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A Survey Analysis of Forest Harvesting and Transportation Operations in Michigan

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Abstract

This paper assesses the technology involved in commercial forest harvesting and delivery operations. It investigates existing forest-based production capacity and its potential to supply the startup of large scale forest-based industries. A survey of harvesting and transportation workforce and technology was mailed to 1,130 logging firms operating in Michigan and four Wisconsin counties that adjoin Michigan's Upper Peninsula. The response rate received was 28%. The paper details and analyses the different operational matters, conditions, equipment and transportation use reported by logging firms. The study provides technical forest products operations information and methods for assessing the capacity of logging firms and markets looking to expand their businesses.

Keywords: loggers, operations, products, equipment, transportation

1. Introduction

Employment in the logging industry in the United States has been heavily impacted in recent years by the economic downturn, which has greatly reduced the demand for wood-frame housing (Drapala 2009), and through more systematic declines in the pulp and paper and furniture industries (Grushecky et al. 2006, Jylhä et al. 2010). One response has been to advocate for the growth of an industry to produce fuel and energy from forest woody biomass material (ESIA 2007, IRGC 2008), which would further increase efforts to promote the development of alternatives to fossil fuel as outlined in the 2007 US Energy Security and Independence Act (ESIA 2007). However, without understanding the supply logistics and operations that influence utilization of wood products from commercial harvesting operations, the economic potential for forestry-dependent industries cannot be accurately assessed. Commercial forest operations supply chains, which provide raw materials for forest industries, include harvesting, forwarding and transportation operations. The supply chain of forest pulpwood and small diameter trees is similar to that of larger trees but potentially includes specialized equipment and techniques to handle and produce value added products such as woodchips. For example, supplying woodchips from harvesting residues and small diameter trees requires a chipper or grinder unit in addition to the standard forest harvesting equipment.

As available information of logging firms' technological capabilities was limited prior to this study, the objective was to investigate existing forest-based production capacity to supply the startup of large scale forest-based industries in Michigan. To examine this capacity, especially in relation to growing interest in cellulosic ethanol production, a survey instrument was developed that inquired about work force characteristics and conditions, logging equipment and productivity, production rates per harvest conditions and prescriptions, and transportation equipment use.

The survey instrument was used in the study to identify potential for the growth of a cellulosic ethanol facility in the Upper Peninsula of Michigan. Results were provided to assist in understanding the overall logging capacity surrounding the proposed facility. The information related to the Upper Peninsula portion solely was reported to the facility in question, and were proprietary. Since the unique requirements of the proposed facility are expected to be requirements for other potential large scale wood products industries, the survey instrument was expanded to cover a statewide database of loggers, for the potential growth of similar, or other wood products industries, in the state. Results in this study are based on survey responses and analysis from a subset of the logging industries. They do not intend to present a full description of logging firms in Michigan. However, they contribute to the knowledge of the operating conditions and equipment productivity of the state.

2. Background

In 2009, researchers from Michigan State University and Michigan Technological University began studying the operations of the state's forest feedstock supply of pulpwood and small diameter trees; focusing on harvesting, forwarding, on-site processing and transportation operations from natural forest stands to processing facilities. This paper examines the results of a questionnaire carried out to assess the workforce and equipment capacities available for supplying pulpwood, small diameter trees and woodchips from natural forests in the state.

Research on logging equipment productivity has ranged from detailed studies using time and motion analysis (Hartsough et al. 2001, Spinelli and Hartsough 2001, Harris 2003, Hunsberger et al. 2003), to assessments of the cost of the total supply chain and shift level analysis (Han et al. 2004, Spinelli and Visser 2008, Abbas et al. 2011A), to broader-scale analyses involving survey focusing on logging production, business management, and ownership of logging firms (McNeel and Dudd 1996, Luppold et al. 1998, Egan 2001, Rickenbach et al. 2005, Drolet and LeBel 2010, Egan 2011, G.C. and Potter-Witter 2011). The study reported in this paper takes a different approach from previous studies in that it uses a survey instrument to integrate information about harvesting technology, the logging workforce, and the operating environment faced by logging firms in Michigan.

3. Materials and methods

Dillman's »Total Design Method« (Dillman 2000) was implemented. 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 within a limited 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 survey questionnaire was sent to 1,130 logging firms operating in Michigan and four bordering Wisconsin counties (Marinette, Florence, Vilas and Iron). The addressee list was obtained from a dataset from the Department of Forestry at Michigan State University that integrated a database from the Michigan Department of Natural Resources and state forest timber sale bidders (G.C. and Potter-Witter 2011).

Development of the survey involved identifying the information needed, writing questions that would contribute to the project objectives and pilot-testing a series of drafts in consultation with logging machine operators, forestry and forest engineering experts. Pilot testing was carried out with several local logging firms. The final product was a 14-page survey questionnaire booklet that was mailed to logging firms in Michigan.

The survey was conducted in two parts. The first, in 2009–2010, covered listings of loggers in the Eastern Upper and Northern Lower Peninsula of Michigan. The second, in 2010–2011, covered listings of loggers in the remaining parts of the state and the four neighboring counties in Wisconsin. The funding for the entire project was received over two years from two different sources. The first part was surveyed for a private industry that was interested in investigating supply potentials in the northeastern parts of Michigan. The process was then replicated to cover the entire state once funding from the Department of Energy was received.

Each addressee was given a unique ID code. Most of the received questionnaire responses were mailed in, but there was an option provided for a web-based response instead. Respondents were permitted to access the online questionnaire by using their assigned ID code. The Michigan State University Office for Survey Research (an independent third party) mailed the questionnaire and received completed questionnaires. A $20.00 incentive check was mailed for each returned and completed survey.

The first-phase mailing was sent to 612 logging firms and 112 responded. The second phase mailing was sent to 518 logging firms operating in counties that were not covered in the first phase and 110 responded. The survey was relatively complex, required detailed technical and comprehensive information, and was considerably long (14 pages), which required extensive input from logging firms. Using the American Association for Public Opinion Research response rate calculation methods (AAPOR 2010), the total response rate was calculated at approximately 28%. The response rate was found to be consistent with similar loggers' surveys publications that targeted data collection from logging firms (Luppold et al. 1998, Greene et al. 2001, Milauskas and Wang 2006). The 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. Additionally, the AAPOR Standard Definitions Response Rate 4 formula makes one other adjustment to the number of eligible prospective respondents in the sample.

There were three broad categories of outcomes based on the results of the mailings. Listings that are clearly determined to be eligible listings, listings that are clearly determined to be ineligible listings, and listings where there is no response that indicates whether the listing is actually eligible or not, i.e., the status is ambiguous. Response Rate 4 presumes that a fraction of the listings that are ambiguous are probably ineligible. The proportion of logging firm listings that are eligible divided by the sum of those that are eligible and those that are not eligible is used to multiply the number of ambiguous listings. The sum of this adjusted number of ambiguous listings plus the number of eligible listings is used as the denominator to calculate the percentage of eligible listings that responded, as indicated in equation (1). 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.

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

Responses were received from loggers in 40 out of 83 counties. Nine respondents completed the online version of the survey. Most of the responses were received from the Upper Peninsula of Michigan, where the highest concentration of timber resources in the state exists. Contact with each survey participant involved up to five contact attempts, all by mail, 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 from each participant were cataloged and analyzed using SPSS/PASW Statistics 18.0 and then transferred to Microsoft® Excel® 2010. 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. Statistical analysis used in the publication permitted a description of real data. The database was inclusive of the logging firms of the entire state and the four Wisconsin neighboring counties. We could not control the response rate, but targeted the entire logging population. Statistical analysis of survey results described the count of respondents and used mean, mode, median, minimum, maximum, standard deviation and percentages of operations functions. Data analysis linked productivity data per equipment types to develop entire supply chain productivity estimates. The questionnaire requested information on the following:

⇒ Workforce characteristics and conditions;

⇒ Logging production capacity;

⇒ Equipment used for all supply chain activities;

⇒ Production rates for several different harvesting systems, configurations, conditions and prescriptions;

⇒ Mean hauling distance and preference for various modes of transportation.

4. Results and discussion

4.1 Operational matters

Respondents were asked to relate their current actual production to their firm's total operating capacity given the current crew and equipment. On average, respondents reported operating at 73% of their total capacity. For the most part, 87% of the respondents were owners and operators of logging firms. Only 8% of the respondents reported working as logging operators who do not own the logging firm, and 5% reported they were owners who do not operate their own equipment.

The survey asked questions about current and under normal conditions number of employees. It was difficult to compare the 2010 and 2011 surveys in that respect, because the year in question was different and the economic situation was dynamically changing due to the decline in the housing and the pulp and paper industries. To account for this bias, we aggregated value pertaining to number of employees per firm under normal conditions. On average, the respondents' firms have been in business for 28 years and under normal conditions averaged 6.5 employees. This response is similar to a previous study carried out in 2008 within Michigan that identified firms having been in business for 29 years with an average of 7 employees per firm (G.C. and Potter-Witter 2011). An earlier survey study, however, carried out in 2003 in Wisconsin and the Upper Peninsula of Michigan reported there were only 4.8 employees per firm on average, including 0.7 part-time employees (Rickenbach et al. 2005). Stumpage price is a very significant part of the total harvesting and supply cost incurred. Stumpage price contributed about 11% of the harvest and delivery supply cost of pulpwood in Michigan (Abbas et al. 2013). Operations that required stumpage purchase averaged 70% of the operations of respondents, with a standard deviation of 39%, based on 180 responses.

4.2 Operational conditions

4.2.1 Landownership

Michigan's forests cover over 19 million acres. More than 12 million acres are privately owned. The State of Michigan owns 4 million acres (Pedersen 2005). Since land ownership and decisions can impact the amount of forest resources available for removal, the survey inquired about the ownership patterns. Almost 60% of harvest volumes came from private non-industrial lands, based on the responses for that particular question (Table 1). These results were consistent with an earlier survey that reported 64% of harvested volumes came from non-industrial private forests (G.C. and Potter-Witter 2011).

Table 1 Percentage of wood volumes harvested from each property type

Wood property type sources	Percent
Non-industrial private lands	59.2%
Forest industry or real estate timber	10.0%
State forest lands	22.8%
National forest lands	4.4%
Other public lands	2.5%
Tribal lands	0.1%
Unsure of ownership	1.1%

4.2.2 Terrain

The type of terrain has a major influence on the cost and productivity of harvesting operations. More difficult terrain yields higher operating costs because of the site conditions, time spent in extraction and maneuverability of equipment. The survey results suggested that most operations in Michigan are performed on flat ground (34% of reported operations) and rolling hills (32% of reported operations), with smaller fractions of operations run in lowland terrain (wetter grounds – 24% of reported operations) and steep hilly areas (10% of reported operations). This is not unusual, since harvesting operations need to be performed under suitable soil conditions. For example, Minnesota timber harvesting guidelines recommend entering lowlands and wet soils only under frozen or dry site conditions to avoid displacing the soil (Abbas et al. 2011b). The fraction of firms that indicated a percentage of harvesting that takes place under wetter conditions, needs to be investigated further, since such operations could displace soil properties, as the cited guidelines suggest. Results, on the other hand, concerning where most of the operations were performed, could aid in determining locations for the startup of new facilities, since the concentration of logging operations would unlikely be in these lowland or steep terrains.

4.2.3 Winter and summer operations

Mean shift hours were collected for both summer and winter operations. Results, at a 99% confidence level, did not differ significantly for the two seasons. This finding was unexpected since winter day times are shorter. Respondents indicated that their operations were limited to a single daily shift with mean summer hours of 37.6 per week with a standard deviation of 19.1 from 193 respondents, and mean winter hours of 37.4 per week with a standard deviation of 18.2 from 192 respondents.

4.2.4 Product types and the size of harvested stands

The survey queried loggers about the types of products they processed. Results were structured into the percentage of their operations that involved sawlogs, pulpwood and woodchips products. While 97% of 206 respondents reported working with sawlogs, and 95% of these respondents reported working with pulpwood products, only 15% of 132 respondents indicated working with woodchips for at least part of their operations.

Survey responses of the average harvest stand size were analyzed and the mean, median, and mode were reported. Also, responses for the two different questions reported the minimum and maximum stand size harvests were analyzed. The responses averaged 19 ha for the average stand harvested, and 7 and 64 ha for the minimum and maximum stands harvested, respectively (Table 2). The reported average harvested area was unsurprising considering: the cost of moving equipment to the site, potentially building roads and a landing/processing area that is accessible regularly in the harvest area, and because data were collected for different logging firms with different operational business sizes.

Table 2 Maximum, minimum and mean size of harvested stands in 2009 and 2010, hectares

	Minimum stand size harvested, ha	Maximum stand size harvested, ha	Mean stand size harvested, ha
Mean	7	64	19
Standard deviation	9	59	15
Median	10	100	16
Mode	10	80	16
Minimum	0	0	0
Maximum	97	275	101
Number of respondents	177	179	185

A broader question inquired about the smallest operations in terms of volume and area on which operators would be willing to bid. The smallest volume 143 respondents were willing to bid on averaged 494 t (~237 cords), with a standard deviation of 435 t (~208 cords). On the other hand, the smallest area 192 respondents were willing to bid on averaged 9 ha.

4.2.5 Harvest types

The largest percentage of harvesting prescriptions (45.7%) involved removing 30% of the harvestable volume from site. The next larger percentage (27.4%) involved removing 70% of the harvestable volume, followed closely by clearcutting (26.9%). This type of information is critical when considering the supply radius for a sustainable quantity of forest products for a potential new facility, since assuming clearcut sizes of removals would not be a practical option.

To better understand the extent to which operations involved residue removal, survey questions inquired about percentages of clearcut and partial removal operations that removed residue. Most operations (>78%) did not involve residue removal. Responses indicated that over half of the logging operations involved partial cut harvesting with residues left on site (Table 3).

Table 3 Residue management options, percent

Residue management options	Percent
Clearcut and leave residue	27.8%
Clearcut and remove residue	9.9%
Partial removal and leave residue	50.9%
Partial removal and remove residue	9.7%
Other method	1.7%

4.2.6 Skidding and forwarding distance

Since skidding and forwarding contribute significantly to the supply operations because of the fuel use and the labor involved, the survey enquired about the distance travelled using this equipment type. In the analysis, the mean of the skidding/forwarding distances responses were filtered to a maximum of 3.2 km (2 miles). Three eliminated responses from 186 responses reported an unrealistic average extraction distance of 5, 6 and 8 km. whereas, the maximum reported skidding/forwarding distances was 8.0 km (5 miles). Three eliminated responses from 179 responses reported an unrealistic maximum extraction distance of 145, 241 and 515 km. The survey question did not make a distinction between the extraction equipment used, be it a forwarder or a skidder. We could assume that the larger distances are more likely travelled by forwarders, the most popular skidding/forwarding system in the state and the unit that permits longer travel distance because of its truck-like features. The reported skidding/forwarding distance averaged 520 meters (0.25 miles) with a standard deviation of 870 meters (0.5 miles) based on 177 responses. Whereas the reported maximum forwarding/skidding distance averaged 1.16 km (0.72 miles) with a standard deviation of 1.3 km (0.8 miles) based on 176 responses.

4.2.7 Logging equipment

4.2.7.1 Equipment types

Respondents were asked to provide information about the type and number of harvesting equipment they owned, along with key descriptive information of this equipment. Reporting these data required a detailed technical understanding of equipment used by operators. A large variety of equipment was re-

Table 4 Technical analysis of harvesting equipment

Equipment type	Number of units	Model year	Total machine hours	Fuel use (l hr^{-1})
Cut-to-length	191	2003 ± 4.1* (132)	9,286 ± 6,543 (151)	18.55 ± 8.71 (142)
Feller buncher harvester	57	1996 ± 8.3 (35)	9,384 ± 6,696 (38)	23.85 ± 9.84 (37)
Feller delimber	4	1988 (1)	12,467 ± 6,788 (3)	10.22 ± 2.27 (3)
Forwarder	247	1997 ± 9.5 (153)	10,666 ± 6,138 (165)	12.11 ± 7.19 (159)
Harwarder	18	2001 ± 5 (5)	9,053 ± 7,586 (6)	8.33 ± 1.89 (5)
Chainsaw	569	2006 ± 4.9 (113)	668 ± 990 (36)	4.16 ± 2.27 (35)
Grapple skidder	86	1995 ± 8.1 (47)	11,583 ± 6,116 (31)	19.31 ± 8.71 (33)
Cable skidder	26	1976 ± 8.8 (17)	8,889 ± 3,772 (9)	9.08 ± 3.79 (11)
Loader	54	1996 ± 6.7 (30)	7,525 ± 7,429 (24)	14.38 ± 7.19 (26)
Grinder	9	2003 ± 1.0 (5)	2,459 ± 772 (6)	30.28 ± 3.41 (4)
Slasher	24	1995 ± 7.6 (14)	9,607 ± 7,140 (15)	14.76 ± 6.81 (18)
Delimber	8	1996 ± 8 (3)	6,220 ± 3,561 (5)	11.36 ± 0 (3)
Debarker	4	1997 ± 2 (2)	7,333 ± 1,155 (3)	50.35 ± 10.98 (3)
Chippers	31	1997 ± 9.1 (18)	8,798 ± 8,584 (17)	54.89 ± 33.69 (18)
Bulldozers	132	1992 ± 14.0 (72)	4,866 ± 3,226 (87)	14.38 ± 7.95 (79)

* For each item, the number following ± is the sample standard deviation and the value in parentheses is the number of survey responses from which the mean and standard deviation were calculated

ported in use among the different respondents (Table 4). Cut-to-length equipment was the predominant type of harvesting equipment throughout the state, with forwarders the most common off-road transport equipment. Cut-to-length equipment was reported to be the most popular style of mechanized harvesting equipment, outnumbering feller bunchers by nearly 3:1. Similarly, forwarders were the most common extraction equipment used, followed by skidders. Chainsaws represented the most ubiquitous type of equipment reported by respondents; used not only for felling trees but also for removing tops and branches, releasing vegetation and removing brush when it obstructs heavy machinery.

4.2.7.2 Equipment use

In one of the longer questions, survey respondents were asked to provide mechanical details about the equipment used for their operations (Table 5). Respondents reported the total number of equipment, equipment model, type and year, total hours on equipment, hours on equipment and hours operated in the survey years (2009/2010), fuel use, equipment head type, and whether the equipment used tires or tracks, from a list of available harvesting equipment. Most reported equipment types were depreciated beyond the 5 years life time expectancy of new equipment. The age of the full range of equipment averaged 15 years old. Cut-to-length equipment was among the youngest equipment age group and averaged 10 years old. Cable skidders were among the oldest equipment used, averaging 35 years old. On average the equipment with highest machine hours were the feller-delimbers and grapple skidders. The maximum of the reported hours per year per equipment use averaged 1,161 hrs. Based on a full time utilization rate of equipment of 2,000 hrs. yr^{-1}, on average the highest utilization rate was reported by the cut-to-length equipment users, that runs at 58% and the harwarder (combined harvester/forwarder equipment) users' utilization rate that runs at 45%. Reported utilization rates in this study could aid in the analysis of depreciated equipment and associated hours of operation to estimate the cost of harvesting operations. As production was reported on an hourly basis from a regular workday, these values were assumed to be scheduled machine hours used to determine harvest cost (Abbas et al. 2013). However, it is important to note that these utilization rates are reported within the limited number of responses, and under market conditions that have not fared well due to the economic downturn in the forest products industries (Table 5).

Table 5 Equipment mean age and utilization rates per year

Equipment type	Mean age of equipment	Mean h yr^{-1}	Utilization rates, 2000 h yr^{-1}*
Cut-to-length	8	1,161	58%
Feller buncher harvester	15	626	31%
Feller-delimber	23	542	27%
Forwarder	14	762	38%
Harwarder	10	905	45%
Chainsaw	5	134	7%
Grapple skidder	16	724	36%
Cable skidder	35	254	13%
Loader	15	502	25%
Grinder	8	307	15%
Slasher	16	600	30%
Delimber	15	415	21%
Debarker	14	524	26%
Chippers	14	628	31%
Bulldozers	19	256	13%

* This is based on 8 hours per day for 5 days. There are 52 weeks in a year with a two week vacation. Therefore: 8 h X 5 days X 50 weeks = 2,000 hours per year

4.2.7.3 Repair and maintenance

An analysis was conducted to identify the type of equipment that required the most repairs and the repair time of equipment per day, with particular attention to equipment that requires the most repair time. The time spent repairing and maintaining equipment reduces operating, production and efficiency time for both the operators and the equipment. The questions for this section were phrased as follows: 1) in an average work day, approximately how many hours do you allocate for repairs and maintenance?; and 2) which of your equipment types requires the most repair time per day? On average, operators reported repairing and maintaining equipment on site for about 1.3 hours per day. Out of 171 responses, 32% reported that the cut-to-length equipment required the most repair, 22% reported that the feller buncher equipment required the most repair, but only 14% reported that chainsaws required the most repair. These cutting systems that required the most repair time, were followed by the skidding/forwarding systems that required the second most repair time; 11% of the respondents reported that the forwarder required the most repair, followed by the skidder (9%). Although the cut-to-length– forwarder configuration was reported by the larger number of respondents as the system that required the most repairs, it was also cited as the most used system. Therefore, having most repairs associated with this system does not necessarily reflect on the functionality of this equipment type, rather that it is more widely used and as a result the system more likely to be identified within the responses.

4.2.8 Production rates of equipment configurations

Respondents were asked which harvesting equipment configuration they utilized for different harvesting scenarios and in different forest types. Responses were reported in cords or short tons of wood per hour and converted to metric units in this publication. Equipment configurations were grouped into three main categories:

A – Cut-to-length and forwarder;

B – Whole tree feller buncher with skidder and slasher;

C – Chainsaws and skidder.

To minimize error from including respondents that owned many pieces of equipment but did not use them equally or at all times, the analysis focused on respondents who owned only one or two pieces of cutting equipment (cut-to-length, and whole tree feller bunchers). Productivity was normalized to a single unit of harvesting equipment (i.e., production rates reported by respondents with two sets of harvesting equipment were divided by 2). Responses that indicated chainsaw use were also included. This analysis procedure, however, was not followed for chainsaw-based harvesting, as multiple chainsaws are typically used by logging crews relying on this equipment configuration. Operators reporting the chainsaws-skidder configuration for >50% of their operations reported using 2.6±2.0 chainsaws. As a result, reported productivity for chainsaws is based on the assumed production of 2.6±2.0 chainsaws plus one skidder. For cut-to-length equipment and forwarders, the mean reported productivity increased as harvesting intensity increased from 30% selective cut up to clearcutting, as would be expected. In almost every case, productivity in each harvesting scenario was highest in softwood plantations, which are typically on even terrain, easier on equipment and stocked with optimal timber for harvesting. Tables 6, 7 and 8 summarize the reported roundwood harvesting productivity of different equipment configurations.

Table 6 Cut-to-length and forwarder productivity

Treatment	Forest type	Productivity per harvester, t system h^{-1}		
		N*	Mean	Std. dev.
30% cut (selective)	Natural hardwoods	54	6.97	2.88
	Mixed hardwood/softwood	48	7.99	3.09
	Natural softwoods	47	8.24	4.51
	Softwood plantations	37	9.54	4.40
70% cut (shelterwood)	Natural hardwoods	43	8.53	3.76
	Mixed hardwood/softwood	41	9.41	3.78
	Natural softwoods	38	9.72	4.49
	Softwood plantations	29	10.37	4.44
Clearcutting	Natural hardwoods	43	11.50	5.72
	Mixed hardwood/softwood	47	11.83	5.22
	Natural softwoods	40	12.67	5.82
	Softwood plantations	35	14.54	8.39

* N is the number of harvesting equipment units included in the analysis

Table 7 Feller buncher harvester, skidder and slasher productivity

Treatment	Forest type	Productivity per harvester, t system h^{-1}		
		N*	Mean	Std. dev.
30% cut (selective)	Natural hardwoods	15	7.76	3.17
	Mixed hardwood/softwood	15	7.64	2.73
	Natural softwoods	13	7.03	2.75
	Softwood plantations	8	8.37	1.94
70% cut (shelterwood)	Natural hardwoods	14	9.89	2.98
	Mixed hardwood/softwood	15	9.66	2.96
	Natural softwoods	16	10.47	3.34
	Softwood plantations	9	11.25	3.61
Clearcutting	Natural hardwoods	13	14.23	5.59
	Mixed hardwood/softwood	13	13.75	6.22
	Natural softwoods	11	13.40	5.90
	Softwood plantations	9	14.81	8.74

* N is the number of harvesting equipment units included in the analysis

Feller buncher-skidder-slasher system operators reported highest productivity per t hr^{-1} system under clearcut conditions. The maximum productivity of the whole tree system came close to 14 t hr^{-1}. Cut-to-length-forward system operations reported the maximum productivity of about 13 t hr^{-1}. An analysis of the lowest production tonnes per hour was reported by chainsaw users (3 t hr^{-1}, under clearcut conditions).

Table 8 Chainsaw and skidder productivity

Treatment	Forest type	Productivity**, t system h^{-1}		
		N*	Mean	Std. dev.
30% cut (Selective)	Natural hardwoods	32	4.21	2.78
	Mixed hardwood/softwood	19	4.07	3.05
	Natural softwoods	17	3.84	3.26
	Softwood plantations	13	3.67	1.79
70% cut (shelterwood)	Natural hardwoods	20	4.59	3.36
	Mixed hardwood/softwood	18	4.05	2.92
	Natural softwoods	14	3.92	3.09
	Softwood plantations	12	3.63	2.21
Clearcutting	Natural hardwoods	12	4.17	2.34
	Mixed hardwood/softwood	14	3.99	1.92
	Natural softwoods	13	2.96	1.25
	Softwood plantations	9	3.71	2.30

* N is the number of harvesting equipment units included in the analysis

** Operators reporting this configuration for >50% of operations reported using 2.6±2.0 chainsaws in this equipment configuration

The reported productivity within 30%, 70% and clearcut treatments using all three harvesting systems averaged 8 t hr^{-1}.

4.2.9 Transportation

4.2.9.1 Trucks

The survey inquired about trucks used by respondents to transport pulpwood, small diameter trees and woodchips. Truck data were analyzed for the larger 10–11 axle log trucks, smaller 2–9 axle log trucks, and chip vans. Large log trucks were found to be younger in age, with lower average fuel use and larger annual usage than other trucks represented in the survey, but the distribution of annual mileage data for trucks varied considerably in all truck classes. Table 9 summarizes the main characteristics of trucks owned by survey respondents. On average, 86% of roundwood was reported to be transported by self-loading trucks. Based on responses, most log trucks in the state of MI are equipped with self-loaders. Over 70% of respondents indicated that 100% of their roundwood production was transported with self-loading trucks.

Forest products are delivered to a variety of end-users and intermediate supply chain points. Respondents were asked to report percentages of products that were delivered to different facilities. Pulpwood and hardwood sawmills received the largest percentage of products totaling 59% of the products generated from logging firms (Table 10). Results were consistent with results from 2008 survey work that reported 58% of production was delivered to pulp and paper mills and hardwood sawmills (G.C. and Potter-Witter 2011). Survey respondents were asked about the percentage of their annual production delivered to different destinations (Table 10).

Table 9 Trucking equipment descriptive summary

Year	Fuel use, km l^{-1}	Annual use, km yr^{-1}
All trucks reported: 2000±7* (156)	1.9±0.76 (148)	88,417±96,348 (150)
Large log trucks (10–11 axles): 2003±6 (76)	1.56±0.37 (71)	105,132±63,209 (66)
Small log trucks (2–9 axles): 1997±8 (84)	2.24±0.83 (74)	75,500±117,928 (76)
Chip Vans: 1998±7 (15)	1.78±0.42 (21)	68,880±45,636 (20)

* Numbers following ± represent standard deviations based on indicated number of respondents inside parentheses

Table 10 Percentage of production delivered to different facilities

Recipient forest products industries	Percent
Hardwood sawmill	23.9%
Softwood sawmill	12.5%
Veneer mill	4.1%
Pulp mill	36.1%
Other panel mill	4.0%
Oriented strand board mill	6.0%
Wood pellet fuel mill	1.1%
Wood power generator	1.6%
Truck/rail landing	3.3%
Other location	7.5%

Pulp mills were reported to be the most popular destination for forest products in the state of Michigan. Transport distances for each of the three main forest products (sawlogs, pulpwood, chips) followed a similar pattern (Fig. 1). Respondents were asked to list what percentage of their annual production of sawlogs, pulpwood, and chips was transported by truck for several mileage categories. Over 55% of the respondents transported saw logs within 60 miles (approx. 97 km). Whereas only 45% of the responses for pulpwood and chips reported they transported less than 60 miles. Results coincide with results from an earlier study that has shown that 90% of sawlogs were delivered to mills within approx. 145 km (90 miles) from logging sites (G.C. and Potter-Witter 2011). Wood chips were the product transported the longest distance, with over 27% of production traveled more than approx. 145 km by truck.

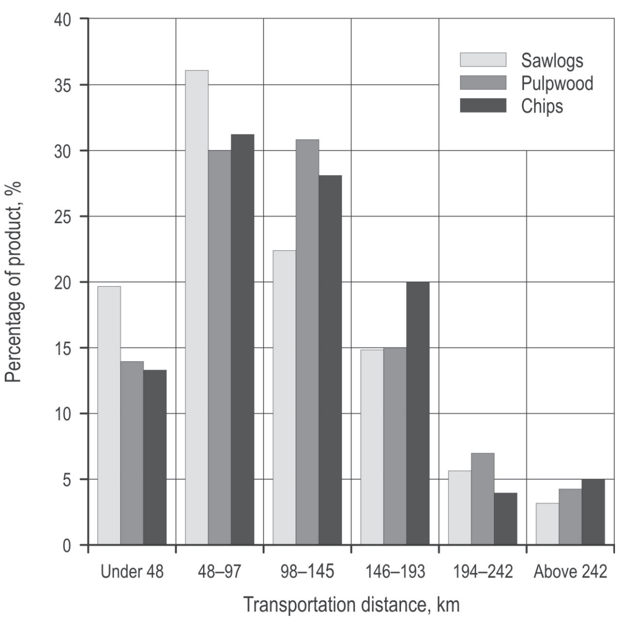

Fig. 1 Truck transport distances for main forest products

4.2.9.2 Rail

Rail transport was utilized unevenly throughout the state of MI for the transportation of forest products. In 2010 survey, respondents were asked about their most recent use of rail transportation, and over 60% of the respondents who answered the question indicated that they had never used rail transport (Table 11). Respondents were asked about the percentage of their annual production that was moved using rail transport. The 25 respondents that indicated some portion of their production had been moved by rail (12.7% of responses) moved approximately 22.1%±19.2% of their annual production by rail. It should be noted that all of the respondents indicating a use of rail transport were based in the Upper Peninsula of Michigan.

Table 11 Most recent use of rail transportation

Time frame	Responses	Percent of respondents
(1) In past 6 months	9*	14.1%
(2) In past year	2	3.1%
(3) In past 3 years	3	4.7%
(4) In past 5 years	4	6.3%
(5) In past 10 years	5	7.8%
(6) In past 15 years	2	3.1%
(7) Not at all	39	60.9%
(8) No response	46	--

* Data originated from 2010 respondents to logger survey, 2nd phase

When asked about the factors that limited their use of rail transport for moving forest products, survey respondents indicated that reliability of service and limited access in main work areas were the primary reasons that rail transport was not used more extensively (Table 12). Existing transport contracts and lack of knowledge about rail were the factors that limited use of rail transport the least among survey respondents (Table 12), indicating that loggers might have been familiar with the operations of the rail industry within the state, and they were not meeting the needs of the loggers.

Table 12 Reasons that limit use of rail transport by Michigan loggers

Reason	Mean Response* 1= not limiting, 5 = extremely limiting
Lack of knowledge rail contractual arrangements	2.48±1.58
Reliability of service	3.53±1.47
Speed of delivery	3.39±1.45
Limited rail access in main work areas	3.49±1.64
Prices not competitive with other modes	3.03±1.51
Minimum shipment too large	2.49±1.69
Existing contract with other provider	2.12±1.57

* No. of responses ranged from 68 to 78 loggers for each reason listed

5. Conclusion

The study helped provide detailed information of the state of forest products harvesting and transportation industries in the State of Michigan and four adjoining Wisconsin counties. A survey instrument was used to compile operational factors. Results, based on responses, helped identify interconnectedness between key operational matters such as work conditions, product types, and equipment and transportation logistics. The response rate was 28% from the respondents who received the survey from the database of loggers. Based on the extensive details required in the survey and other logging surveys sited in the study, this response rate is not uncommon. With this in mind, results do not provide a 100% analysis of the logging firms of the state. Conclusions were drawn from the analysis of responses to help explain operating conditions of a subset of loggers who responded to the survey.

Even though the paper started with pointing to the decline in the harvesting industry because of recent economic downturn impacts, the results of the study intend to help attract further industries to replace this short coming. Based on survey results the problems for logging firms are larger than merely replacing, or introducing, forest products markets. Many issues emerged in this study that shed light on the importance of paying attention to the logging workforce and their operating conditions. For example, the prices of timber are widely accessible. The productivity of equipment from the survey results offer a chance to forest equipment operators to look into what they might be able to produce, as well as, what their peers' capacity looks like. Detailing operational logistics and the workforce capacity could help industries make a more informed decision when starting a forest products industry in the state and elsewhere.

Different studies have explored the rate of employees per firm in Michigan. The rate is slightly lower in this study than previously reported. However, because of the recent shutdown of pulp and paper industries, the difficult and expensive work conditions, it is assumed that unless markets are in place, equipment operators would further be leaving the industry. Most logging firms identified in this study were found to be located in the upper peninsula of Michigan and were run by owners who operate their own equipment; at a reported operating capacity averaging 73%. This result is lower than the percentage reported in an earlier study that reported that logging firms worked at 82% of their full capacity (G.C. and Potter-Witter 2011). Interest in working within a fuller capacity needs to account for the full logistics conditions involved in harvest operations. Further, most of the harvest volume came from partial cut treatments, especially within 30% selected cut treatment types. Industries may not assume a natural area would be clearcut to fit their wood supply objectives. The equipment of highest use in Michigan was the cut-to-length equipment, but the largest productivities were reported by the whole tree feller buncher under clearcut conditions to be up to 14 t hr^{-1}. A significant finding in the study was that most operations did not involve residue removal or chipping of material. In fact, grinders and chippers were used by only a few number respondents, since only 8 grinders and 14 chippers were reported.

It is unclear from the responses why chipping and grinding equipment were very few in the responses. Hypothetically, this could be due to multiple factors, including: the large number of cut-to-length systems, or that most harvests fell within 30% cut treatments or that the residue material left behind from these operations did not justify investing in a chipping system. Further explanation could also be attributed to the lack of sufficient wood chips industries and markets that account for the cost of purchasing chipping equipment.

Based on the survey responses, non-industrial private land owners were found to be the source for most of the products extracted within Michigan. Most products were transported within 97–145 km. Most of reported products were delivered to pulpwood mills, and most respondents who responded to the use of rail in transportation reported they never used rail, citing the reliability of service and accessibility as the reasons most limiting to the use of rail transportation. The survey inquired about the terrain types linked to harvesting operations. Most operations were reported to be within flat and rolling ground operations, which is a key factor when determining where to deploy operations when identifying a location for a forest products facility, since starting a facility on the foothills may not be the ideal location, based on productivity details.

The survey instrument used is transferable to other regions since even though responses might be different, they shed light on the factors that need to be considered when investigating forest harvesting and transportation operations. Findings are relevant to other regions and countries beyond the study because they pull together interpretations of key operational matters, conditions, work seasons, product types, equipment and transportation in an integrated manner. Results could be compared with other regions to draw a more realistic representation of logging firms and operations. For example, in southern states it would be rare to detect cut-to-length operations. The stark differences between harvesting equipment, and their productivity with existing equipment, are worthy of investigation to determine productivity and existing equipment potentials.

Data in the study applies to harvesting under both natural and plantation stand types. Results could be compared against similar variables from other regions, to determine unique productivity rates. Unique productivity rates could be used to promote wider involvement of stakeholders in the supply chain to build stronger forest products businesses. For example, one purpose of this study was to help inform the logging community about the productivity of their peers under their similar operating conditions. Promoting further knowledge transfer among the logging firms would help promote a more informed, integrated and rounded approach to logging operations analysis to build stronger forest products businesses.

Results analyzed helped develop a fuller description of operating conditions to identify to what extent the logging community is responsive to the potential for the startup or expansion of new industries. The reported productivity of existing systems in different forest types, and the age of the technology running the operations, can help determine the extent of the size of facilities and the required attention needed to improve the harvest and delivery options in the state. Productivity from this study helped develop a cost of the supply chain logistics of forest material (Abbas et al. 2013). Attention to improving the efficiencies and conditions of these harvesting and transportation operations offer opportunities that can make the harvesting and delivery options more efficient for logging firms and more attractive to forest products industries.

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