comprise 20 percent of the 140 mills with a sampling intensity ≥ 30. The benchmark mean turn-time is estimated at 20.49 minutes [99%CI, 19.83-21.14 minutes]. The benchmark 90-percentile upper bound = 33 minutes, 95-percentile upper bound = 42 minutes, and 99-percentile upper bound = 74 minutes. ROS values are based on a sub-set of 7,683 loads or the remaining 75% of the sample. Mean total turn-time for the ROS sub-set is estimated at 32.49 minutes [99%CI, 31.75-33.22 minutes]. The ROS 90-percentile upper bound = 60 minutes, 95-percentile upper bound = 80 minutes, and 99-percentile upper bound = 135.3 minutes.

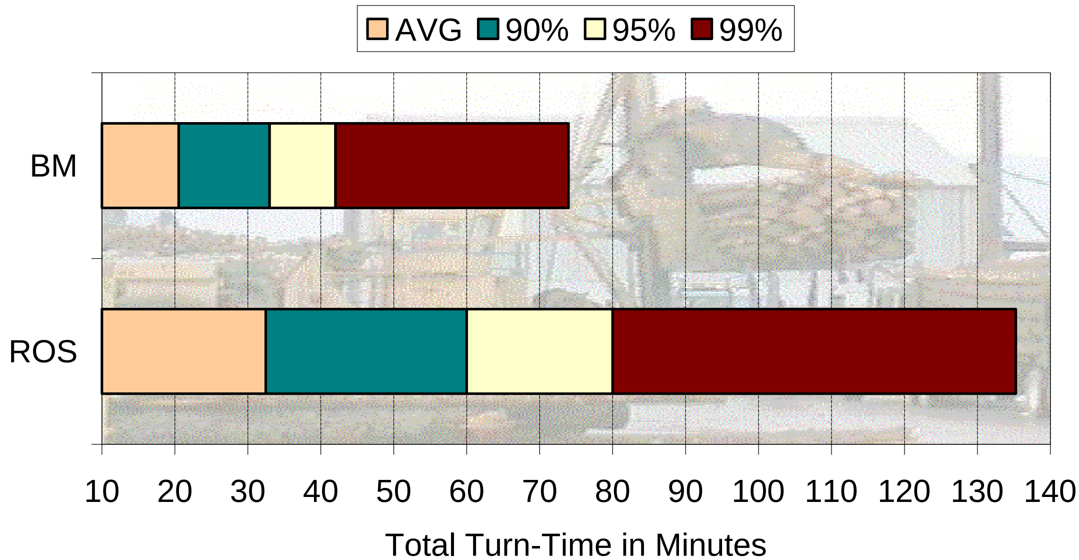


Figure 1. Benchmark and rest-of-sample turn-time intervals at the 90, 95, and 99 percentiles.

- For the benchmark (N=2,561), mean arrival to weigh-in = 3.83 minutes, mean weigh-in to crane/loader = 6.76 minutes, mean unloading time = 6.12 minutes, mean crane/loader to weigh-out = 4.22 minutes, mean scale-to-scale turn-time = 16.59 minutes, and mean total turn-time = 20.49 minutes. For the ROS sub-set (N=7,683), mean arrival to weigh-in = 8.17 minutes, mean weigh-in to crane/loader = 10.84 minutes, mean unloading time = 8.45 minutes, mean crane/loader to weigh-out = 5.20 minutes, mean scale-to-scale turn-time = 24.27 minutes, and mean total turn-time = 32.49 minutes.
- By activity, benchmark average net gains are as follows: arrival time to weigh-in +4.34 minutes (53.1% gain), weigh-in to crane/loader +4.08 minutes (37.6% gain), unloading time +2.33 minutes (27.6% gain), crane/loader to weigh-out +0.98 minutes (18.8% gain), scale-to-scale turn-time +7.68 minutes (31.6% gain), and total turn-time +12.00 minutes (36.9% gain). The Spearman (nonparametric) correlation coefficient between scale-to-scale turn-time and total turn-time (N = 9,972) is .846. In other words, a 0.85% reduction in mean scale-to-scale turn-time equates to a 1.0% reduction in mean total turn-time at the average sample mill.

Wood Supply System Cost Estimates

NOTE: log & haul costs (range $10-$25 per ton) used in this report are for illustrative purposes only and are not based on empirical results generated from this or other research. Only the turn-time minute/hour values, marginal minute/hour values, and potential minute/hour gains are empirically supported by this research.

- Wood supply system marginal cost estimates are the sum of direct system cost (DSC) and indirect system cost (IDSC) that can potentially be captured by reducing ROS (75% of all loads sampled) mean total turn-time and variance to benchmark levels (25% of all loads sampled). Reducing ROS mean total turn-time to the benchmark value implies reducing ROS variance to benchmark variance. Comparing the ROS sub-set to the benchmark sub-set, 4,680 or 60.1% of all ROS cases are above the benchmark mean total turn-time of 20.49 minutes. 2,110 or 27.1% of all ROS cases above the benchmark mean value can potentially be reduced by an average .370 hours per load. An additional 2,571 or 33% (expected value) of all ROS cases above the benchmark mean can potentially be reduced by an average .160 hours per load. Given a DSC range of $41.67 to $69.44 (mean = $55.56) per truck hour, this amounts to a potential reduction in ROS marginal DSC of 1,191.9 truck hours * [$41.67-$69.44] per truck hour or from $49,666 to $82,766. The per load equivalent is from $10.61 to $17.69 for the 4,680 (60.1%) ROS loads above the benchmark mean total turn-time value. DSC expansion to the study area (AL, FL, GA, LA, ME, MS, SC, TX, and VA) is accomplished by multiplying the net ROS percentage of recoverable cases by 75% of total annual logging output (5.5 million loads) in the study area then, multiplying by the marginal DSC per load. Study area marginal DSC estimates range from $35.1 to $58.5 million.
- In the context of statistical process control, estimation of IDSC requires that a benchmark upper bound percentile value be chosen as a point of reference. IDSC percentiles provide a range of breakpoints where accounting for the opportunity cost of lost logging production kicks in. ROS cases with total turn-time values greater that the benchmark upper bound incur IDSC. The net effects or net ROS IDSC values are estimated by subtracting the benchmark effects from the sample. At the 90 percentile, 21.5% of ROS total turn-time cases can potentially be reduced by an average .425 hours per load. An additional 10% (expected value at the 90 percentile) of the ROS cases can be reduced by an average .125 hours per load. At the 95 percentile, 14.9% of ROS cases can potentially be reduced by an average .480 hours per load. An additional 5% (expected value at the 95 percentile) of the ROS cases can be reduced by an average .129 hours per load. At the 99 percentile, 5.0% of ROS cases can potentially be reduced by .584 hours per load. An additional 1.0% (expected value at the 99 percentile) of the ROS cases can be reduced by an average .127 hours per load.
- IDSC per truck hour ($24.42-$77.70) is multiplied by the potentially recoverable excess idle-time hours at each percentile for the ROS sub-set. Potentially recoverable ROS marginal IDSC estimates are as follows: [$19,506 to $62,065] or [$10.61 to $17.69 per load] for the 31.5% of all ROS loads that are above the

benchmark 90 percentile, [$14,630 to $46,550] or [$9.57 to $30.44 per load] for the 19.9% of all ROS loads that are above the benchmark 95 percentile, and [$5,714 to $18,182] or [$12.39 to $39.44 per load] for the 6.0% of all ROS loads that are above the benchmark 99 percentile. IDSC expansion to the study area (AL, FL, GA, LA, ME, MS, SC, TX, and VA) is accomplished by multiplying the net ROS percentage of recoverable cases by 75% of total annual logging output (5.5 million loads) in the study area then, multiplying by the average expected gain per load. Study area IDSC estimates due to excessive variance in truck turn-times are as follows: [$14.0 to $44.4 million] at the 90 percentile, [$10.5 to $33.3 million] at the 95 percentile, and [$4.1 to $13.0 million] at the 99 percentile.

- Study area marginal system cost estimates, the sum of DSC and IDSC **(Figure 2),** are as follows: [$49.1 to $102.9 million] at the 90 percentile, [$45.6 to $91.8 million] at the 95 percentile, and [$39.2 to $71.5 million] at the 99 percentile. To put things into perspective, the average benchmark mill consuming 1.5 million tons of roundwood per year contributes virtually zero marginal cost to the wood supply system. On the other hand, the average ROS mill consuming 1.5 million tons of roundwood per year contributes an average $14.15 per load for 60.1% of all loads delivered or $477,763 in marginal DSC (60.1% * 56,180 loads @ 26.7 tons per load) plus an additional $297,835 in IDSC at the 90-percentile level, or an additional $223,708 at the 95-percentile level, or an additional $87,337 at the 99-percentile level. Hence, the average ROS mill consuming 1.5 million tons of roundwood annually contributes either $775,598 or $701,471 or $565,100 in marginal system cost, depending on where the line is drawn and the opportunity costs of lost logging production kick in.

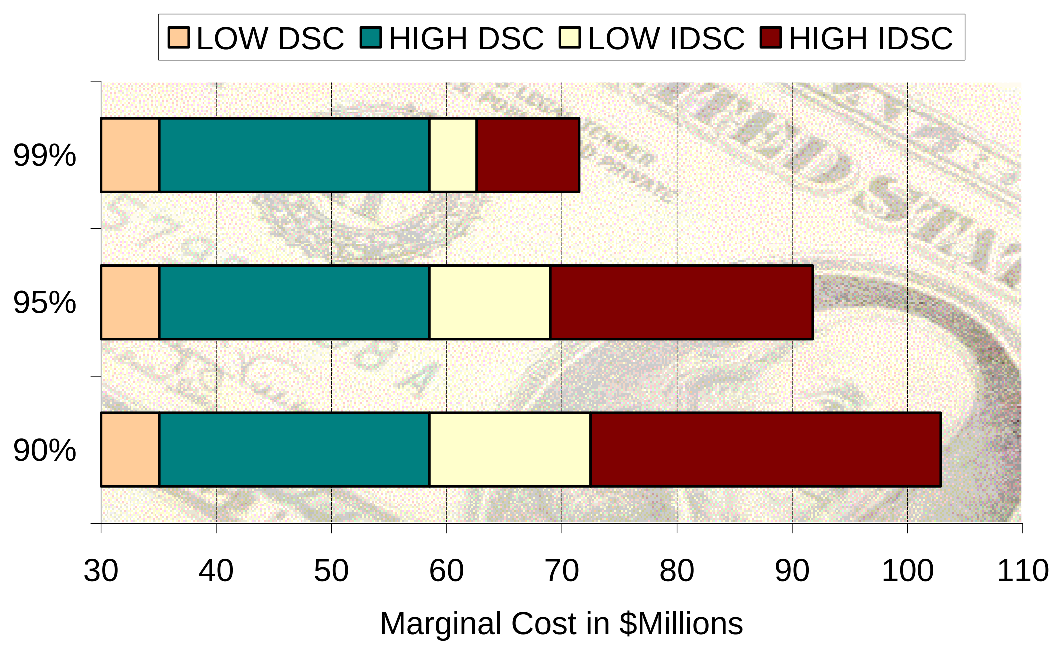


Figure 2. Study area marginal system cost estimates at the 90, 95, and 99 percentiles.

Variables Affecting Truck Turn-Time

- Univariate Analysis of Variance (ANOVA) is utilized to test the main effects of categorical variables with respect to total turn-time. The following variables are statistically significant above the 99% probability level: month of delivery, mill name, wood/load form, and unloading equipment used. Truck/trailer type is significant above the 95% probability level. Month of delivery was originally included as a proxy for weather. However, normal seasonal weather patterns were non-existent during the study period. Hence, there is no empirically supported interpretation of the variable. A purely subjective interpretation is that the month of delivery variable reflects variation in market conditions and roundwood delivery quotas during the data collection period.
- The mill name variable results provide conclusive empirical evidence that a portion of the variance in truck turn-time is related to mill-specific factors across the sample. The Univariate ANOVA model used to test for main effects of all driver observed variables accounts for 22.2% of the variance in total turn-time with mill name comprising 16.8% of the total variance accounted for. Implications for turn-time process improvement are far reaching and point to quantitative and qualitative mill-specific attributes not examined in this study. These attributes may include physical and operational characteristics of the woodyard, managerial attention to truck turn-times, and market factors.
- It is surmised that the wood/load form, unloading equipment, and truck/trailer type variables affect total turn-time by way of unloading time. Full factorial Univariate ANOVA is utilized to test both the main effects and interaction effects of wood/load form, unloading equipment, and truck/trailer type with respect to unloading time. The main effects of unloading equipment are significant above the 99% probability level. Interaction effects of wood/load form * unloading equipment are significant above the 95% probability level. However, only a small portion of the total variance in unloading time is captured by the tested variables. For tree-length loads, wheel loader mean unloading time is 5.82 minutes [95%CI, 5.49-6.15 minutes]. For double bunk loads, wheel loader mean unloading time is 6.34 minutes [95%CI, 5.88-6.90 minutes]. For piggy-back loads, OH crane mean unloading time is 10.62 minutes [95%CI, 9.44-11.80 minutes]. For short-wood bolts, OH crane mean unloading time is 6.22 minutes [95%CI, 2.35-10.09 minutes]. For the other category, wheel loader mean unloading time is 4.49 minutes [95%CI, 2.80-6.18 minutes]. Empirical evidence suggests tree-length loads can, on average, be unloaded faster than double bunk or piggy-back loads regardless of unloading equipment used. In terms of time efficiency alone, wheel loaders out perform other unloading equipment types for the tree-length and double bunk wood/load forms while OH cranes out perform other equipment types for piggy-back, and short-wood bolts.

Frequencies and Causes of Delays

- Considering all sample cases greater than the benchmark 90 percentile upper bound value (33.0 minutes) (N = 2,661), 1,391 unique cases reported a total of 1,571 delays at various points in the four activity turn-time process, i.e. arrival to weigh-in, weigh-in to loader, unloading, and loader to weigh-out. 1,212 or 87.1% of the cases recorded one delay during the turn-time process. 178 cases or 12.9% of the cases recorded two delay causes. One case recorded three delay causes. No cases recorded more than three delay causes. 529 cases of the 90-percentile sample reported a delay from arrival time to weigh-in. 681 cases reported a delay from weigh-in to crane/loader. 300 cases reported an unloading delay. 61 cases reported a delay from crane/loader to weigh-out.
- By delay cause **(Figure 3)**, 162 delays (10.3% of the responses) are "lack of space". 17 delays (1.1% of the responses) are "poor road conditions". 836 delays (53.2% of the responses) are "unloading equipment cannot keep up". 109 delays (6.9% of the responses) are "crane/loader breakdown". 2 delays (0.1% of the responses) are "truck breakdown". 114 delays (7.3% of the responses) are "scale closed". 3 delays (0.2% of responses) are "poor load quality". 28 delays (1.8% of responses) are "operator error". 2 delays (0.1% of responses) are due to "OSHA/DOT regulations. 298 delays (19.0% of responses) are "other".

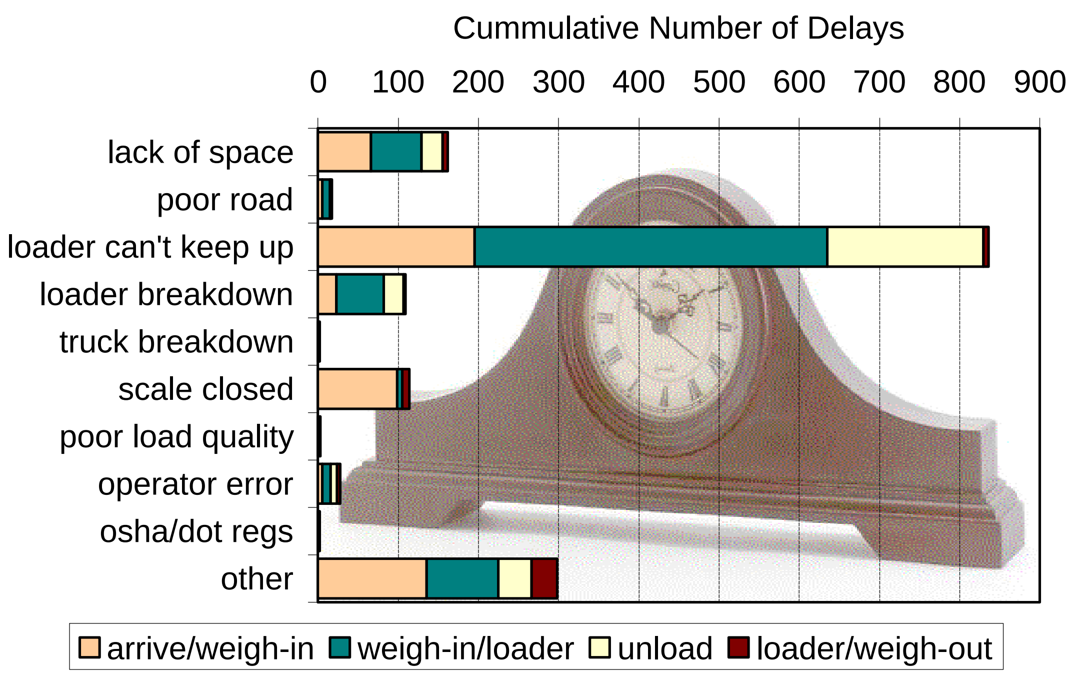


Figure 3. 90-percentile driver reported delay causes by turn-time process activity.

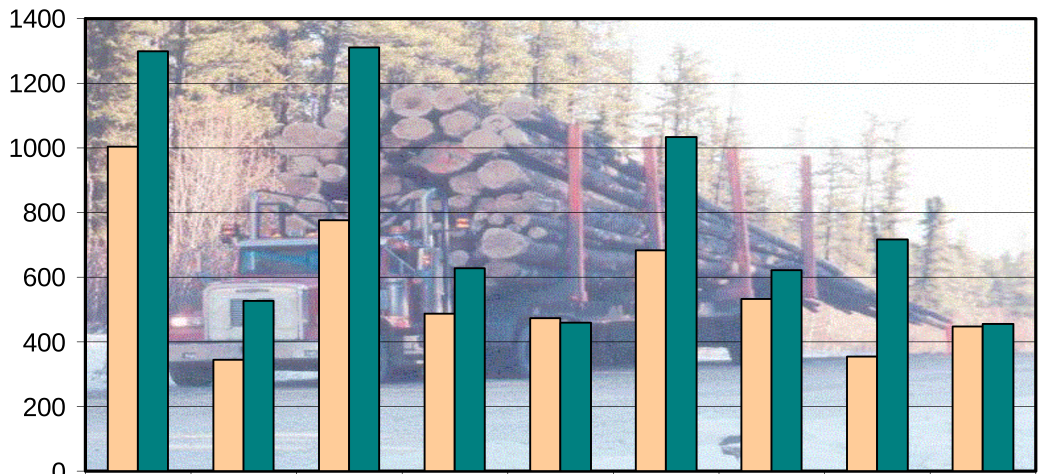
- Driver reported delays offer some insight with respect to the causes of excessive variance in truck turn-time. For all case values greater than the 90-percentile benchmark upper bound (33 minutes) (N=2,661), driver reported delays focus turn-time process improvement attention on unloading equipment systems capacity (53.2% of reported delays) and utilization rates. Delays caused by unscheduled crane/loader downtime are significant (6.9% of reported delays). Another potential area of opportunity is human resources utilization. For example, delays due to scales being closed are 7.3% of the reported delays. Unloading delays due to lack of space comprise 10.3% of reported delays. The relative importance of unloading delays due to lack of space during the study period may be inflated with respect to the long-term because unusually dry weather patterns and volatile market conditions caused mill woodyards to be packed near full capacity over the entire 12 month study period (only geographic exception is Maine).

Summary Statement

- The authors' analyses and interpretations provide answers to a few fundamental questions, as outlined by WSRI in the project deliverables. However, many questions with respect to the causes of excessive variance in truck turn-time are left unanswered. More specific process improvement recommendations are impossible to make based on empirical evidence generated from primary data collected because of the lack of mill-specific quantitative and qualitative data to support and explain the categorical differences. In effect, a significant proportion of the underlying causes of excessive variance in truck turn-times are mill specific and, most certainly, include a number of physical, managerial, and market factors that were not examined as part of this research project. Further research is required in order to statistically demonstrate and explain the relationships between the mill-specific causal factors and truck turn-time efficiency. The next obvious step is to compare the now established set of benchmark mills to a control group, examining mill-specific quantitative and qualitative variables that address physical, managerial, and product market factors.

BACKGROUND

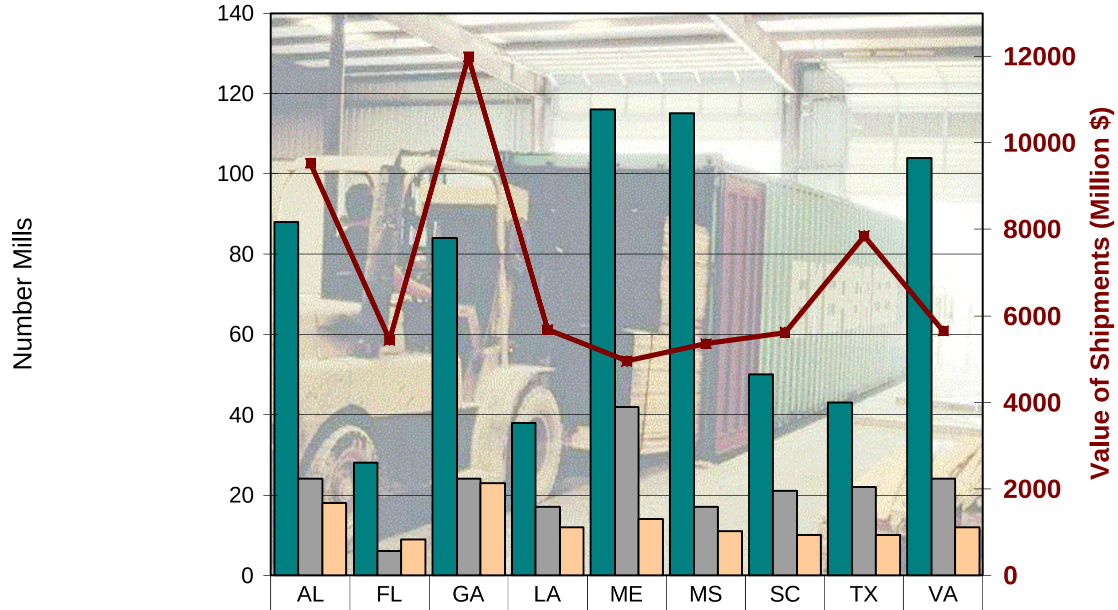
Approximately 5,105 logging firms in 8 Southern states and Maine produce a total of 7,052.9 million cubic feet of roundwood annually. This production furnishes 982 primary wood products manufacturing plants with the bulk of wood transport being by truck (approximately 7.33 million loads annually). A state-by-state breakdown of the number of logging firms and roundwood output is presented in **Figure 4**. Alabama, Georgia, and Mississippi are the leaders in terms of number of logging firms with 1,003, 777, and 684 respectively. When considering annual roundwood output, Georgia, Alabama, and Mississippi produce 1,311.5, 1,299.7, and 1,034 million cubic feet respectively. A state-by-state breakdown of the number of mills and value of shipments by type and state is presented in **Figure 5**. Maine, Mississippi, and Virginia are the leaders in number of primary manufacturing facilities with 172, 143, and 140 respectively. When considering value of shipments from primary manufacturing facilities as a measure of economic impact, Georgia, Alabama, and Texas, lead with shipments of $12.0 billion, $9.5 billion, and $7.8 billion respectively. By value of shipments, firms manufacturing primary forest products represent 8.4 percent of all manufacturing in the Southern U.S.



	AL	FL	GA	LA	ME	MS	SC	TX	VA
Loggers	1003	345	777	488	474	684	532	354	448
Output	1299.7	527	1311.5	627.2	459.9	1034	622	716	455.6

Sources: Logging firm data from US Dept. of Commerce, 1992 Census of Manufactures, Geographic Area Series. Roundwood production (million cubic feet) from USDA Forest Service, 1996, RB SRS-33.

Figure 4. Number of logging firms and roundwood production for 8 Southern states and Maine.



	AL	FL	GA	LA	ME	MS	SC	TX	VA
Sawmills	88	28	84	38	116	115	50	43	104
Ply&OSB	24	6	24	17	42	17	21	22	24
Paper Mills	18	9	23	12	14	11	10	10	12
Value Shipments	9532.7	5442.4	11988	5680.5	4954.7	5356.9	5610.6	7848.1	5652.7

Source: U.S. Dept. of Commerce, 1992 Census of Manufactures, Geographic Area Series.

Figure 5. Number of mills and value of shipments for 8 Southern states and Maine.

The wood supply value chain, from stump to mill, is broadly divided into two segments, logging and hauling. These activities need to be operating in balance with each other and in balance with mill demand in order to maximize the overall economic efficiency of the supply system. The contribution of excessive variance in roundwood truck turn-time, the time it takes to receive at the mill, unload, and return transportation assets to the road, is the focus of this research. An estimate of the wood supply system cost penalty with respect to excess truck idle-time requires consideration of the direct costs of truck idle-time and the opportunity costs associated with lost production at the logging site.

METHODS

Primary Data Collection

While scale-to-scale clock time gives an indication of truck turn-time, it does not account for time delays at the mill gate prior to weigh-in and gives no useful information with respect to identifying the factors that are relevant to excessive turn-times. Hence, primary data collection using a stratified sampling design is utilized in order to measure the range of variance associated with truck turn-time and to identify factors that have a statistically significant relationship with excessive variance in truck turn-time, while ensuring proportional geographic representation. Sample units are logging firms/truck drivers geographically grouped by WSRI member/study cooperator state/regional logger's association/council **(Table 1)**. A total of eight Southern states and Maine are represented in the study.

Table 1. Roundwood truck turn-time sampling design.

Stratified Variable = State Logger's Association/Council	Sample Unit Population[a]	Percentage by Output[b]	Sample Units in Study	Sample Elements per Unit	Sample Elements (n =)
AL	1,003	20%	24	50	1,200
FL	345	8%	10	50	500
GA	777	20%	24	50	1,200
LA[c]	488	10%	12	50	600
ME	474	7%	8	50	400
MS	684	15%	18	50	900
SC	532	9%	12	50	600
TX	354	11%	12	50	600
subtotals	**4,657**	**100%**	**120**	**50**	**6,000[d]**
VA[e]	448	n/a	"determined by WSRI membership"		
totals	**5,105**	**"dependent on participation and budget constraints"**			

[a]Source for number of firms: U. S. DOC, Bureau of Census, 1992 Census of Manufactures, Geographic Series.
[b]Percent roundwood production (million cubic feet) from USDA Forest Service, 1996, RB SRS-33.
[c]Study cooperator is Louisiana Logging Council.
[d]Actual sample size determined by the number of willing participants, contractual time constraints, and contractual budget constraints.
[e]Virgina sample size determined by WSRI membership.

The sample units (logging firms/truck drivers) are distributed proportionally by weighting state level roundwood production volume requiring participation from a minimum 120 truck drivers. Potential participants (loggers/truck drivers) are identified from contacts provided by WSRI members and study cooperators. The final pool of participants is chosen based on referrals, initial level of interest, and geographic diversity.

Each driver records data for every load hauled reporting 50 consecutive loads delivered. Under "normal" operating conditions, it is estimated to take from 3 to 5 weeks for one driver to haul 50 loads, assuming an average 2.5 loads per day and 20 workdays per month. The logic behind the sampling scheme is threefold. First, by cycling through a minimum of 20 drivers each month, the burden of data collection is limited for any individual truck driver. Second, by recording every load hauled, there is no opportunity to be selective about which loads to report. Finally, the scheme allows for data to be collected in each state for the entire length of the data collection period at a rate proportional to state-by-state production levels.

When viewed as a flow process, roundwood truck turn-time can be disaggregated into a series of operations, material movements (transportation), predefined processes (e.g. weigh-in, unload, and weigh-out), and potential delays **(Figure 6)**. In this example, total turn-time is 45 minutes. If delays are eliminated, the process is completed in 30 minutes. Data collection procedures for weight scale mills require the driver to record clock time at each of five critical points in the turn-time process: (i) arrival time at the mill queue, (ii) arrival time at the in-bound scale, (iii) arrival time at the crane/loader, (iv) departure time from the crane/loader, and (v) arrival time at the out-bound scale. Loads delivered to stick scale mills require similar data records. Observable factors affecting each activity (delays) are recorded by the truck driver, if applicable. A list of nine factors potentially affecting truck turn-time is presented in **Figure 7**. The factors are divided into four groups: 1) Woodyard Layout & Maintenance, 2) Equipment Systems, 3) Human Resources, and 4) Regulatory. The nine factors are summarized and coded for use with the load data collection form. In addition, a limited set of mill and load attribute data is recorded by the truck driver. Variables derived by and recorded by the researchers based on scale ticket information and load data forms include: total turn-time, net load weight and number of work days required to haul 50 loads. A summary of all variables included in the study (total = 17) is presented in **Table 2**. The actual data collection form distributed to truck drivers **(Appendix A)** fits on one 81/2 by 11 inch piece of paper. Other data collection considerations are as follows:

- Load Type - limit load type to roundwood (no chip vans).
- Mill Type - minimize the number of loads delivered to small hardwood sawmills.
- Loads are tracked by individual driver and by destination; **a copy of the scale ticket must be attached to each completed load data collection form**, as a control, in order to ensure high quality data.

Time	Flow Process Activities	Activity Description	Apparent Problem (blank if none)
5 min.		**Wait** to weigh-in at scale	
2 min.		Weigh-in at scale **(clock time in)**	
5 min.		Drive to unloading point	
5 min.		Remove and store load binders	
5 min.		**Wait** to unload	
10 min.		Unload	
5 min.		Drive to scale	
5 min.		**Wait** to weigh-out	
3 min.		Weigh-out **(clock time out)**	
Total 45 min.			

Legend:

Operation **Transportation** **Predefined Process** **Delay**

Figure 6. Flow process chart for roundwood truck turn-time at weight scale mills.

I. Woodyard Layout & Maintenance	**Codes for Apparent Problem in Figure 6**	
1. Physical capacity of woodyard	1	Lack of inventory space
2. Road conditions	2	Poor road conditions in yard
II. Equipment Systems		
3. Equipment Unloading Capacity	3	Crane/Loader(s) can’t keep up
4. Equipment Utilization	4	Crane/Loader(s) breakdown
5. Unscheduled truck downtime (in yard)	5	Truck breakdown
III. Human Resources		
6. Scale (woodyard) hours of operation	6	Scale/woodyard not open
7. Load quality relative to mill specs	7	Poor load quality: tops, limbs
8. Operator error	8	Operator error
IV. Regulatory		
9. OSHA and DOT regulations	9	OSHA and DOT regulations
V. Other	10	Other

Figure 7. Observable Variables affecting roundwood truck turn-time.

Table 2. Summary of variables included in the roundwood truck turn-time study.

Variable	Measure	Key
Recorded by Driver		
Driver name	coded 1-120+	unique identifier
Mill name/location	coded 1-???	unique identifier
Scale method	coded 1-2	weight or stick (if MBF, specify log scale used)
Mill type	coded 1-6	pulp/paper, sawmill, plywood, OSB, chip mill, other
Wood/Load form	coded 1-6	tree-length single tier, cut-to-length single tier, double bunk, piggy-back, short bolts, other
Truck/trailer type	coded 1-5	road tractor w/frame trailer, road tractor w/pole trailer, x-axle truck, x-axle truck w/pup trailer, other
Unloading equipment	coded 1-6	single-pass OH crane, double-pass OH crane, single-pass wheel loader, double-pass wheel loader, knuckle boom, other
Unloading site	coded 1-2	at mill, off-site (i.e. overflow area, satellite yard)
Arrive at mill queue	numerical	clock time converted to minutes turn-time
Weigh-in or (arrive gate)	numerical	clock time converted to minutes turn-time
Arrive at crane/loader	numerical	clock time converted to minutes turn-time
Depart from crane/loader	numerical	clock time converted to minutes turn-time
Weigh-out or (out gate)	numerical	clock time converted to minutes turn-time
Delay cause, if any	coded 1-10	refer to Figure 7
Recorded by Researcher		
Total turn-time	numerical	sum of minutes turn-time
Load weight (net)	numerical	all volume units converted and recorded in tons
#days/loads hauled	numerical	number of work days required to haul 50 loads
Time of year	coded 2-10	recorded by month (i.e. February through October)

Data analysis procedures are completed using analytical routines supplied with SPSS for Windows™. Data analysis consists of a four-stage process. First, summary statistics are generated for load data and mill attribute data. Second, statistical process control procedures are used to establish the "time penalty" associated with excessive variance in truck turn-time. Third, the established "time penalty" is converted to dollar values. Finally, Analysis of Variance (ANOVA) procedures are used to identify factors (categorical data) that have a statistically significant relationship with variance in truck turn-time.

Truck Turn-Time and Benchmarking

Total turn-times are calculated for each case by summing the time interval required for each turn-time process activity, i.e. arrival to weigh-in, weigh-in to crane/loader, unloading time, and crane/loader to weigh-out. Sample mean total turn-time, variance, associated statistics, and analyses referred to in the report as "sample" are estimated using the entire data set (N = 10,244). Benchmark turn-time values are derived from the sample by first, ranking all mills in the study by mean total turn-time, then, identifying the upper quartile of loads/mills considering mills with a sampling intensity ≥ 30 cases. Benchmark values are estimated based on a sub-set comprising 25% of the sample cases representing all sampled deliveries to benchmark mills. Since the sample element is the load, benchmark total turn-time is based on 25% of the loads in the sample, not 25% of the mills in the sample. The actual number of mills used to define the benchmark depends on the number of cases (loads) delivered to each mill. This is a completely random assignment resulting in unequal sampling intensity of individual mills. Benchmark turn-time upper bound values are estimated at the 90 percentile, 95 percentile, and 99 percentile levels based on the actual frequency distribution of the benchmark sub-set (N = 2,561). Once the benchmark sub-set is defined the sample is split. The rest-of-sample (ROS) mean total turn-time, variance, associated statistics, and analyses referred to in the report as "ROS" are estimated using the ROS data sub-set, i.e. sample minus benchmark (N = 7,683). ROS turn-time upper bound values are estimated at the 90 percentile, 95 percentile, and 99 percentile levels based on the actual frequency distribution of the ROS sub-set.

Estimating Marginal System Costs

NOTE: log & haul costs (range $10-$25 per ton) used in this report are for illustrative purposes only and are not based on empirical results generated from this or other research. Only the turn-time minute/hour values, marginal minute/hour values, and potential minute/hour gains are empirically supported by this research.

Cost penalties to the wood supply system are estimated using principles of "synchronous" production by focusing on system bottlenecks and normal buffers. These principles have major implications for estimation of the opportunity costs associated with excessive variance in truck turn-times. Given the dynamics of log and haul, either activity can become a bottleneck for a particular logging contractor depending on equipment spread, unscheduled downtime, and a host of other variables. For the purposes of this research, it is surmised that there is a 50/50 probability of either logging or hauling being a production bottleneck at any given time (unless the operator is on a delivery quota) assuming balanced log/haul operations. Under a scenario of no artificial production restrictions, if a specific log/haul operation is not in balance (mismatched equipment), the cost of inefficiency is borne directly by the logger, not the system. In addition, if aggregate logging capacity in the study area is not in balance with aggregate demand for roundwood in the study area, the cost of inefficiency is borne by the wood supply system. For the purposes of this research, it is assumed that aggregate logging capacity and aggregate demand for roundwood is in balance in the study area.

The direct system cost (DSC) of excess variance in truck turn-time is estimated using a range of $300-$500 per day to own and operate a log truck assuming a logging season of 48 weeks per year and average productive machine hours (PMH) = 36 hours per week or 7.5 hours per day. The cost of owning and operating a log truck is converted to an hourly rate range of $41.67 to $69.44 per PMH **(Appendix B)**. 100% of the direct cost of truck idle-time greater than benchmark mean total turn-time value is accrued as DSC because regardless of whether or not hauling is a bottleneck at any point in time, in an otherwise balanced log-haul operation, excessive truck idle-time cannot be recovered. While wood can be decked on a landing and stored for a short period of time (normal buffer), the haul function is not storable. The only way for a logging contractor to offset (buffer) excessive truck turn-time is to increase haul capacity above what would be required with more efficient truck turn-times. This directly impacts (increases) the system cost of the haul activity.

Estimation of the indirect system cost (IDSC) of excessive variance in truck turn-time requires that a benchmark upper bound percentile value be chosen as a point of reference. IDSC percentiles provide a range of breakpoints where accounting for the opportunity cost of lost logging production kicks in. IDSC is derived by assigning a per truck hour dollar value to lost production at the logging site, reflecting the opportunity cost on a per truck hour basis. Per truck hour value is the average cost of logging per hour divided by the average number of trucks per firm. Average number of trucks per firm is estimated by determining how many trucks are required to haul average annual production. Average firm size and productivity is estimated using published U.S. Bureau of Census data and U.S.D.A. Forest Service data. Cost of logging estimates range from $48.84 to $155.40 per truck hour, assuming a 48 week logging season, average PMH = 36 hours per week, and average number of trucks per firm = 2.5. IDSC is accrued on a 50 percent basis (range = $24.42 to $77.70 per truck hour) or the proportion of time that logging is surmised to be a bottleneck **(Appendix B)**. Summing the turn-time minute values that are outliers at the 90, 95, and 99 percentiles and subtracting the benchmark upper bound turn-time values for each percentile facilitates calculation of the IDSC "time penalty" due to excessive variance in turn-times. The time penalty is converted to a system "cost penalty" estimate by multiplying the excess truck idle-time by the IDSC per truck hour.

RESULTS & DISCUSSION

Primary Data Collection and Quality Control

A total of 10,244 valid turn-time cases were collected by 254 participating truck drivers with roundwood deliveries to 290 mills. 312 loads were collected in February, 475 loads in March, 770 loads in April, 1,023 loads in May, 2,054 loads in June, 1,828 loads in July, 2,684 in August, 989 in September, and 109 in October. All state level data collection targets, as outlined in the contract, were substantially exceeded **(Table 3)**. Geographic distribution of the sample is approximately proportional to output levels by state as outlined in the original sampling design. Load data from Virginia is supplied by a WSRI member company and is additional to the original sample design. Reported cases are as follows: Alabama = 1,580 loads, Florida = 865 loads, Georgia = 1,472 loads, Louisiana = 1,137 loads, Maine = 768 loads, Mississippi = 1,637 loads, South Carolina = 780 loads, Texas = 1,512 loads, and Virginia = 493 loads. Geographic distribution by mill type **(Table 4)** is completely random depending on the product mix and delivery patterns of the individual logging contractors/drivers participating in the study. A total of 4,548 loads were delivered to pulp/paper mills, 3,166 loads were delivered to sawmills, 781 loads were delivered to plywood mills, 315 loads were delivered to OSB mills, 1,265 loads were delivered to chip mills, and 169 loads were delivered to other.

Overall, data quality is surmised to be excellent. 9,999 cases or 97.6% of the total 10,244 are weight scaled as opposed to stick scaled. Stick scaled loads have no clock times on the scale ticket. 9,553 cases or 95.5% of the weight scaled cases have scale tickets attached with at least one clock time stamped on the ticket. As a quality control check, driver reported scale-to-scale turn-times are compared to scale ticket time stamps for 1,000 randomly selected cases. The resulting Pearson bivariate correlation coefficient is .994 for the 1,000 case sub-set, indicating a sampling error of ± 0.6%.

Table 3. Summary of load data collected by month and state.

State	Test Loads Feb	Actual Loads March	Actual Loads April	Actual Loads May	Actual Loads June	Actual Loads July	Actual Loads Aug	Actual Loads Sept	Actual Loads Oct	Sum Loads Project	Sample Intensity Targets
AL	42	21	64	295	262	160	505	207	24	**1,580**	1,200
FL	0	39	67	64	222	196	207	70	0	**865**	500
GA	0	0	117	180	502	159	300	163	51	**1,472**	1,200
LA[a]	34	104	117	116	205	386	137	38	0	**1,137**	600
ME	0	0	0	0	27	170	307	238	26	**768**	400
MS	74	207	167	137	272	135	593	52	0	**1,637**	900
SC	0	0	99	154	209	31	142	145	0	**780**	600
TX	89	58	102	54	281	516	399	13	0	**1,512**	600
subtotals	239	429	733	1,000	1,980	1,753	2,590	926	101	9,751	6,000
VA[b]	73	46	37	23	74	76	93	63	8	493	
Totals	312	475	770	1,023	2,054	1,828	2,684	989	109	**10,244**	

[a]Includes 73 loads delivered to border mills in AR.
[b]Includes 33 loads delivered to a mill in WV.

Table 4. Geographic distribution of sample by mill type.

Mill Type	State Delivered	N	% of Total N
pulp/paper	AL	831	8.1%
	FL	677	6.6%
	GA	565	5.5%
	LA	526	5.1%
	ME	422	4.1%
	MS	529	5.2%
	SC	268	2.6%
	TX	237	2.3%
	VA	493	4.8%
	Total	**4,548**	**44.4%**
sawmill	AL	495	4.8%
	FL	106	1.0%
	GA	470	4.6%
	LA	335	3.2%
	ME	168	1.6%
	MS	682	6.7%
	SC	294	2.9%
	TX	616	6.0%
	Total	**3,166**	**30.9%**
plywood	AL	81	.8%
	FL	24	.2%
	GA	79	.8%
	LA	170	1.7%
	MS	184	1.8%
	SC	9	.1%
	TX	234	2.3%
	Total	**781**	**7.6%**
osb	AL	35	.3%
	GA	105	1.0%
	LA	7	.1%
	ME	21	.2%
	TX	147	1.4%
	Total	**315**	**3.1%**
chip mill	AL	112	1.1%
	FL	57	.6%
	GA	228	2.2%
	LA	67	.7%
	ME	155	1.5%
	MS	186	1.8%
	SC	198	1.9%
	TX	262	2.6%
	Total	**1,265**	**12.3%**
other	AL	26	.3%
	FL	1	.0%
	GA	25	.2%
	LA	32	.3%
	ME	2	.0%
	MS	56	.5%
	SC	11	.1%
	TX	16	.2%
	Total	**169**	**1.6%**

Truck Turn-Times and Benchmarking Results

Total turn-time histograms (frequency distributions) are presented for the benchmark sub-set **(Figure 8)**, and rest-of-sample (ROS) sub-set **(Figure 9)**.

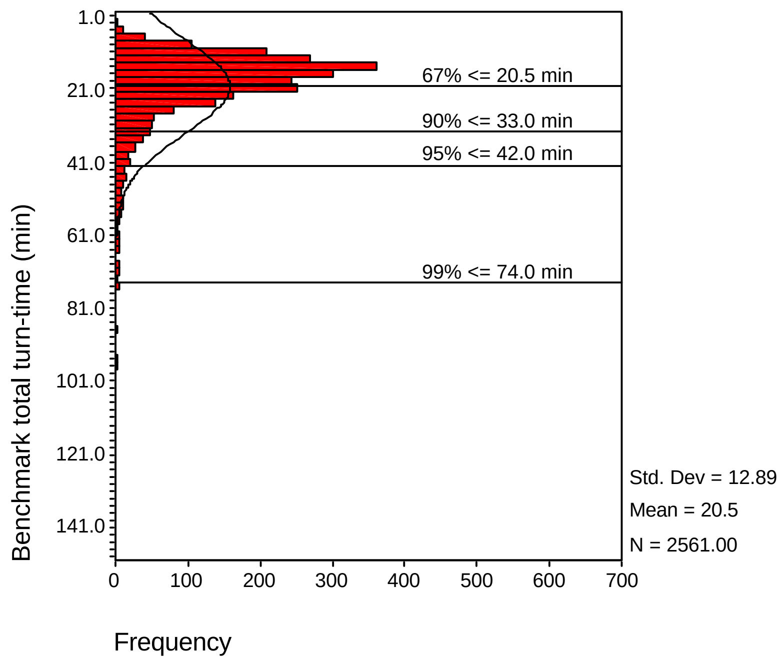


Figure 8. Histogram of benchmark total turn-times compared to a normal distribution.

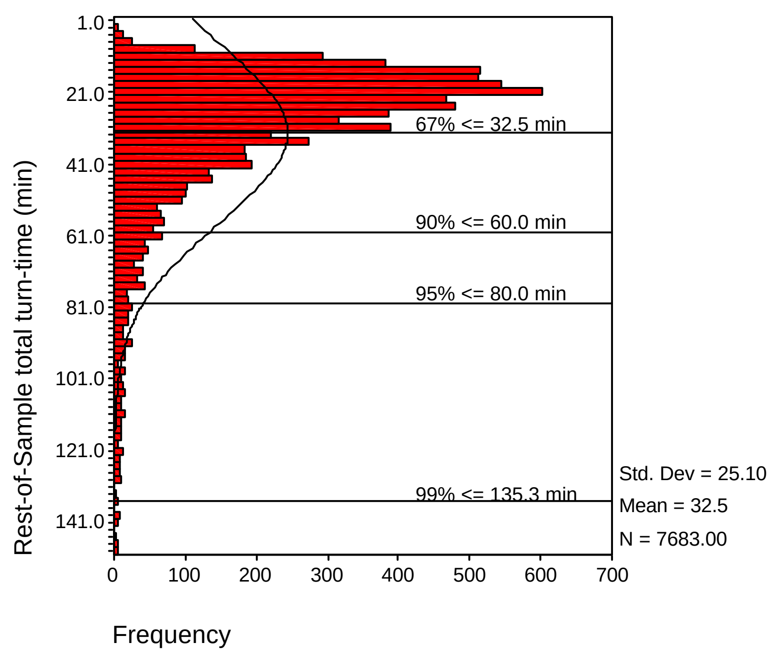


Figure 9. Histogram of rest-of-sample (ROS) total turn-times compared to a normal distribution.

Benchmark values are estimated based on a sub-set of 2,561 loads (25% of sample cases) representing all reported deliveries to 28 mills, approximately 20 percent of mills with a sampling intensity ≥ 30 cases. Lack of fit between the actual frequency distribution and a standard normal distribution indicates the use of standard deviation increments to estimate benchmark upper bound percentile values is not appropriate. Hence, benchmark percentile intervals are estimated using the actual frequency distribution of the benchmark sub-set.

The benchmark mean total turn-time (N = 2,561) is estimated at 20.49 minutes [99%CI, 19.83-21.14 minutes]. 67.0% of all benchmark cases have a total turn-time ≤ 20.49 minutes. The benchmark 90-percentile upper bound = 33 minutes, 95-percentile upper bound = 42 minutes, and 99-percentile upper bound = 74 minutes. Mean total turn-time for the ROS sub-set (N = 7,683) is estimated at 32.49 minutes [99%CI, 31.75-33.22 minutes]. 67.0% of all ROS cases have a total turn-time ≤ 32.49 minutes. The 90-percentile upper bound = 60 minutes, 95-percentile upper bound = 80 minutes, and 99-percentile upper bound = 135.3 minutes.

ROS and benchmark turn-times by activity, i.e. arrival to weigh-in, weigh-in to loader, unloading time, and loader to weigh-out, are presented in **Table 5.**

Table 5. Mean turn-time elements for ROS and benchmark by activity (minutes).

Group	arrival to weigh-in	weigh-in to loader	unloading time	loader to weigh-out	scale-to-scale turn-time	total turn-time
ROS						
N (loads)	7,683	7,683	7,577	7,683	7,577	7,683
Mean	**8.17**	**10.84**	**8.45**	**5.20**	**24.27**	**32.49**
Std. Dev.	15.63	15.20	9.33	5.46	17.50	25.10
Benchmark						
N (loads)	2,561	2,561	2,395	2,561	2,395	2,561
Mean	**3.83**	**6.76**	**6.12**	**4.22**	**16.59**	**20.49**
Std. Dev.	7.90	7.04	5.80	4.08	9.03	12.89
BM Gain	**+4.34 min (+53.1%)**	**+4.08 min (+37.6%)**	**+2.33 min (+27.6%)**	**+0.98 min (+18.8%)**	**+7.68 min (+31.6%)**	**+12.00 min (+36.9%)**

Benchmark N + ROS N = Sample N = 10,244

For the ROS sub-set (N=7,683), mean arrival to weigh-in = 8.17 minutes, mean weigh-in to crane/loader = 10.84 minutes, mean unloading time = 8.45 minutes, mean crane/loader to weigh-out = 5.20 minutes, mean scale-to-scale turn-time = 24.27 minutes, and mean total turn-time = 32.49 minutes. For the benchmark (N=2,561), mean arrival to weigh-in = 3.83 minutes, mean weigh-in to crane/loader = 6.76 minutes, mean unloading time = 6.12 minutes, mean crane/loader to weigh-out = 4.22 minutes, mean scale-to-scale turn-time = 16.59 minutes, and mean total turn-time = 20.49 minutes.

By activity, benchmark average net gains are as follows: arrival time to weigh-in +4.34 minutes (53.1% gain), weigh-in to crane/loader +4.08 minutes (37.6% gain), unloading time +2.33 minutes (27.6% gain), crane/loader to weigh-out +0.98 minutes

(18.8% gain), scale-to-scale turn-time +7.68 minutes (31.6% gain), and total turn-time +12.00 minutes (36.9% gain). Of course, a reduction in scale-to-scale turn-time is strongly related to a reduction in total turn-time. For the sample, the Spearman (nonparametric) correlation coefficient between scale-to-scale turn-time and total turn-time (N = 9,972) is .846. In other words, a 0.85% reduction in mean scale-to-scale turn-time equates to a 1.0% reduction in mean total turn-time at the average sample mill.

Marginal System Cost Estimates

Wood supply system marginal cost estimates are the sum of marginal DSC and marginal IDSC that can potentially be captured by reducing ROS (75% of all loads sampled) mean total turn-time and variance to benchmark levels (25% of all loads sampled). A summary of marginal DSC and marginal IDSC calculations are presented in **Table 6.** Sample cases above the benchmark mean total turn-time value (20.49 minutes) (N = 5,450) comprise 53.2% of all sample loads and represent 1,894.5 truck hours above the benchmark mean. For the 53.2% of sample cases above the benchmark mean, average excess truck idle-time = 0.348 hours/load (mean total turn-time = 41.37 minutes). In comparison, benchmark cases above the benchmark mean (N = 770) comprise 30.1% of all benchmark loads and represent 162.2 truck hours above the benchmark mean. For the 30.1% of benchmark cases above the benchmark mean, average excess truck idle-time = 0.210 hours/load (mean total turn-time = 33.09 minutes).

The net effects or marginal ROS DSC values are estimated by subtracting the benchmark effects from the sample. Comparing the ROS sub-set to the benchmark sub-set, 4,680 or 60.1% of all ROS cases are above the benchmark mean total turn-time of 20.49 minutes. 2,110 or 27.1% of all ROS cases above the benchmark mean value can potentially be reduced by an average .370 hours per load. An additional 2,571 or 33% (expected value) of all ROS cases above the benchmark mean can potentially be reduced by an average .160 hours per load. Given a DSC range of $41.67 to $69.44 (mean = $55.56) per truck hour, this amounts to a potential reduction in ROS marginal DSC of 1,191.9 truck hours * [$41.67-$69.44] per truck hour or from $49,666 to $82,766. The per load equivalent reduction ranges from $10.61 to $17.69 for the 4,680 (60.1%) ROS loads above the benchmark mean total turn-time value. DSC expansion to the study area (AL, FL, GA, LA, ME, MS, SC, TX, and VA) is accomplished by multiplying the net ROS percentage of recoverable cases by 75% of total annual logging output (5.5 million loads) in the study area then, multiplying by the marginal DSC per load. Study area marginal DSC estimates range from $35.1 to $58.5 million.

In the context of statistical process control, estimation of IDSC requires that a benchmark upper bound percentile value be chosen as a point of reference. IDSC percentiles provide a range of breakpoints where accounting for the opportunity cost of lost logging production due to excessive variance in truck turn-time kicks in. ROS cases with total turn-time values greater that the benchmark upper bound incur IDSC. The net effects or marginal ROS IDSC values are estimated by subtracting the benchmark effects from the sample. The mathematical procedure is basically the same as estimating marginal DSC and is applied to three benchmark upper bound percentiles instead of the benchmark mean.

Table 6. Summary of marginal DSC and marginal IDSC calculations.

Group	# Mill	N loads	Mean	90 Percentile	95 Percentile	99 Percentile
Sample	290	10,244	29.49 min	P<=54 min	P<=73 min	P<=127 min
Sample N > BM Value			N = 5,450 (53.2 S%)	N = 2,661 (26.0% S)	N = 1,656 (16.2% S)	N = 484 (4.7% S)
Sample Hours > BM Value			1,894.5 hrs .348 hr/load	1,101.7 hrs .414 hr/load	778.3 hrs .470 hr/load	279.9 hrs .578 hr/load
Benchmark	28[a]	2,561[b]	20.49 min	P<=33 min	P<=42 min	P<= 74 min
BM N[c] > BM Value			N = 770 (30.1% B)	N = 238 (9.3% B)	N = 127 (5.0% B)	N = 23 (0.9% B)
BM Hours > BM Value			162.2 hrs .210 hr/load	71.5 hrs .300 hr/load	44.6 hrs .351 hr/load	10.5 hrs .457 hr/load
ROS Values	262	7,683	32.49 min	P<=60 min	P<=80 min	P<=135 min
ROS N > BM			N = 4,680 (60.1% ROS)	N = 2,423 (31.5% ROS)	N = 1,529 (19.9% ROS)	N = 461 (6.0% ROS)
ROS Hours > BM			1,732.3 hrs .370 hr/load	1,030.2 hrs .425 hr/load	733.7 hrs .480 hr/load	269.4 hrs .584 hr/load
Fully Recoverable ROS N > BM Values			***N = 2,110 (27.1% ROS) *.370 hr per load***	***N = 1,653 (21.5% ROS) * .425 hr per load***	***N = 1,145 (14.9% ROS) * .480 hr per load***	***N = 384 (5.0% ROS) * .584 hr per load***
Partially Recoverable ROS N[d] > BM Values			***N = 2,570 (33.0% ROS) *.160 hr per load***	***N = 770 (10.0% ROS) * .125 hr per load***	***N = 384 (5.0% ROS) * .129 hr per load***	***N = 77 (1.0% ROS) * .127 hr per load***
S Recoverable ROS Hours			***1,191.91 hrs***	***798.8 hrs***	***599.1 hrs***	***234.0 hrs***

[a] 28 of 140 mills or 20% of mills in the sample with number of cases ≥ 30.
[b] 2,561 cases = 25% of all cases in the sample.
[c] N and % are actual benchmark values >21 min., >33 min., >42 min., and >74 min.
[d] N and % are expected values based on the benchmark frequency distribution.

Sample cases above the benchmark 90-percentile upper bound (N = 2,661) comprise 26.0% of all sample loads and represent 1,101.7 truck hours above the benchmark 90-percentile upper bound. Sample cases above the benchmark 95-percentile upper bound (N = 1,656) comprise 16.2% of all loads in the sample and represent 778.3 truck hours above the benchmark 95-percentile upper bound. Sample cases above the benchmark 99-percentile upper bound (N = 484) comprise 4.7% of all loads in the sample and represent 279.9 truck hours above the benchmark 99-percentile upper bound. For the sample, average excess truck idle-time = 0.414 hours/load above the benchmark 90-percentile upper bound (mean total turn-time = 78.84 minutes), 0.470 hour/load above the benchmark 95-percentile upper bound (mean total turn-time = 101.20 minutes), and 0.578 hours above the benchmark 99 percentile upper bound (mean total turn-time = 161.68 minutes).

In comparison, benchmark cases above the benchmark 90-percentile upper bound (N = 238) comprise 9.3% of all benchmark loads and represent 71.45 truck hours above the benchmark 90-percentile upper bound. Benchmark cases above the benchmark 95-percentile upper bound (N = 127) comprise 5.0% of all benchmark loads and represent 44.60 truck hours above the benchmark 95-percentile upper bound. Benchmark cases above the benchmark 99-percentile upper bound (N = 23) comprise 0.9% of all benchmark loads and represent 10.53 hours above the benchmark 99-percentile upper bound. For the benchmark sub-set, average excess truck idle-time = 0.300 hours/load above the benchmark 90-percentile upper bound (mean total turn-time = 51.00 minutes), 0.351 hour/load above the benchmark 95-percentile upper bound (mean total turn-time = 63.06 minutes), and 0.457 hours above the benchmark 99-percentile upper bound (mean total turn-time = 101.42 minutes).

The net effects or net ROS IDSC values are estimated by subtracting the benchmark effects from the sample. At the 90 percentile, 21.5% of ROS total turn-time cases can potentially be reduced by an average .425 hours per load. An additional 10% (expected value) of the ROS cases can be reduced by an average .125 hours per load. At the 95 percentile, 14.9% of ROS cases can potentially be reduced by an average .480 hours per load. An additional 5% (expected value) of the ROS cases can be reduced by an average .129 hours per load. At the 99 percentile, 5.0% of ROS cases can potentially be reduced by .584 hours per load. An additional 1.0% (expected value) of the ROS cases can be reduced by an average .127 hours per load.

IDSC per truck hour [$24.42-$77.70] is multiplied by the potentially recoverable excess idle-time hours at each percentile for the ROS sub-set. Recoverable marginal ROS IDSC estimates are as follows: [$19,506 to $62,065] or [$10.61 to $17.69 per load] (N = 2,423) at the 90 percentile, [$14,630 to $46,550] or [$9.57 to $30.44 per load] (N = 1,529) at the 95 percentile, and [$5,714 to $18,182] or [$12.39 to $39.44 per load] (N = 461) at the 99 percentile. IDSC expansion to the study area (AL, FL, GA, LA, ME, MS, SC, TX, and VA) is accomplished by multiplying the net ROS percentage of recoverable cases by 75% of total annual logging output (5.5 million loads) in the study area then, multiplying by the marginal IDSC per load. Study area marginal IDSC estimates due to excess variance in truck turn-times are as follows: [$14.0 to $44.4 million] at the 90 percentile, [$10.5 to $33.3 million] at the 95 percentile, and [$4.1 to $13.0 million] at the 99 percentile.

A summary of marginal system cost estimates (DSC + IDSC) for excess variance in truck turn-time are presented for the 90, 95, and 99-percentile benchmark values in **Table 7**. Study area marginal system cost estimates are as follows: [$49.1 to $102.9 million] at the 90 percentile, [$45.6 to $91.8 million] at the 95 percentile, and [$39.2 to $71.5 million] at the 99 percentile. To put things into perspective, the average benchmark mill consuming 1.5 million tons of roundwood per year contributes virtually zero marginal cost to the wood supply system. On the other hand, the average ROS mill consuming 1.5 million tons of roundwood per year contributes an average $14.15 per load for 60.1% of all loads delivered or $477,773 (60.1% * 56,180 loads @ 26.7 tons per load) in marginal DSC plus an additional $297,835 in marginal IDSC at the 90-percentile level, or an additional $223,708 at the 95-percentile level, or an additional $87,337 at the 99-percentile level. Hence, the average ROS mill consuming 1.5 million tons of roundwood annually contributes either $775,598 or $701,471 or $565,100 in marginal system cost, depending on where the line is drawn and the opportunity costs of lost logging production kick in.

Table 7. Marginal system cost estimates of excess variance in turn-times by percentile.

BM % Upper Bound	Net ROS DSC[a] [RANGE]	Study Area DSC[b] [RANGE]	Net ROS IDSC[c] [RANGE]	Study Area IDSC[b] [RANGE]	Study Area Marginal System Cost (DSC+IDSC) [RANGE]
90% =33min	[$49,666 to $82,766] or [$10.61 to $17.69/load]	[$35.1 to $58.5] Million	[$19,506 to $62,065] or [$8.05 to $25.61/load]	[$14.0 to $44.4] Million	**[$49.1 to $102.9] Million**
95% =42min	[$49,666 to $82,766] or [$10.61 to $17.69/load]	[$35.1 to $58.5] Million	[$14,630 to $46,550] or [$9.57 to $30.44/load]	[$10.5 to $33.3] Million	**[$45.6 to $91.8] Million**
99% =74min	[$49,666 to $82,766] or [$10.61 to $17.69/load]	[$35.1 to $58.5] Million	[$5,714 to $18,182] or [$12.39 to $39.44/load]	[$4.1 to $13.0] Million	**[$39.2 to $71.5] Million**

[a]Marginal ROS DSC and marginal ROS DSC per load (N = 4,680).
[b]Study area includes: AL, FL, GA, LA, ME, MS, SC, TX, and VA, total loads = 7,330,261; expansion by recoverable percentage of loads * recoverable dollars per load.
[c]Marginal ROS IDSC and marginal ROS IDSC per load; 90% N = 2,423, 95% N = 1,529, and 99% N = 461.

Variables Affecting Truck Turn-Time

Univariate Analysis of Variance is utilized to test the main effects of categorical variables with respect to total turn-time **(Table 8)**. The following variables are found to be statistically significant above the 99% probability level: month of delivery, mill name, wood/load form, and unloading equipment used. Truck/trailer type is significant above the 95% probability level. R Squared for the model = 0.222. Month of delivery was originally included as a proxy for weather. However, normal seasonal weather patterns were non-existent during the study period. Hence, there is no empirically supported interpretation of the variable. A purely subjective interpretation is that the month of delivery variable indirectly reflects variation in market conditions and delivery quotas during the data collection period.

Table 8. Univarite ANOVA for main effects of variables affecting turn-time.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Eta Squared[b]**
Corrected Model	1198123.485[a]	313	3827.871	8.800	.000	.222
Intercept	29851.704	1	29851.704	68.624	.000	.007
Month of Delivery	22632.279	8	2829.035	6.504	**.000**	**.005**
Mill Name	850487.348	285	2984.166	6.860	**.000**	**.168**
Scale Method	74.847	1	74.847	.172	.678	.000
Number of Scales	657.401	2	328.700	.756	.470	.000
Mill Type	1349.398	5	269.880	.620	.684	.000
Wood/Load Form	9133.038	4	2283.260	5.249	**.000**	**.002**
Truck/Trailer Type	5120.013	4	1280.003	2.943	**.019**	**.001**
Unloading Equip.	11069.066	3	3689.689	8.482	**.000**	**.003**
Unloading Site	78.845	1	78.845	.181	.670	.000
Error	4201242.564	9658	435.001			
Total	14103027.035	9972				
Corrected Total	5399366.049	9971				

Dependent Variable = Total Turn-Time

[a]R Squared = .222

[b]Eta Squared statistic describes the proportion of total variance attributable to the factor.

The significance of mill name as a variable affecting truck turn-time is a critical finding. The empirical results provide conclusive evidence that a significant proportion of the variance in truck turn-time is related to mill-specific factors across the sample. The Univariate ANOVA model used to test for main effects of driver observed variables on total turn-time accounts for 22.2% of the variance in total turn-time for the sample. The Eta Squared value (.168) for mill name indicates mill-specific factors account for the majority of variance explained by the ANOVA model. Opportunities for turn-time process improvement point to quantitative and qualitative mill-specific attributes not examined in this study. These mill-specific attributes may include physical and operational characteristics of the woodyard, managerial attention to turn-times, and market factors.

It is surmised that wood/load form, unloading equipment, and truck/trailer type affect total turn-time by way of unloading time. Full factorial Univariate ANOVA is utilized to test both the main effects and interaction effects of wood/load form, unloading equipment, and truck/trailer type with respect to unloading time. The main effects of unloading equipment are significant above the 99% probability level. Interaction effects of wood/load form * unloading equipment are significant above the 95% probability level **(Table 9).**

Table 9. Full factorial Univariate ANOVA for variables affecting unloading time.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared[b]
Corrected Model	60872.615[a]	47	1295.162	18.639	.000	.081
Intercept	7971.149	1	7971.149	114.714	.000	.011
Wood/Load Form	84.442	4	21.111	.304	.876	.000
Unloading Equip.	1929.566	3	643.189	9.256	**.000**	**.003**
Truck/Trailer Type	472.623	4	118.156	1.700	.147	.001
Wood/Load Form * Unloading Equip.	1584.847	12	132.071	1.901	**.030**	**.002**
Wood/Load Form * Truck/Trailer Type	612.315	7	87.474	1.259	.267	.001
Unloading Equip. * Truck/Trailer Type	687.788	7	98.255	1.414	.195	.001
Wood/Load Form * Unloading Equip. * Truck/Trailer Type	290.621	9	32.291	.465	.899	.000
Error	689587.858	9924	69.487			
Total	1371758.000	9972				
Corrected Total	750460.473	9971				

Dependent Variable = Unloading Time
[a]R Squared = .081
[b]Eta Squared statistic describes the proportion of total variance attributable to the factor.

Based on the results of the full factorial ANOVA, unadjusted pair-wise marginal mean values for unloading time, based on the interaction effects of wood/load form and unloading equipment, are of primary interest. However, only a small portion of the total variance in unloading time is captured by the tested variables. R Squared for the unloading time model = .081. Unadjusted pair-wise estimates of mean unloading time for wood/load form * unloading equipment are reported in **Table 10.** In the interest of brevity, only the shortest interval unloading times by wood/load form are discussed. For tree-length loads, wheel loader mean unloading time is 5.82 minutes [95%CI, 5.49-6.15 minutes]. For double bunk loads, wheel loader mean unloading time is 6.34 minutes [95%CI, 5.88-6.90 minutes]. For piggy-back loads, OH crane mean unloading time is 10.62 minutes [95%CI, 9.44-11.80 minutes]. For short-wood bolts, OH crane mean unloading time is 6.22 minutes [95%CI, 2.35-10.09 minutes]. For the other category, wheel loader mean unloading time is 4.49 minutes [95%CI, 2.80-6.18 minutes].

Table 10. Summary statistics for mean unloading time, wood/load form * unloading equipment.

Wood/Load Form	Unloading Equipment	N	Mean[abc] (minutes)	Std. Error	95% CI Lower Bound	95% CI Upper Bound
tree-length	OH crane	4242	7.825	.129	7.573	8.077
	wheel loader	**2490**	**5.817**	**.168**	**5.488**	**6.146**
	knuckle boom	634	11.513	.333	10.860	12.165
	other	69	9.652	1.008	7.675	11.629
double bunk	OH crane	446	8.345	.397	7.568	9.123
	wheel loader	**1025**	**6.388**	**.262**	**5.875**	**6.901**
	knuckle boom	100	14.360	.838	12.718	16.002
	other	10	10.200	2.649	5.008	15.392
piggy-back	**OH crane**	**193**	**10.617**	**.603**	**9.435**	**11.799**
	wheel loader	85	13.318	.909	11.537	15.099
	knuckle boom	139	13.705	.711	12.312	15.098
	other	20	17.800	1.873	14.128	21.472
shortwood bolts	**OH crane**	**18**	**6.222**	**1.974**	**2.352**	**10.092**
	wheel loader	9	13.000	2.792	7.527	18.473
	knuckle boom	176	12.222	.631	10.984	13.459
	other	138	16.007	.713	14.609	17.405
other	OH crane	69	7.667	1.008	5.690	9.643
	wheel loader	**94**	**4.489**	**.864**	**2.796**	**6.183**
	knuckle boom	9	21.000	2.792	15.527	26.473
	other	6	15.167	3.420	8.463	21.870

Dependent Variable = Unloading Time
[a]**Bold** denotes shortest unloading time(s) by wood/load form.
[b]Unadjusted pair-wise marginal mean values for wood/load form * unloading equipment.
[c]Single-pass and double-pass equipment types are combined for reporting purposes.

Frequencies and Causes of Delays

Driver reported delays by turn-time process activity are reported for the sample (N = 10,244) and for all cases with turn-time values greater than the 90-percentile value (N = 2,661) **(Table 11)**. For the sample, 1,757 unique cases (individual loads) reported a total of 1,943 delays at various points in the four activity turn-time process, i.e. arrival to weigh-in, weigh-in to loader, unloading, and loader to weigh-out. 1,571, 89.4% of the cases reporting delays, recorded one delay during the turn-time process. 185 cases, 10.6% of the cases reporting delays, recorded two delay causes during the turn-time process. One case recorded three delay causes. No cases recorded more than three delay causes across the four turn-time activities.

Table 11. Sample and 90-percentile driver reported delays by turn-time process activity.

Reported Delay	Arrive to Weigh-in (Sample)	Arrive to Weigh-in (90%)	Weigh-in to Loader (Sample)	Weigh-in to Loader (90%)	Unload (Sample)	Unload (90%)	Loader to Weigh-out (Sample)	Loader to Weigh-out (90%)
Lack of space	71 (4.0%)	66 (4.2%)	78 (4.4%)	63 (4.0%)	37 (2.1%)	26 (1.7%)	12 (0.7%)	7 (0.4%)
Road conditions	8 (0.5%)	5 (0.3%)	13 (0.7%)	10 (0.6%)	3 (0.2%)	1 (0.1%)	1 (0.1%)	1 (0.1%)
Crane/loader can't keep up	213 (12.1%)	195 (12.4%)	540 (30.7%)	440 (28.0%)	291 (16.6%)	195 (12.4%)	8 (0.5%)	6 (0.4%)
Crane/loader breakdown	23 (1.3%)	23 (1.5%)	67 (3.8%)	59 (3.8%)	35 (2.0%)	25 (1.6%)	2 (0.1%)	2 (0.1%)
Truck breakdown	0 (0%)	0 (0%)	2 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	0 (0%)
Scale closed	112 (6.4%)	99 (6.3%)	8 (0.5%)	6 (0.4%)	0 (0%)	0 (0%)	14 (0.8%)	9 (0.6%)
Load quality	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (0.2%)	3 (0.2%)	0 (0%)	0 (0%)
Operator error	6 (0.3%)	5 (0.3%)	15 (0.9%)	11 (0.7%)	16 (0.9%)	8 (0.5%)	5 (0.3%)	4 (0.3%)
OSHA/DOT	2 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Other	145 (8.3%)	135 (8.6%)	108 (6.1%)	90 (5.7%)	56 (3.2%)	41 (2.6%)	46 (2.6%)	32 (2.0%)
TOTALS	**580 (33.0%)**	**529 (33.7%)**	**832 (47.4%)**	**681 (43.3%)**	**442 (25.2%)**	**300 (19.1%)**	**89 (5.1%)**	**61 (3.9%)**

Sample N = 10,244 with 1,943 driver reported delays.
90 percentile N = 2,661 with 1,571 driver reported delays.

Some 580 cases of the 10,244-case sample reported a delay from arrival time to weigh-in. 832 cases reported a delay from weigh-in to crane/loader. 442 cases reported an unloading delay. 89 cases reported a delay from crane/loader to weigh-out. By delay cause, 198 delays (10.2% of the responses) are due to "lack of space". 25 delays (1.3% of the responses) are due to "poor road conditions". 1,052 delays (54.1% of the responses) are due to "unloading equipment cannot keep up". This is the most common delay reported during the turn-time process. 127 delays (6.5% of the responses) are due to "crane/loader breakdown". 4 delays (0.2% of the responses) are due to "truck breakdown. 134 delays (6.9% of the responses) are due to "scale closed". 3 delays (0.2% of responses) are due to "poor load quality". 42 delays (2.2% of responses) are due to "operator error". 3 delays (0.2% of responses) are due to "OSHA/DOT regulations. 355 delays (18.3% of responses) are due to "other".

Examining all turn-time cases greater than the benchmark 90-percentile value (33.0 minutes) (N = 2,661), 1,391 unique cases (individual loads) reported a total of 1,571 delays (80.85% of all reported delays in the sample) at various points in the four activity turn-time process. 1,212, 87.1% of the cases reporting delays, recorded one delay during the turn-time process. 178 cases, 12.9% of the cases reporting delays, recorded two delay causes during the turn-time process. One case recorded three delay causes across the four turn-time activities. None of the 90 percentile cases recorded more than three delay causes across the four turn-time activities.

Some 529 cases of the 90 percentile sub-set (N = 2,661) reported a delay from arrival time to weigh-in. 681 cases reported a delay from weigh-in to crane/loader. 300 cases reported an unloading delay. 61 cases reported a delay from crane/loader to weigh-out. By delay cause, 162 delays (10.3% of the responses) are due to "lack of space". 17 delays (1.1% of the responses) are due to "poor road conditions". 836 delays (53.2% of the responses) are due to "unloading equipment cannot keep up". This is the most common delay reported during the turn-time process. 109 delays (6.9% of the responses) are due to "crane/loader breakdown". 2 delays (0.1% of the responses) are due to "truck breakdown. 114 delays (7.3% of the responses) are due to "scale closed". 3 delays (0.2% of responses) are due to "poor load quality". 28 delays (1.8% of responses) are due to "operator error". 2 delays (0.1% of responses) are due to "OSHA/DOT regulations. 298 delays (19.0% of responses) are due to "other". Sample and 90-percentile driver reported delay cause frequency distributions are nearly identical by turn-time process activity. This suggests consistency in delay cause reporting by turn-time process activity across the entire sample.

Driver reported delays offer some insight with respect to the causes of excessive variance in truck turn-time. For all case values greater than the 90-percentile benchmark (N=2,661), driver reported delays focus process improvement attention on unloading equipment systems capacity (53.2% of reported delays) and equipment utilization rates. Delays caused by unscheduled crane/loader downtime are significant (6.9% of reported delays). Delays due to scales being closed are 7.3% of the reported delays. Unloading delays due to lack of space comprise 10.3% of reported delays.

CONCLUSIONS

The transport cost function of the wood supply value chain is an important area to consider in terms of potential system-wide efficiency gains. Obvious reasons for examining log truck delivery cycle-time in the contexts of operational and economic efficiency are: (i) to determine if opportunities exist to increase efficiency and decrease costs, and if so, (ii) to estimate the amount of capital that potentially can be appropriated to help alleviate the problem of excessive variance in truck turn-times. It boils down to a marginal cost/marginal benefit analysis. This research examines only the marginal cost side of the equation. Based on benchmarking results, excessive variance in truck turn-time adds significant system costs to roundwood volume delivered in the study area.

Benchmark total turn-time mean and frequency distribution values provide a yardstick that can be used to measure turn-time efficiency at various scales. Comparisons between the benchmark sub-set and the ROS sub-set are based on the potential of reducing ROS mean total turn-time and variance to benchmark values. Applications range from the individual mill level to the corporate level and beyond. The 28 mills selected as benchmark mills demonstrate what is realistically achievable in terms of reducing average roundwood delivery cycle-time and reducing the associated variance in roundwood delivery cycle-time.

Wood supply system marginal cost estimates are the sum of DSC and IDSC that can potentially be captured by reducing ROS (75% of all loads sampled) mean total turn-time and variance to benchmark levels (25% of all loads sampled). The net effects or marginal ROS DSC values are estimated by subtracting the benchmark effects from the sample. Comparing the ROS sub-set to the benchmark sub-set, 4,680 or 60.1% of all ROS cases are above the benchmark mean total turn-time of 20.49 minutes. Given a DSC range of $41.67 to $69.44 (mean = $55.56) per truck hour, this amounts to a potential reduction in ROS marginal DSC of 1,191.9 truck hours * [$41.67-$69.44] per truck hour or from $49,666 to $82,766. The per load equivalent ranges from $10.61 to $17.69 for the 4,680 (60.1%) ROS loads above the benchmark mean total turn-time value. This represents the direct per-load cost in addition to the benchmark cost of doing business. Study area marginal DSC estimates range from $35.1 to $58.5 million.

In the context of statistical process control, estimation of IDSC requires that a benchmark upper bound percentile value be chosen as a point of reference. IDSC percentiles provide a range of breakpoints where accounting for the opportunity cost of lost logging production due to excessive variance in truck turn-time kicks in. ROS total turn-time values greater than the selected benchmark upper bound incur IDSC at a rate ranging from $24.42 to $77.70 per truck hour based on the percentage of recoverable cases and the average recoverable hours above each percentile. Potentially recoverable ROS marginal IDSC estimates are: $19,506 to $62,065 ($10.61 to $17.69 per load) for the 31.5% of all ROS loads that are above the benchmark 90 percentile of 33 minutes, $14,630 to $46,550 ($9.57 to $30.44 per load) for the 19.9% of all ROS loads that are above the benchmark 95 percentile of 42 minutes, and $5,714 to $18,182 ($12.39 to $39.42 per load) for the 6.0% of all ROS loads that are above the benchmark 99 percentile of 74 minutes. This represents the per-load opportunity cost of lost logging production associated with the average ROS mill. Study area IDSC estimates due to excess variance in truck turn-times are: $14.0 to $44.4 million at the 90 percentile, $10.5 to $33.3 million at the 95 percentile, and $4.1 to $13.0 million at the 99 percentile.

To put things into perspective, the average benchmark mill consuming 1.5 million tons of roundwood per year contributes virtually zero marginal cost to the wood supply system. On the other hand, the average ROS mill consuming 1.5 million tons of roundwood per year contributes an average $14.15 per load for 60.1% of all loads delivered or $477,773 (60.1% * 56,180 loads @ 26.7 tons per load) in marginal DSC plus an additional $297,835 in marginal IDSC at the 90-percentile level, or an additional $223,708 at the 95-percentile level, or an additional $87,337 at the 99-percentile level. Hence, the average ROS mill consuming 1.5 million tons of roundwood annually contributes either $775,598 or $701,471 or $565,100 in marginal system cost, depending on where the line is drawn and the opportunity costs of lost logging production kick in.

What is the most appropriate percentile upper bound for estimating IDSC? The answer depends on your perspective. From a logger's perspective, indirect system cost does not matter as much as direct out-of-pocket expense. If given the choice, a logger will, most certainly, prefer to have the opportunity cost of lost in-woods production fully accounted for. This means the logger's choice is the 90-percentile upper bound or less. In other words, the opportunity cost of lost in-woods production (IDSC) is accounted for in the portion of the turn-time frequency distribution above the benchmark 90-percentile. From the consumer's perspective, higher indirect system cost is preferred because it means less direct out-of-pocket expense. If given the choice, a fiber procurement manager will, most certainly, prefer not to account for IDSC or, at most, to account for IDSC at the benchmark 99-percentile level. The middle-of-the-road may be the benchmark 95-percentile upper bound as the default breakpoint. Regardless of which percentile is used, if any, the basic concept requires that one think of truck turn-time as a highly skewed frequency distribution as opposed to just an average value.

Statistically significant categorical variables affecting truck turn-time include month of delivery, mill name, wood/load form, and unloading equipment used. Month of delivery was originally included as a proxy for weather. However, normal seasonal weather patterns were non-existent during the study period. Hence, there is no empirically supported interpretation of the variable. A purely subjective interpretation is that the month of delivery variable indirectly reflects variation in market conditions and delivery quotas during the data collection period.

The significance of mill name as a variable affecting truck turn-time is a critical finding. The empirical results provide conclusive evidence that a significant proportion of the variance in truck turn-time is related to mill-specific factors across the sample. The ANOVA model used to test for main effects of driver observed variables accounts for 22.2% of the variance in total turn-time for the sample. The Eta Squared value (.168) for mill name indicates mill-specific factors account for the majority of variance explained by the ANOVA model. Implications for turn-time process improvement are far reaching and point to quantitative and qualitative mill-specific attributes not examined in this study. These mill-specific attributes may include physical and operational characteristics of the woodyard, managerial attention to turn-times, and market factors.

Wood/load form, unloading equipment, and truck/trailer type are interrelated variables and more-or-less uncontrollable. Wood/load form depends heavily on a mill's end product and unloading equipment used depends somewhat on wood/load form. In other words, while these attributes have a statistically significant effect on truck turn-time, there are no direct procedures available for process efficiency improvement, short of major capital investment. However, there are a few long-run considerations. Empirical evidence suggests tree-length loads can, on average, be unloaded faster than double bunk or piggy-back loads regardless of unloading equipment used. In terms of time efficiency alone, wheel loaders out perform other unloading equipment types for the tree-length and double bunk wood/load forms while OH cranes out perform other equipment types for piggy-back, and short-wood bolts.

Driver reported delays offer some insight with respect to the causes of excessive variance in truck turn-time. For all case values greater than the 90-percentile benchmark (N=2,661), driver reported delays focus process improvement attention on unloading equipment systems capacity (53.2% of reported delays) and equipment utilization rates. Delays caused by unscheduled crane/loader downtime are significant (6.9% of reported delays). Another potential area of opportunity is human resources utilization. For example, delays due to scales being closed are 7.3% of the reported delays. Unloading delays due to lack of space comprise 10.3% of reported delays. The relative importance of unloading delays due to lack of space during the study period may be inflated with respect to the long-term because unusually dry weather patterns and soft market conditions caused woodyards to be packed near full-capacity during the data collection period (only exception is Maine).

In summary, the authors' analyses and interpretations provide answers to a few fundamental questions, as outlined by WSRI in the project deliverables. However, many questions with respect to the causes of excessive variance in truck turn-time are left unanswered. More specific process improvement recommendations are impossible to make based on empirical evidence generated from primary data collected because of the lack of mill-specific quantitative and qualitative data to support and explain the categorical differences. In effect, a significant proportion of the underlying causes of excessive variance in truck turn-times are mill specific and, most certainly, include a number of physical, managerial, and market factors that were not examined as part of this research project. Further research is required in order to statistically demonstrate and explain the relationships between the mill-specific causal factors and truck turn-time efficiency. The next obvious step is to compare the now established set of benchmark mills to a control group, examining mill-specific quantitative and qualitative variables that address physical, managerial, and product market factors.

APPENDICES

APPENDIX A:

RECRUITMENT & DATA COLLECTION MATERIALS

LOUISIANA TECH UNIVERSITY

School of Forestry

RECRUITMENT HANDOUT

An Investigation of Roundwood Truck Turn-Time

a research project funded by the

Wood Supply Research Institute

conducted by

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What is the Wood Supply Research Institute?

WSRI is a joint project of professional loggers and forest products firms that seeks to facilitate and fund research to promote and improve efficiencies in wood supply systems. Current members (01/01/2000) include Alabama Loggers Council, Southeastern Wood Producers Association, South Carolina Timber Producers Association, Professional Logging Contractors of Maine, Texas Logging Council, Champion International, Georgia-Pacific, International Paper, Westvaco, and Weyerhaeuser.

What are the objectives of this study?

The goal of this study is to improve understanding of the role of roundwood truck turn-time in the overall efficiency of the wood supply system. The specific **objectives** are as follows: (i) establish an **industry benchmark** truck turn-time value, (ii) **identify factors** associated with excessive truck turn-times, and (iii) present a valid method for assigning **dollar values** to the "system cost" of excessive turn-times.

What type of logging contractors are we looking for?

We are looking for logging businesses that are considered to be average to above average loggers and business people by their peers in the industry. They do not have to be a member of a state logging association.

How will cooperating logging contractors be identified and selected?

We are asking logging contractors to volunteer to participate. Also, loggers or mill companies will be asked to suggest/recruit firms that they feel should be included in the study. The decision to participate will be made by each individual logging business.

If I agree to participate, what is expected from me and my business?

You will be asked to **provide one to three drivers (average =2), depending on the size of your operation,** that are willing to record load attribute data for 50 consecutive loads each, to attach copies of the appropriate scale ticket to each load, and to forward the information on a weekly basis until the **50 load per driver target** is met (approximately one month). All information that you provide during the study will be kept strictly confidential.

How much time will the data reporting take each week?

We intend to make the process as simple and painless as possible. Data collection for each load involves recording nine basic load and mill attributes, five clock times at critical points in the turn-time process, and possible delay causes (please refer to attached load data form). **Data recording is estimated to take approximately 3 minutes per load. Allow additional time for copying scale tickets and weekly return mailings.** During the study, we will be available to answer questions or resolve issues that arise. When the study begins, we will ask you to mail us reporting forms each week.

What do I get in return for my participation?

Each participating contact/contractor will receive a non-technical summary of the study results. In addition your logging association and/or the firm that you are delivering to is funding this study. This study cannot be a success without your participation.

How long will this study last?

Current plans call for the study to run from January 2000 through December 2000.

How do I get started?

Contact Don Deckard at:

School of Forestry
Louisiana Tech University
1201 Reese Drive, Room 111 (FEDEX address)
P.O. Box 10138 T.S. (USPS address)
Ruston, LA 71272
O: 318-257-4926
Fax: 318-257-5061
Email: ddeckard@rans.latech.edu
URL:http://ans.latech.edu/homes/ddeckard/index.html

RETURN FAX OR MAIL THIS SHEET

Truck Turn-Time Logger Participation Form

A project funded by the
Wood Supply Research Institute
and conducted by Louisiana Tech University

Company Name ____

Your name ____

Mail Address ____

City ____________________________ State _____________ ZIP _______________

Mobile Phone____

Office/Shop Phone ____

Home Phone ____

Fax ____

Email ____

Number of Trucks Owned/Operated __________________________________

Number of Contract Trucks _______________________________________

Primary Markets ____

____

____

Return to:

Don Deckard
School of Forestry
Louisiana Tech University
P.O. Box 10138 T.S.
Ruston, LA 71272
Phone: (318) 257-4926
Fax: (318) 257- 5061
Email: ddeckard@rans.latech.edu
Internet: http://ans.latech.edu/homes/ddeckard/index.html

WSRI Truck Turn-Time Load Data Form (revised 3/10/00) **Date: ______________**

Driver Name/Phone #: ____

Mill Name/City/State: ____

Scale Ticket #: ____

(attach copy of scale ticket)

Driver: check appropriate answers

Scale method: ☐ **weight** ☐ **stick (if MBF, specify log scale used) ______________________**

Number of scales used to weigh load: ☐ **none (stick scale)** ☐ **one** ☐ **two**

Mill type: ☐ **pulp/paper** ☐ **sawmill** ☐ **plywood** ☐ **OSB** ☐ **chip mill** ☐ **other**

Load form: ☐ **single tier/ tree-length** ☐ **double bunk** ☐ **piggy-back** ☐ **shortwood bolts** ☐ **other**
(clarification on reverse side)

Truck/trailer: ☐ **tractor w/ frame trailer** ☐ **tractor w/ pole trailer** ☐ **single or multi-axle truck** ☐ **single or multi-axle truck w/pup trailer** ☐ **other**

Unloading Equipment: ☐ **single-pass OH crane** ☐ **double-pass OH crane** ☐ **single-pass wheel loader** ☐ **double-pass wheel loader** ☐ **knuckle boom** ☐ **other**

Unloading site: ☐ **at mill** ☐ **off-site (mill overflow or satellite yard)**

Driver: record clock times and delay codes (if any) NOTE: USE YOUR WATCH TIME FOR ALL VALUES

Arrival time at mill queue: ____________

Weigh-in time (weight scale) or in-bound mill gate (stick scale): ____________ ***Delay Code (if any):*** __________

Arrival time at crane/loader: ____________ ***Delay Code (if any):*** __________

Departure time from crane/loader: ____________ ***Delay Code (if any):*** __________

Weigh- out time (weight scale) or out-bound mill gate (stick scale): ____________ ***Delay Code (if any):*** __________

Delay Codes (record one # only or leave blank if none)

1	**Lack of inventory space**
2	**Poor road conditions in yard**
3	**Crane/Loader(s) can't keep up**
4	**Crane/Loader(s) breakdown**
5	**Truck breakdown**
6	**Scale not open**
7	**Poor load quality: small tops, limbs, rot, etc.**
8	**Operator error**
9	**OSHA/DOT regulations**
10	**Other (please specify)________________**

____

Return weekly to:
Don Deckard
School of Forestry
Louisiana Tech University
1201 Reese Drive, Room 111
P.O. Box 10138 T.S.
Ruston, LA 71272
Phone: (318) 257-4926
Fax: (318) 257-5061

[instructions on back]

PROJECT SUMMARY

TITLE: "An Investigation of Roundwood Truck Turn-Time." Financial support provided by the Wood Supply Research Institute (WSRI).
PRINCIPAL INVESTIGATOR: Donald L. Deckard, Assistant Professor, School of Forestry, Louisiana Tech University, P.O. Box 10138 T.S., Ruston, LA, Phone: (318) 257-4926, Fax: (318) 257-5061, E-mail: ddeckard@rans.latech.edu, Online: [http://www.ans.latech.edu/homes/ ddeckard/index.html].
PURPOSE OF STUDY: The purpose of this study is to estimate elemental times incurred by logging trucks while at woodyards. The study focus is on measuring activities and delays from the time of arrival at the mill's woodyard until the time of final departure from the mill's woodyard. Potential delay factors are included in the primary data collection process.
SUBJECTS: Subjects consist of loggers/truck drivers that are members of WSRI and approved study cooperators representing a geographic area of seven Southern states plus Maine.
SUBJECTS RIGHTS: This project has been reviewed and approved by the Louisiana Tech University Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to Dr. Mary Livingston (phone: 318-257-4315) or Dr. Terry McConathy (phone: 318-257-2924).
PROCEDURES: Approximately 120 loggers/drivers voluntarily complete questionnaires reporting basic woodyard characteristics, load information, and truck turn-times for approximately 6,000 loads (50 loads per driver). At total of 9 categorical and 5 quantitative variables are recorded by the driver for each load. Data are analyzed in order to identify factors contributing to excessive truck turn-times and to estimate the system "cost penalty", if any, of excessive variance in truck turn-times.
INSTRUMENTS AND MEASURES TO INSURE PROTECTION OF CONFIDENTIALITY: All data and results derived therefrom will be reported in a manner that maintains confidentiality of the individual firm. Access to raw data is limited to the principal investigator, co-investigators, and research assistants. Your privacy is protected by federal law.
COMPENSATION: A non-technical summary of the project results will be mailed to each participating contact/contractor. However, there is no direct monetary compensation for those choosing to participate.

CLARIFICATIONS AND INSTRUCTIONS

Load form:

single tier/tree-length --- cut-to-length or random length pieces, loaded single tier, with tops trimmed to a specified diameter; any load potentially unloaded with one pass by a crane/loader
double bunk --- cut-to-length or random length pieces loaded in at least two tiers; requires at least two passes with the crane/loader to unload
piggy back --- two product load (long-wood with tops) or two-way load (long-wood/random length stacked two directions), requires at least two passes with the crane/loader to unload
shortwood bolts --- 4' or 8' pulpwood
other --- any load that does not fit in one of the above categories

Summary instructions for drivers:

1. Record data for loads from the woods landing to woodyard or mill overflow yard only.
2. Record date, your name, mill name/location, and scale ticket number for each load.
3. Record clock times from your watch at each of the designated points in the turn-time process. Round values to the nearest minute. NOTE: Scale clock times will not necessarily match your watch. However the variance will be consistent on both the in-bound and out-bound scale times.
4. Once data collection is started, record all loads hauled until the 50 load target is met.
5. Be sure to staple a copy of the appropriate scale ticket to each completed load data form.
6. Record appropriate delay code if applicable or leave blank.
7. Submit completed forms weekly until the 50 load target is met.

APPENDIX B:

COST CALCULATIONS

CALCULATIONS FOR DIRECT AND INDIRECT SYSTEM COST OF EXCESS TRUCK IDLE-TIME

NOTE: log & haul costs (range $10-$25 per ton) used in this report are for illustrative purposes only and are not based on empirical results generated from this or other research. Only the turn-time minute/hour values, marginal minute/hour values, and potential minute/hour gains are empirically supported by this research.

Assumptions for estimating system costs:
1. Mill raw material requirements and practical logging capacity are in balance, i.e., no delivery quotas or artificial restrictions on logging output.
2. Each logging firm has balanced log-haul capacity, i.e., 50% probability of logging being a production bottleneck at any given point in time.

DIRECT SYSTEM COST (DSC) OF EXCESS IDLE-TIME
Given:
Logging season = 48 weeks
Average scheduled machine hours (SMH) = 40 hours per week
Average productive machine hours (PMH) @ 90% scheduled machine hours (SMH)
PMH per week = 36 hours; PMH per day = 7.5 hours
Cost to own & operate RANGE [$300 to $500] per day

DSC attributable to excess idle-time = 100% = RANGE [$41.67 to $69.44] per truck hour

INDIRECT SYSTEM COST (IDSC) OF EXCESS IDLE-TIME
Given:
Number of logging firms = 5,105 [a]
Total annual output = 7,052.9 million cubic feet roundwood [b]
Convert cubic feet to tons using 55.5 lbs/cu.ft. [c]
Average net load weight = 26.7 tons [d]
Total annual output = 195,717,975 tons = 7,330,261 loads
Average annual production per firm = 38,338.5 tons
Cost of log & haul RANGE [$10 to $25] per ton
Logging season = 48 weeks
PMH @ 90% scheduled machine hours (SMH)
Average PMH @ 36 hours per week = 1,728 hours per year
Haul cost @ 2.5 loads per truck per day RANGE [$300 to $500]/66.75 tons = RANGE [$4.50 to $7.50] per ton
Average annual number loads per firm = 1,436 = 6.24 loads per day; requires 2.5 trucks per firm
Proportion idle time when logging is bottleneck = 50%

Logging firm production per PMH:
38,338.5 tons per year / 1,728 PMH per year = 22.2 tons per PMH

RANGE logging cost per PMH:
[$5.50 to $17.50] per ton @ 22.2 tons per PMH = RANGE [$122.10 to $388.50] per PMH

RANGE logging cost per productive truck hour:
[$122.10 to $388.50] per PMH / 2.5 trucks per firm = RANGE [$48.84 to $155.40] per truck hour

Proportion of IDSC attributable to excess idle-time = 50% = RANGE [$24.42 to $77.70] per truck hour

Sources:
[a] US DOC, Bureau of the Census. 1992 Census of Manufactures, Geographic Area Series. MC92-A
[b] Johnson, T.G. and D.P. Stratton. 1998. Historical Trends in Timber Product Output in the South. Research Bulletin RB SRS-33. USDA Forest Service, Southern Research Station, Asheville, NC
[c] Newbold, Ray A. 1999. Weight and Volume Determination for Planted Loblolly Pine in North LA. Unpublished working paper. School of Forestry, Louisiana Tech University, Ruston, LA
[d] Sample N = 9,553; Std. Deviation = 4.0 tons

APPENDIX C:

VALID CASES BY VARIABLE & CD

Case processing summary for the sample.

Variable	Description	Cases Included (N)	Percent Included	Cases Excluded (N)	Percent Excluded
MONTH	month of delivery	10244	100.0%	0	.0%
CONTRACT	contractor	10244	100.0%	0	.0%
DRIVER	driver	10244	100.0%	0	.0%
MILL_NAM	mill name	10244	100.0%	0	.0%
STATE	state delivered	10244	100.0%	0	.0%
SCAL_MET	scale method	10244	100.0%	0	.0%
NUM_SCAL	number of scales	9972	97.3%	272	2.7%
MILL_TYP	mill type	10244	100.0%	0	.0%
FORM	wood/load form	10244	100.0%	0	.0%
TRUK_TYP	truck/trailer type	10244	100.0%	0	.0%
UNLOD_EQ	unloading equipment	10244	100.0%	0	.0%
SITE	unloading site	10244	100.0%	0	.0%
ARIV_WIN	arrival time to weigh-in (min)	10244	100.0%	0	.0%
A_WIN_D	arrival time to weigh-in delay	580	5.7%	9664	94.3%
WIN_LOAD	weigh-in to loader	10244	100.0%	0	.0%
WIN_LD_D	weight-in to crane/loader delay	832	8.1%	9412	91.9%
UNLOAD	unloading time	9972	97.3%	272	2.7%
UNLOD_DE	unloading delay	442	4.3%	9802	95.7%
LOD_WOUT	loader to weigh-out time	10244	100.0%	0	.0%
LD_WUT_D	loader to weigh-out delay	89	.9%	10155	99.1%
TURN_TIME	total turn-time (min)	10244	100.0%	0	.0%
NETWEIGH	load weight (net tons)	9553	93.3%	691	6.7%
BMFILTER	benchmark filter (binary)	2561	25.0%	7683	75.0%

Total number of cases =10,244

Summary of category codes and valid cases.

Variable	Code[a]	Value Label	Valid N[b]
month of delivery	2	February	312
	3	March	475
	4	April	770
	5	May	1023
	6	June	2054
	7	July	1828
	8	August	2684
	9	September	989
	10	October	109
contractor	unique id	1-131	131
driver	unique id	1-254	254
mill name	unique id	1-290	290
state of delivery	1	AL	1580
	2	FL	865
	3	GA	1472
	4	LA	1137
	5	ME	768
	6	MS	1637
	7	SC	780
	8	TX	1512
	9	VA	493
scale method	1	weight	9999
	2	stick	245
number of scales	0	none (stick scale)	244
	1	one scale	6492
	2	two scales	3236
mill type	1	pulp/paper	4464
	2	sawmill	3051
	3	plywood	747
	4	osb	315
	5	chip mill	1226
	6	other	169
wood/load form	1	tree-length	7435
	2	double bunk	1581
	3	piggy-back	437
	4	shortwood bolts	341
	5	other	178
truck/trailer type	1	tractor w/frame trailer	7292
	2	tractor w/pole trailer	2080
	3	single/multi-axle truck	55
	4	single/multi axle truck w/pup trailer	533
	5	other	12
unloading equip	1	OH crane	4968
	2	wheel loader	3703
	3	knuckle boom	1058
	4	other	243
unloading site	1	at mill	9611
	2	off-site	361

[a]Refer to Figure 7 or the load data form (Appendix A) for delay codes and delay labels.
[b]Sum of valid N by variable does not necessarily equal total number of sample cases.

CONTENTS OF CD

File name: final_report_pdf.pdf (full text final report with graphics)

File name: turntime_sav.sav (SPSS format data file)
24 variables and 10,244 cases

File name: turntime_xls.xls (EXCEL format data file)
24 variables and 10,244 cases

```
Variable: MONTH      Month of Delivery    Type: Number   Width:  8   Dec: 0
Variable: DATE       Date of Delivery     Type: Date     Width:  8   Dec: 0
Variable: CONTRACT   Logging Contractor   Type: Number   Width:  8   Dec: 0
Variable: DRIVER     Driver Name          Type: Number   Width:  8   Dec: 0
Variable: MILL_NAM   Mill Name            Type: Number   Width:  8   Dec: 0
Variable: STATE      State of Delivery    Type: Number   Width:  8   Dec: 0
Variable: SCAL_MET   Scale Method         Type: Number   Width:  8   Dec: 0
Variable: NUM_SCAL   Number of Scales     Type: Number   Width:  8   Dec: 0
Variable: MILL_TYP   Mill Type            Type: Number   Width:  8   Dec: 0
Variable: FORM       Wood/Load Form       Type: Number   Width:  8   Dec: 0
Variable: TRUK_TYP   Truck/Trailer Type   Type: Number   Width:  8   Dec: 0
Variable: UNLOD_EQ   Unloading Equipment  Type: Number   Width:  8   Dec: 0
Variable: SITE       Unloading Site       Type: Number   Width:  8   Dec: 0
Variable: ARIV_WIN   Arrival/Weigh-in(min)Type: Number   Width:  8   Dec: 0
Variable: A_WIN_D    A/WI Delay           Type: Number   Width:  8   Dec: 0
Variable: WIN_LOAD   Weigh-in/Loader(min) Type: Number   Width:  8   Dec: 0
Variable: WIN_LD_D   WI/L Delay           Type: Number   Width:  8   Dec: 0
Variable: UNLOAD     Unload Time(min)     Type: Number   Width:  8   Dec: 0
Variable: UNLOD_DE   Unload Delay         Type: Number   Width:  8   Dec: 0
Variable: LOD_WOUT   Loader/Weigh-out(min)Type: Number   Width:  8   Dec: 0
Variable: LD_WUT_D   L/WO Delay           Type: Number   Width:  8   Dec: 0
Variable: TURN_TIM   Total Turn-Time(min) Type: Number   Width:  8   Dec: 0
Variable: NETWEIGH   Net Weight (tons)    Type: Number   Width:  8   Dec: 2
Variable: BMFILTER   Benchmark Filter     Type: Number   Width:  8   Dec: 0
```