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# A Survey Analysis of Harvesting Logistics in Tennessee

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## Abstract

The State of Tennessee is located in the Southeastern part of the United States and is recognized for the production of high quality hardwood lumber used in multiple pulp, paper and veneer wood industries. To capture the potential growth of forest products businesses, the logistics of harvesting and transportation operations were investigated through pilot meetings with loggers and an in-depth statewide 12-page logging and transportation logistics survey. No study prior to this one has detailed the existing logging logistics and capacity of the state. The results explain the critical state of the existing logging and transportation logistics and operational conditions. It highlights the machine operators' limited compensation. The integrated harvest logistics, operations, workforce and conditions findings demonstrate the importance of understanding the joint operations and workforce capacity and regulations to develop a better understanding of forest products industries and forest products supply chains from removal to end use.

**Keywords:** Forestry, Operations, Equipment, Logging, Transportation, Supply chain

## 1. Introduction

The purpose of this study is to help explain and improve forest feedstock harvesting, processing and hauling efficiencies in the State of Tennessee (TN). It is essential to analyze the supply chain logistics of operations for multiple reasons. Some of these reasons include: develop and compare different harvest, delivery and production systems, optimize production factors, reduce broader negative environmental impacts, test the supply effects on the ecosystem and analyze existing capacity for the startup of forest products industries.

The State of Tennessee has a 52% tree cover, which is equivalent to 14 million acres or 5.7 million hectares. Private landowners (including private industry) own an estimated 84% of the forestland, while 16% is publicly administered by local, State, or Federal agencies (Hoyle, 2012). Wood products manufacturing is among the state's largest basic industries. Secondary wood products, such as flooring, cabinetry, manufactured homes and paperboard are based on forest products industry in addition to the provision of $US 2.5 billion in wages paid to approximately 42,000 Tennesseans (Lockman, 2012). In spite of the importance of the forest products industry, there is very little known about the existing work conditions, and the logging and transportation logistics in TN.

This study attempts to present in-depth details of the state's existing forest products supply logistics to help promote information serving logging firms and the startup of new forest products industries. This paper is one of three papers that look into the logistics, cost and life cycle assessment of the supply chain of forest products in TN. It is structured to first explain the study background, its methodology, results and discussion and conclusion.

The State of Tennessee is located in the Southeastern United States and is recognized for the production of high quality hardwood lumber used in multiple pulp, paper and veneer wood industries. In TN, the east and plateau regions are covered with pine, oak-pine and oak-hickory forest types. Upland hardwood sites generally are concentrated in the central and west-central regions (Hopper et al., 1995). Figure 1 shows an integrated USA/TN land use and cover classification map (Fry et al., 2011; TWRA GIS, 2006). The dotted oval shapes along the middle and eastern parts of the map indicate where the most deciduous forested regions exist. Most of the eastern region is part of the Great Smokey Mountain National Park.

This study is based on a forest products supply chain logistics study that was developed in the State of Michigan (MI) in 2010. The study investigated the

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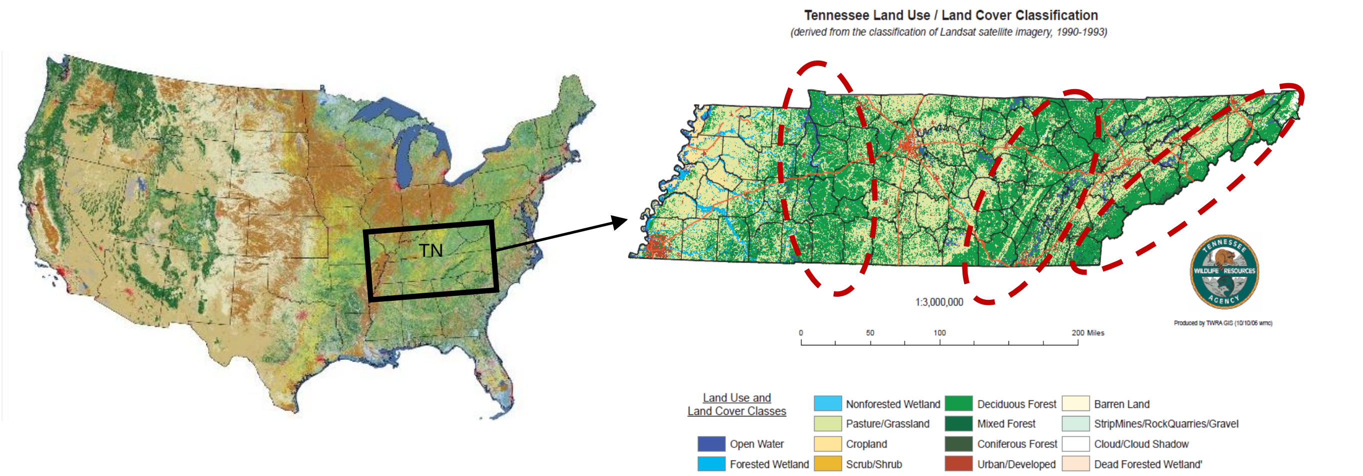


Figure 1. Integrated USA and TN land use and land cover map: dotted regions are deciduous forest cover types (adapted from Fry et al., 2011 and TWRA GIS, 2006).

supply of forest operations as a part of joint private and public collaboration. It helped provide information on the value and emissions of logging operations in relation to the forest products supplied (Abbas et al., 2013; Abbas et al. 2014; Handler et al., 2014). After an investigation into the current state of harvesting and operations logistics in TN, and conducting a series of operator-focused “Logging Logistics Cost Assessment” workshops (Abbas, 2012) organized by the Tennessee Forestry Association (TFA), it became obvious that very little work has explored this particular field. Both MI and TN are hardwood producing states. However, the situation in TN was found to be very different. In TN no prior study has investigated the logging and transportation logistics nor the operating conditions of the logging workforce. This project was funded through the USDA McIntyre Stennis Program formula funds and Tennessee State University in Nashville, TN.

## 2. Materials and Methods

A survey instrument was sent out to the logging firms of Tennessee using the Dillman’s “Total Design Method” (Dillman, 2000). This methodology, as opposed to face-to-face interviews or direct observations, was identified as the most effective method to meet research objectives. The survey instrument allowed the research group to reach the largest number of logging firms possible in the state of TN within the limited project time frame, preserved anonymity, facilitated data analysis and captured the opinions of different logging firms interested in the survey questions regardless of their stratification into different sized or targeted groups. The methodology and analysis followed a previous study carried out in MI (Abbas et al., 2014).

Survey development involved identifying the information needed, writing questions that would contribute to the project purpose and objectives and pilot-testing a series of drafts in consultation with logging machine operators, forestry and forest engineering experts attending the Tennessee Master Logger Program (TFA, 2013). The result of the meetings was a 12-page survey questionnaire booklet that was mailed to logging firms in the state. The survey was mailed out in 2013 and collected data for the year 2012. Data were collected, entered and analyzed and then results were piloted with members from the TFA database of logging firms and foresters.

The survey questionnaire was mailed to 806 logging firms operating in Tennessee, 156 responses were considered complete and entered. The addressee list was obtained from a databased developed by the TFA. The database categories were those of: logger-owner, logger-crew, and other from the database used in this study. The “other” criteria referred to here is usually unknown and could include any other criteria like truckers, landowners, loggers, consultants, forest products industries and others. The database was filtered to all those who had last attended the Master Logger Program and continuing education training within the last five years prior to the survey data collected full year of enquiry (2007 - 2012). Each addressee was given a unique ID code. A $20.00 incentive check was mailed for each returned and completed survey. The survey was relatively complex, required detailed technical and comprehensive information, and was considerably long (12 pages), which required extensive input from logging firms.

Contact with each survey participant involved up to five mailing attempts, as follows:

- Preliminary notice by mail to notify respondents about the survey and its objectives.
- The actual questionnaire booklet with a cover letter and a postage-paid return envelope.
- Postcard reminder/thank you note, containing the URL to the online survey site; sent to the entire mailing list two weeks after initial mailing
- Reminder sent to non-respondents about two weeks after the previous reminder, with a replacement questionnaire and cover letter including the URL to the online survey site, and a postage-paid return envelope.
- Mailing of incentive checks to all respondents.

Responses were received from 57 out of 95 counties of TN, mostly from Middle Tennessee regions (50%), followed by Eastern TN (28%) and Western TN (21%). The true response rate came out to be 19.5%. However, this rate did not include factors such as those whose mail was returned, wrong addresses, duplicates, deceased or ineligible. Using the American Association for Public Opinion Research response rate calculation methods (AAPOR, 2010), the total response rate was calculated at approximately 21%. The response rate was found to be consistent with similar loggers' surveys publications that targeted data collection from logging firms (e.g. Luppold et al., 1998; Milauskas and Wang, 2006; Abbas et al., 2014).

The AAPOR response rate was calculated as the number of respondents who returned completed questionnaires divided by the number of eligible prospective respondents in the sample. However, some listings in the full listing of the initial sample were determined to be no longer in business and therefore were not eligible. Mailings to some other listings were returned as not deliverable or not valid. These were also considered ineligible. The number of ineligible listings was subtracted from the number of listings in the initial sample in computing the percent that responded. The AAPOR Standard Definitions Response Rate 4 formula, equation (1), makes one other adjustment to the number of eligible prospective respondents in the sample. Using this method allowed us to account for illegible, ineligible and ambiguous groups. It was not possible to compute non-response bias because of the lack in information of the non-respondents, and therefore, we opted to use eligibility standards instead (Abbas et al., 2014).

$$RR4 = \frac{Number\ of\ Completed\ Questionnaires}{(Eligible + ((Eligible/(Eligible + noneligible) \times Ambiguous)} \quad (1)$$

Survey responses were cataloged and analyzed using Microsoft® Excel® 2013. Statistical analysis described in this publication permitted a description of real data. Results described the count of respondents and used mean, mode, median, minimum, maximum, standard deviation and percentages of operations functions. Survey questions that involved units of measure permitted responses in English units (short tons, gallons, miles, acres) or common forest industry units (cords) in order to obtain accurate responses from loggers. Units were later converted into metric units for this publication; 1 short ton = 0.9072 metric tonnes (t) and 1 cord = 2.09 metric tonnes. The survey inquired about the following details:

- Workforce characteristics and conditions
- Harvest and transportation operations
- Logging production capacity
- Equipment used for timber and residue supply chains
- Production rates per harvesting configuration, conditions and harvest treatments and tree species
- Source and delivery destination of material removed
- Cost changes in different terrain, forest types and treatments
- Hauling distance and preference for various modes of transportation.

## 3. Results and Discussion

### 3.1. Operating Conditions

One of the key findings of the study has shown that workman's compensation, and health insurance is valued very low. Tennessee workers compensation laws make it legally mandatory for every employer with five or more employees to carry insurance coverage for work-related accidents. The exception here is for construction contractors their insurance required mandates a workman's compensation (NFIB, 2011). This exception does not cover logging operations. The average number of employees per firm came out to be 3.76 employees.

The survey asked about the number of employees during the survey year and the normal conditions to offset biases in interpretation of number of employees per firms. The number of employees per firm (3.76) was identical between the survey year and number of employees under normal conditions. Hence the survey data presented could be seen as a representation of typical operational years. However, this too means that the average number of employees has sustained below five employees, so no requirement for workman's compensation has been a normal working criteria for loggers.

The importance of this finding was paramount, as from out of the 152 respondents to the question that enquired about whether or not respondents received workman's compensation, health insurance or had equipment insurance coverage, the responses came out to be 42.7%, 13.8% and 71%, respectively, had coverage. This investigation highlights the unsafe conditions that many operators are subjected to in Tennessee. This simply meant, as an operator put it, that equipment were valued more than operators. Laws that require mandatory coverage of health and compensation in other regions meant that more were employed per logging firm. More workman focused policy would need to improve workman's compensation rules for the logging community in Tennessee.

The average age of the logging firm businesses in Tennessee was reported to be 23 years old. Concentration of survey respondents were mainly within middle and west Tennessee. Most of the respondents (n=153) produced sawlogs (98%), followed by pulpwood (79%) and only 7% of the respondents reported any type of woodchips production. This low woodchips production is further emphasized by the reported very low number (5 units) of chippers and grinders.

Loggers were mostly owners and operators of their logging equipment. Out of 150 respondents, 122 reported they operated for 100% of their work with their own equipment, with 144 (96% of responses) used their own equipment mostly in their operations. On the other hand, renting out of equipment is not common. There were 127 respondents who reported they do not rent out or subcontract their equipment, as opposed to only 3 who reported they did. Approximately 21 pieces of equipment were reported to be subcontracted. These equipment were mostly off site trucks, followed by trailers.

On average, 51% of operations involved stumpage purchase. This meant that operators were not overly involved in sorting the products for potentially different markets. Operators were asked to what percent of their full capacity they operated, average responses were at 73% of total capacity, which is consistent with other studies that have explored this capacity question (Abbas, 2014).

Shift hours varied significantly per week, between summer and winter. Not surprisingly since there could be a difference of five hours between daylight time in summer and winter in Tennessee. Out of 96% of the survey respondents' summer and winter hours per week were reported to average 40.1 and 30.5 hours, respectively. It is encouraging that the statewide average forestry voluntary best management practices implementation rate is as high as 89% (TN DoA, 2013).

### 3.2. Harvest Conditions

The survey enquired about the average percentage of operations that fell within typical treatments that prescribed 30%-50%, 50%-70%, clearcut removals. Sites harvested per logging operations were mostly from small removals. It was found that 44% of the operations fell within 30%-50% partial removals cut type, followed by 27.5% and 28.5%, respectively. Determining locations for industries that supply wood products need to factor in larger travel distances and transportation costs than with an assumption that the surrounding area would be dedicated to the supply.

There were 130 operators who responded to the question that enquired about the average size of trees cut. Most cuts (31%) targeted 15-20 inches DBH trees, followed by 30% of removals over 20 inches DBH. This was followed by 10-15 inches trees (22%) and the least percentages of harvests fell within <5 inches DBH trees range (4%). Larger trees over 25 inches DBH constituted about 11% of the harvests. Based on these results, total cuts over 15 inches DBH accounted for over 70% of the entire cuts. This information confirms that several sites in Tennessee target commercially desirable larger trees, which might indirectly confirm the high-grading problems facing the state's forestlands (Hopper et al., 1995).

To get a better understanding of the terrain conditions, the survey requested information about land types where different operations took place. The results showed that 41% and 35% of operations occurred on hilly and steep terrain, respectively. The results also showed that 15% and 9% of operations occurred on flat and low land terrain, respectively. These results are significant since the impact on equipment is different from one type of terrain to the other. This further impacts the quantity of material delivered in one hour, since steep terrain require further agility and time from the operators, as opposed to flatter terrain. Hence it need not be assumed that because Tennessee has better year round climate conditions that removals are going to be higher. Since a seasonally accessible flat site might yield more harvests that a steeper terrain under normal weather conditions.

Average mean of harvested areas was reported to be 20 ha per respondent, with an average minimum area harvested of 8 ha and maximum average of 62 ha. Most respondents (39%) reported their preparedness to move equipment to a new job for 0-500 tons, followed by 25% for the 500-1000 tons, then 12% for 1,000-2,000 tons, 12% for 2000-6,000 tons, 7% for 6,000-10,000 tons and 5% for over 10,000 tons jobs. This means that operators are prepared to move equipment for smaller operations which raises questions about the economies of scales and profit at such lower rate and compensation matters.

In terms of approximate annual area harvested per respondent, most of the respondents (41%) harvested 0-88 ha, 30% harvested 80-200 ha, 18% harvested 200-400 ha, 8% harvested 400-800 ha and only 3% harvest 800 or more ha. These smaller areas harvested per year results likely reflect harvest from multiple small-sized stands from small private-land owners across Tennessee. These results were rather surprising at first, because of how small the areas were in relation to an entire year of harvest. However, the results may not be far from the current situation. This is based on the assumption that the total number of potentially active loggers in the TFA database came up to be about 825 operators. Approximately 230,000 acres (93,078 ha) on a10-year average, are harvested annually in Tennessee, whether complete or partial harvests (Oswalt et al., 2012). If we assume that average tract size is 20 hectares (based on survey results), then the total 93,078 ha harvested per year would amount to about 113 ha per logging firm. Accordingly, there would be expected to be 4,654 logging jobs or tracts per year in Tennessee.

Since the cost of operations are impacted by the type of harvest, terrain and species, the survey asked the respondents, how their cost of operations were impacted by working from "regular to difficult" terrain, "clearcut to selective cut" and "softwood to hardwood species". The results showed that operators on average found a cost increase of 31%, 16% and 13%, respectively in these different circumstances. These results are significant because they show the diversity in the types of operations that supply wood to consumers. The cost differences of operations need to be accounted for in the overall final cost of the supplied product. Operators experience different work conditions, rather than fixed ones, at their end.

The percentage of operations that leave residue behind after harvest operations came out to be very high. The survey enquired about the percentage of operations that “clearcut and leave residue”, “clearcut and remove residue”, “partial removal and leave residue”, “partial removal and remove residue” and “other methods”. The results came out to be 29.80%, 3.40%, 56.60%, 7.60% and 2.60%, respectively. Most likely the lack of grinding/chipping equipment contributed to this condition of lower residue removed from the site. However, based on the condition of equipment in Tennessee, the introduction of a new type of equipment might not be effective or justified.

### 3.3. Timber from Source to Delivery

To understand the extent of the source-to-end supply of timber in TN, the survey inquired about sources of timber removed and their destinations criteria. Based on results, most of the feedstock (81%) was removed from “non-industrial private lands”. The least quantity of feedstock (0.4%) came from “National Forestlands”. Products removed from “State forest lands” were 1.1%, “industry or real estate timber management organizations” were 13.6%, “other public lands” were 3.4%, and 0.7% came from sources that operators were “unsure” of.

Most of the feedstock was delivered to “hardwood sawmills” (57%) followed by “pulpmills” (33%). The least was delivered to “fuel wood users” (0.3%) and “particle board” uses were (0.3%). “Softwood sawmills”, and “veneer mills”, received 5% and 2%, respectively. A part of the supply was delivered to “truck/rail landing”, but that only amounted to 1.35% of the supplied wood. “Wood pellet mills” received 0.15% of the supply and “fired wood boilers” only received 0.08% of the supply. This analysis could help determine the likelihoods of the material destination and as a result can contribute to the markets intended from resources removed.

### 3.4.Operations

#### 3.4.1. Harvest equipment

In order to get for the first time a description of existing harvest equipment in Tennessee, the survey inquired about equipment types, numbers, model, make, year, total use hours, per year hourly use, fuel use, and head type. The harvest system in Tennessee is predominantly chainsaw and fellerbuncher-dependent. Other cutting systems, such as cut to length-forwarder systems that are more prevalent in other parts of the country such as the Northern and Northeastern states are almost non-existent in Tennessee. Table 1 describes the reported numbers of equipment and their types by respondents. Reported equipment were aggregated. This information was particularly helpful in developing further analysis. The total hours of equipment use, and their type, were combined with production volumes to develop productivity cost estimates per hour in a different study. The fuel use also helped explain the carbon footprint of the supply chain for an assessment of the life cycle assessment of the supply chain.

#### 3.4.2. Skidding Distance

Yarding in Tennessee is to the most part reported to be carried out with grapple skidders. The skidders’ distance travelled and fuel use contribute significantly to the cost of harvesting. This is especially the case since skidders travel back and forth to harvest sites in order to collect and drop material off at the landing or material collection site. The time and distance spent in a one way travel accordingly has a large impact on the hourly delivered volume, and the productivity of the harvesting operation as a whole. The average mean skidding distance reported by 80 respondents was 531 m (0.33 miles), and the mode (most prevalent) was 402 m (0.25 miles). On the other hand, the average of the reported maximum skidded distances was reported to be 1 km (0.67 miles), with a mode value of 1.6 km (1 mile).

#### 3.4.3. Equipment Repair and Maintenance

Repair and maintenance of equipment is a necessary component for the sustainability of long term logging operations. If machines breakdown considerably, it could become more expensive to maintain and serve the business than to operate. Survey respondents were asked: “In an average work day, approximately how many hours were allocated for repairs and maintenance?” Respondents had the option to respond in hr/day or hr/week. On average, the reported daily repair hours for 88 respondents was 1 hour, and the reported weekly repair hours results were 4 hours. When asked about the equipment that required the most repairs, 47% out of 136 respondents, reported the skidder equipment required the most repairs, followed by fellerbuncher/tree cutter (17%) then chainsaws (14 %), respectively. However, these equipment also contributed to the highest number of equipment used in the system. Hence these values are not an indication of functionality as much as they are a reflection of utilization.

Table 1. Equipment type and number by order of functionality

| Functionality | Equipment Type | No. of Units Reported |
|---|---|---|
| Cutting | Feller buncher | 67 |
| | Cut to length | 2 |
| | Chainsaws | 476 |
| Skidding/ Yarding | Forwarder | 2 |
| | Grapple Skidder | 147 |
| | Cable Skidder | 87 |
| Loading | Knuckleboom Loader/Loader | 180 |
| Slashing | Slasher | 38 |
| Delimbing | Delimber | 46 |
| Comminuting | Grinder | 1 |
| | Chipper | 4 |
| Bulldozing | Bulldozer | 78 |

#### 3.4.4. Equipment Specification and Utilization

Equipment average age in Tennessee is depreciated beyond the expected lifetime of equipment. The average age of equipment ranged from 3 years for chainsaws, to 26 years old cable skidders and 11 and 13 years old grapple skidders and knuckleboom loaders, respectively. Table 2 gives a detailed description of the equipment performance and Table 3 describes the age and utilization of equipment.

#### 3.4.5. System Configuration and Productivity

Assessing the productivity of equipment in TN was not straightforward, because the reported configuration and volume produced for equipment and systems were very different per respondent. Since harvesting operations are predominantly a small scale enterprise in TN (based on the average number of employees per firm that came out to be 3.7 employees under normal and survey year conditions). Business owners need to mix and match to build their own system requirements that are responsive to their operations, finances, the market needs and the area within which they operate. Accordingly, in TN most operators owned and operated their own equipment, and it was difficult to identify similarities across operations within the state.

Table 2. Equipment type and specification

| Equipment type | Model year | Average total machine hours | Fuel use (l/hr) (~1l=0.26 gal.) |
|---|---|---|---|
| Fellerbunch | 2002 +/-5.7 (66) | 6691+/-3443 (57) | 24.7 +/- 10 (44) |
| Cut to Length | 2007 +/-3.5 (2) | 1970+/-1248 (2) | 23.4 (1) |
| Chainsaws | 2009+/-3.23 (50) | 1477 +/-3538 (43) | 3.8 +/-10 (33) |
| Forwarder | 2007 +/- 3.5 (2) | 3450 (1) | 22.7 (1) |
| Grapple Skidder | 2001 +/-7.2 (94) | 8961 +/-5073 (101) | 21.5 +/-8 (65) |
| Cable Skidder | 1986+/-10 (47) | 12128+/-14189 (45) | 12+/-8.7 (36) |
| Knuckleboom Loader | 1999 +/-8.4 (86) | 8944 +/-5327 (89) | 16.3+/-14.6 (69) |
| Loader | 1991 +/-16.5 (10) | 7775+/-6018 (14) | 11.8+/-7.6 (12) |
| Slasher | 2006 +/-5.6 (12) | 5789+/-3977 (10) | NR |
| Delimber | 2002+/-5.8 (15) | 9025+/-7150 (14) | NR |
| Grinder | 1994 (1) | NR | 23.4 |
| Chipper | 1998+/-11 (2) | 4533+/-4786 (3) | NR |
| Bulldozers | 1994 +/-12 (53) | 6191+/-3687 (49) | 18.7+/-9 (30) |

The value between parentheses (_) indicates the number of equipment units reported and used to generate the results

Table 3. Equipment average age and utilization

| Equipment Type | Average Age from 2013 | Utilization Rate | Total hrs. per Eqp. |
|---|---|---|---|
| Fellerbunch (67) | 10 | 33.46% | 6691 |
| Cut to Length (2) | 5 | 19.70% | 1970 |
| Chainsaws (476) | 3 | 24.62% | 1477 |
| Forwarder (2) | 5 | 34.50% | 3450 |
| Grapple Skidder (147) | 11 | 40.73% | 8961 |
| Cable Skidder (87) | 26 | 23.32% | 12128 |
| Knuckleboom Loader (143) | 13 | 34.40% | 8944 |
| Loader (37) | 21 | 18.51% | 7775 |
| Slasher (38) | 6 | 48.24% | 5789 |
| Delimber (46) | 10 | 45.13% | 9025 |
| Grinder (1) | 18 | NR | NR |
| Chipper (4) | 14 | 16.19% | 4533 |
| Bulldozer (78) | 18 | 17.20% | 6191 |

The value between parentheses (_) indicates the number of equipment units reported and used to generate the results.

The only alternative to the lack of a common equipment and system configuration was to identify common equipment units used per respondents regardless of other product processing equipment they reported, such as a slasher or bulldozer. After counting and recounting equipment that could be analyzed based on the reported productivity and type of equipment respondents owned, the following tables were generated for the most commonly used equipment configurations and types (Tables 4 and 5) These configuration were tied with the reported productivity of respondents per their system used. Data analysis linked productivity data per equipment types to develop entire supply chain productivity estimates presented in this paper. The production volume reported is estimated as that volume received at the landing. This information was also run by wood procurement professionals in the state to verify its reasonableness.

Table 4. System one production estimates

| Treatment | 30% - 50% removal | | | 50% - 70% removal | | | Clearcutting | | |
|---|---|---|---|---|---|---|---|---|---|
| Forest type | Hdwds | Sftwds | Mixed | Hdwds | Sftwds | Mixed | Hdwds | Sftwds | Mixed |
| Ave. t/hr | 15.8 | 16.6 | 14.9 | 17.6 | 19 | 16.4 | 20.7 | 22.5 | 21.2 |
| No. of units | 162 | 137 | 143 | 111 | 100 | 111 | 181 | 153 | 140 |

System one: 1.2 fellerbunchers, 3.6 chainsaws, 2 skidders, 1.5 knuckleboomloaders
**Ave. t/hr:** Explains the average tonnes removed per system per treatment per forest type per hour.
**No. of units:** Explains the number of equipment units used to calculate the average t/hr per system, treatment and forest types. **Hdwds:** Hardwoods, **Sftwds:** Softwoods

Table 5. System two production estimates

| Treatment | 30% - 50% removal | | | 50% - 70% removal | | | Clearcutting | | |
|---|---|---|---|---|---|---|---|---|---|
| Forest type | Hdwds | Sftwds | Mixed | Hdwds | Sftwds | Mixed | Hdwds | Sftwds | Mixed |
| Ave. t/hr | 10.4 | 9.6 | 12.8 | 12.1 | 10.2 | 11.0 | 12.6 | 12.5 | 14.4 |
| No. of units | 89 | 55 | 59 | 74 | 46 | 50 | 55 | 49 | 69 |

System two: 3.3 chainsaws, 1.6 skidders, 1.1 knuckleboom loaders
**Ave. t/hr:** Explains the average tonnes removed per system per treatment per forest type per hour.
**No. of units:** Explains the number of equipment units used to calculate the average t/hr per system, treatment and forest types. **Hdwds**: Hardwoods, **Sftwds**: Softwoods

Despite the lack of identical configurations from the results, systems in Tennessee are not complex. The composition of the equipment varied in the total number of equipment reported, for the different cutting, skidding, loading, delimbing, slashing, comminuting and bulldozing functions. These functions were carried out with different types of machines. For example, delimbing and slashing could be carried out with chainsaws. Sometime the bulldozer would skid material based on weather conditions. To simplify results and to assess productivity, we needed to identify at least two systems to analyze, with enough responses that were valid. In this sense, our estimates based the productivity of these systems on the total equipment included in the reported results. The versatility of equipment used and the small number of employees per firm, with operators mostly owning their equipment, make running the business a very user-specific situation. The following is a description of the best available average number of systems configurations that were considered more typical and were paired with reported ton hr-1 reported productivity. Data were aggregated into these system configurations: System one: 1.2 fellerbunchers, 3.6 chainsaws, 2 skidders, 1.5 knuckleboomloaders; and System two: 3.3 chainsaws, 1.6 skidders, 1.1 knuckleboom loaders.

**3.4.6. Transportation**

It was key to understand how far forest products travel from site to end use for multiple reasons. These reasons include: assess existing modes of transportation, and explain how far truckers travel to get to markets. This information is helpful to determine road infrastructure and preparedness around harvest sites. The survey enquired about whether or not the logging firms owned trucks. It was found that 95% of the respondents owned trucks. The total of 179 trucks were owned by 148 respondents. This finding provides a different dimension to the understanding of the start and end of forest products supply chains in Tennessee per logging firm. Results (Figure 2) have further shown that most of the operations, especially largest percentages of logs, pulpwood and wood chips operations travel less than 48 km (30 miles). A larger percentage of pulpwood (39%) traveled within the 48 - 97 km range (30-60 miles). This is positive, since the carbon footprint of hauled material are within a feasible range. It also means that most of the products from TN are transported to local destinations, with very few deliveries to wider ranges. Further research could investigate how far products from TN woods travel.

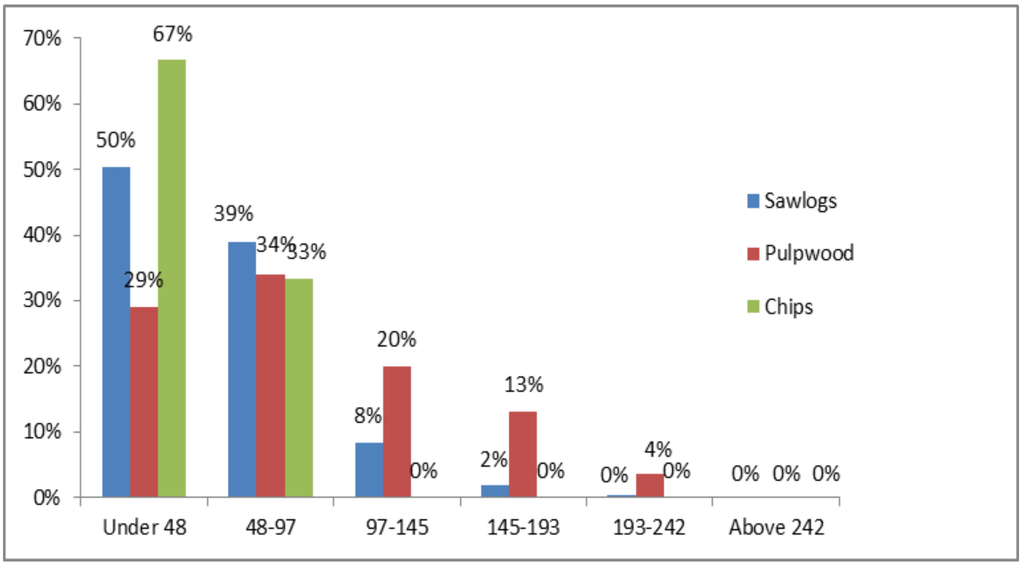

Figure 2. Percentage of wood trucked to different distances (Per km range)

### 3.4.7. Truck and Trailers

Out of 200 records of trucks analyzed, the average age dated back to 1995. The age of the oldest of these equipment dates back to 1965 and the newest to 2013, with a standard deviation of 8 years. Out of 154 records of trailers analyzed, the average age dated back to 1994. The age of the oldest of these equipment dated back to 1955 and the newest to 2012, with a standard deviation of 10 years. Out of 88% of the survey respondents, on average 8.5% of round-wood was loaded by self-loading trucks, with only 7% of these respondents reported hauling more than or equal 50% of their operations with self-loading trucks. Only 0.3% was the approximate percentage of logging removals that were moved by rail. In terms of barrage use to haul wood, this was non-existent.

Out of 197 records of trucks, the average number of axles per truck was 3 axles. Out of 169 records of trailers, the average number of axles per trailer was 2 axles. Therefore, the average number of axles of wood trucks on the roads comes up to 5-axles. This was further confirmed by talking with wood procurement officers in Tennessee. Based on this value, the average 5-axle truck and trailer payload was found to be 24,494 kg (27 tons) of pulpwood, based on conversations with the local industry.

## 4. Conclusion

This study helped identify many potential projects and gaps of knowledge that could help improve the logging and operations systems in Tennessee. One particularly key finding was that more workman focused policy would be needed to improve workman's compensation rules for the logging community in Tennessee. Further, as loggers own about 50% of the stumpage they operate with, hence they do not contribute significantly to sorting out material per market type. This means the landowners have a large role in determining the sorting and destination of timber removed. One other key finding was the lack of a unified harvest configuration. As a result, the study had to identify a common system with productivity operations based on the integration of input from individual respondents to different questions. This information is helpful to identify more unified production systems throughout the state for upcoming work. To conclude, the current state of the equipment and operator work conditions in TN need to be further assessed and improved to help develop healthier workforces, operations, markets and supply chains.

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