FOREST FEEDSTOCK CENTER OF ENERGY EXCELLENCE (COEE)

Final Project Report

From

MICHIGAN STATE UNIVERSITY

To

Frontier Renewable Resources

Project III: Improving Forest Feedstock Harvesting, Processing, and Hauling Efficiencies

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EXECUTIVE SUMMARY

This report pertains to the project 3 task #2 of the overall *proposal entitled, "The Feedstock Supply Chain Center of Energy Excellence (COEE)"*. The project 3 focused on improving feedstock harvesting, processing and hauling efficiencies. Project 3 was further divided in three sub-tasks. Sub-task 2 was concerned with analyzing timber harvesting, forwarding and processing (HFP) systems. There were two main objectives under this task.

1. A survey of existing harvesting, forwarding and processing systems, and
2. Refinement to select best alternatives by incorporating field data for Michigan conditions.

To take a snapshot of Michigan's logging industry especially within the 150-mile radius of Kinross, MI, a survey instrument was developed. The instrument was designed to collect information that would be useful to all projects under the umbrella of COEE. Input from logging industry leaders, forest industry professionals and well as university faculty experts was sought. The instrument was field tested with a few loggers to ensure that we were asking the right questions. The result was a 14-page survey that was mailed out to an entire group of logging firms in the region from an existing MSU-database. Full survey and notices using the Dillman's (2000) method were sent out to logging firms in the region by MSU Institute of Public Policy and Social Research (IPPSR). The survey was approved by MSU Institutional Review Board to comply with human subjects' protection. The survey was conducted in 2009 and was successful in receiving responses from 112 logging firms in the region representing a 30% response rate. The data collected offered a unique opportunity to understand the state of the logging industry and harvesting technology in the region.

We learned that a significant majority of logging firms were owner operated and a very small percentage were owners but not operators. The size of logging firms varied from employing only one employee to a maximum of 32. However, employment was generally down in 2009 from other years. The main product was saw log and pulp wood with wood chips constituting about one third of their business. Naturally, saw mills were the primary destination of timber followed by pulp mills and veneer mills. Very few loggers supplied biomass to pellet mills or wood fired power generators. A large fraction (46%) of the loggers surveyed harvested less than 200 acres whereas only 16% harvested over 100 acres. Loggers indicated that they would be willing to harvest as little as 1 acre and as much as 400 acres. On an average logging firms were in business for over 30 years while some as long as 90 years. Most of the firms owned their equipment and operated their equipment at about 86% capacity in 2009. A majority of loggers purchased stumpage.

A large majority of logging firms owned cut-to-length harvesters (96 units) followed by feller-bunchers (34 units) in the Kinross region. They owned 140 forwarders, 49 grapple skidders and 24 loaders. Therefore, cut-to-length processor and forwarder was the preferred configuration by those that responded to the survey followed by feller-buncher/grapple skidder/delimber/slasher. The average harvest productivity ranged from 8.54 tons/hr for 30% selective cutting to 13.42 tons/hr for clear-cutting. Productivity numbers for feller buncher were comparable to those of full processor. A large majority of loggers were leaving residue on site. This makes sense since biomass market has not been fully established. A large majority of loggers harvested in non-industrial private forests (94) followed by state forests (55). Only 17 loggers reported harvesting in national forests. A large number of loggers harvested in flat terrain followed by rolling terrain. Only 48 reported harvesting in step hilly terrain. They reported increase in harvesting cost when they went from regular to difficult terrain, from clear-cut to selective cut and from softwood to hardwood.

The costs (subtotal to logging truck) of roundwood ranged from $7.91 to $21.20 per green ton for different forest types, harvesting prescriptions, and harvesting systems, as calculated based on survey based data. Increasing the amount of removal from 30% cut to clear cut significantly reduces cost for both whole tree and cut-to-length systems. In whole tree harvesting, a machine combination of two feller-bunchers plus one skidder showed much lower production costs than one feller-buncher plus one skidder combination. This trend is not reflected in the cut-to-length system. Overall, our data analysis indicated that harvesting costs are highly variable and depend upon forest type, stand condition, harvesting prescription, type of equipment, and harvesting system used.

The FRCS model predicted costs of employing a whole tree harvesting system ranged from $17 - 38 per green ton with an average of $29.36 per green ton. The model projected cost for using a cut-to-length system was from $11- 13 dollars per green ton, averaged at $11.86 per green ton. Generally, the whole tree harvesting system cost resulted from FRCS model prediction were higher than those provided by the loggers' survey, however, the model prediction and survey results for cut-to-length system costs were comparable.

Our survey results showed that in the study region a whole tree harvesting system with two feller-bunchers the production rate ranged from 16.10 to 25.30 green tons per PMH; while this range for a cut-to-length system with two harvesters was 14.10 to 20.24 green tons per PMH. With current yearly PMH of 1237.5 hours, a whole tree harvesting system can produce 19923.75 to 31308.75 green tons wood, and a cut-to-length has a production capacity of 17448.75 to 25047 green tons. To meet Mascoma plant's feedstock requirement of 0.5 million tons roundwood per year, at least 16 whole tree harvesting systems or 20 cut-to-length harvesting systems need to be employed for feedstock supply. To reduce the number of harvesting systems required, harvesting operations need to be better organized to improve system utilization rate. Longer scheduled working time also can be considered, as survey results showed that average daily scheduled machine hours were only 6.6 hours in the study region. Please keep in mind that the actual capacity is perhaps considerably higher since not all loggers responded to the questionnaire.

Management factors affecting cost were found to be initial investment, machine economic life, and diesel fuel price. Sensitivity analysis showed that with the use of completely depreciated equipment the production cost can be reduced significantly. The sensitivity analysis indicated that with an increase of machine economic life, machine hourly rate will decrease, resulting in a final production cost reduction. Finally, with 1$/gal diesel price increase, the production cost was found to increase by $0.79 per green ton.

BACKGROUND

Mascoma is a leader in advanced low-carbon biofuels technology and is based in Boston, Massachusetts. Using proprietary microorganisms and enzymes developed at the company's laboratories in Lebanon, New Hampshire, Mascoma is deploying advanced technologies that enable the creation of fuel from a range of non-food biomass feedstocks. Mascoma is developing demonstration and commercial scale production facilities globally. Mascoma has chosen to locate a commercial facility in Chippewa County's Kinross Township in Michigan's Upper Peninsula. The facility will use sustainably harvested mixed hardwood chips and other non-food biomass materials as raw material for the production of cellulosic fuel. The production facility is expected to produce 40 million gallons of ethanol and other valuable fuel products per year.

Mascoma is partnering on this project with JM Longyear, a well-established natural-resources company based in Marquette, Michigan. Longyear owns more than 101,000 acres of northern hardwood commercial timberlands in Michigan's Upper Peninsula and in Ontario, Canada. Longyear is one of the largest suppliers of hardwood logs in the Great Lakes region of the U.S. Its primary customers are in the Upper Midwest, but it also supplies customers in Europe and Asia.

The collaboration between Mascoma and JM Longyear involves the formation of a new company, Frontier Renewable Resources (Frontier), which owns the project. Mascoma Corporation has received funding from the U.S. Department of Energy and the State of Michigan. The Michigan grant specifically includes funds provided by the 21st Century Jobs Trust Fund to establish a center of energy excellence in cellulosic ethanol production.

This is a collaborative project between Michigan State University and Michigan Technological University. There are three broad projects within the COEE:

1. Construction and Refinement of a Feedstock Supply Chain Model
2. Increasing Availability of Feedstock and Ensuring Sustainability
3. Improving Feedstock Harvesting, Processing and Hauling Efficiencies

Each of the above three project teams consists of faculty from the two universities. This report pertains to Project #3. There were three tasks identified in this project:

1. Biomass transportation system evaluation
2. Analyze timber harvesting, forwarding and processing systems
3. Understand economic and environmental impacts of various system alternatives

Lead for task #1 was provided by Pasi Lautala (MTU). Lead for task #2 was provided by Ajit Srivastava (MSU) and for task #3 David Shonnard (MTU).

OBJECTIVES

The objective of the work reported in this report was to analyze timber harvesting, forwarding and processing systems in the 150 mile radius of Kinross, Michigan. Specifically, the following were objectives were defined:

1. Survey existing harvesting, forwarding and processing systems in the Kinross region
2. Refinement to select best alternatives by incorporating field data for Michigan conditions

A SNAPSHOT OF LOGGING INDUSTRY WITHIN 150-MILES OF KINROSS, MI

Introduction

The availability of a steady source of woody biomass at a cost effective price is critical to the cellulosic ethanol plant to be built in Kinross, MI. This depends, among other factors, upon the logging capacity as determined by the number and type of logging equipment available for harvesting woody biomass within the 150 mile radius of Kinross. In order to determine the existing logging capacity and related operational characteristics in the region, a comprehensive survey was completed in 2009-10. Results were collected, aggregated and analyzed to provide an overall snapshot of the state of the logging industry in the region. Results of the survey are presented here to summarize the status of the logging industry in Michigan.

Methodology

Development of the Survey Instrument

We were primarily interested in addressing the following:

- Logging operations (location, owner or operator, number of employees on the crew, and production in acres and tons for 2009)
- Logging capacity (equipment owned or subcontracted, type of equipment used, logging configuration and percentage)
- Production rates per harvest conditions and prescriptions (% of operations per cut types, skidding distances, operations terrain, shift hours, time for repairs, and stand size)
- Transportation and delivery (method, distance and preference for one transportation means over the other)
- Recommendations/expectations of the logging community in the region

ID CODE #______

Logging Equipment and Transportation Survey

The purpose of this study is to identify the logging capacity in the State of Michigan. This survey serves as a key component of the larger research project that Michigan State University and Michigan Technological University are carrying out to assess existing logging capacity to identify optimum harvesting, forwarding and processing equipment and systems for timber and biomass harvested from natural forest stands as well as plantations. Your responses to the survey questions will help describe the current state of the harvesting and transportation equipment, the current production, the potential production and what is needed to reach this potential production for the start-up of potential new facilities. Your participation in this survey is voluntary and the information provided is confidential and will be used only for study purposes.

You can complete an online version of the questionnaire instead at: http://www.loggingMI.ippsr.msu.edu/

You indicate your voluntary consent to participate in the study by completing and returning the questionnaire by mail or fax to:

Office for Survey Research - IPPSR
321 Berkey Hall
Michigan State University
East Lansing, MI 48821-1111 Fax (517) 432-1544

If you have questions or comments about the research, please contact:

Dr. Dalia Abbas, Department of Biosystems and Agricultural Engineering
Michigan State University
Tel. (517) 355-7493 Fax (517) 432-2892
Email: abbasd@msu.edu

Please return your completed questionnaire in the envelope provided. Thank you very much for your help and for taking the time to complete this survey.

Questionnaire designed by the Office for Survey Research

Figure 3.1. Survey introductory page

In 2009, at the onset of the project, the project team contacted local experts and reviewed the literature about existing information. No comprehensive study of the existing harvesting and transportation technology. As a result it was difficult to undertake a study that explained harvesting operations in the region without knowing the information presented in this section of the report. As a result, a comprehensive analysis of needed questions was developed to explain the business sectors, equipment use and productivity, and operational capacities. The survey development process took about 6 months of consultations and edits. When a draft was prepared it was piloted with local logging firms. The result was a 14-page survey that was mailed out to an entire group of logging firms from an existing MSU-database. Full survey and notices using the Dillman's (2000) method were sent out to logging firms in the region. The survey was successful in receiving responses from 112 logging firms in the region. The data collected offers a unique opportunity to understand the state of the harvesting technology in the region. The survey was approved by MSU Institutional Review Board to comply with human subjects' protection.

Survey Method and Stages
Each respondent had a unique web and survey ID that was entered when respondents chose the online option using the website http://www.loggingMI.ippsr.msu.edu/. The following steps were used in the survey process in consultation with Prof. Hembroff in the Office of Survey Research of Michigan State University:

- Mailing #1: Pre-notice by mail to notify about the survey.
- Mailing #2: Mail contains the survey, a cover letter, and a business postage-paid return envelope
- Mailing #3: Postcard reminder/thank you, containing the URL to the survey site; sent to everyone about two weeks after mailing #1
- Mailing #4: Mail sent to non-respondents only about two weeks after the postcard mailing; contains a replacement questionnaire, with cover letter that includes the URL to the survey site, and a postage-paid return envelope

Results and Analysis
Survey results were completed and aggregated using SPSS statistical package. Response rate was 33%, following number of respondents of 112 out of the 622 sent out. The rate is based on the American Association for Public Opinion Research response rate data analysis equations (www.aapor.org). All responses were coded to reflect 526 variables. Survey results were shared with other principal investigators of the project.

Geographical Distribution of Logging Firms
Table 3.1 includes responses from logging firms in the various counties within the 150-mile radius from Kinross, MI.

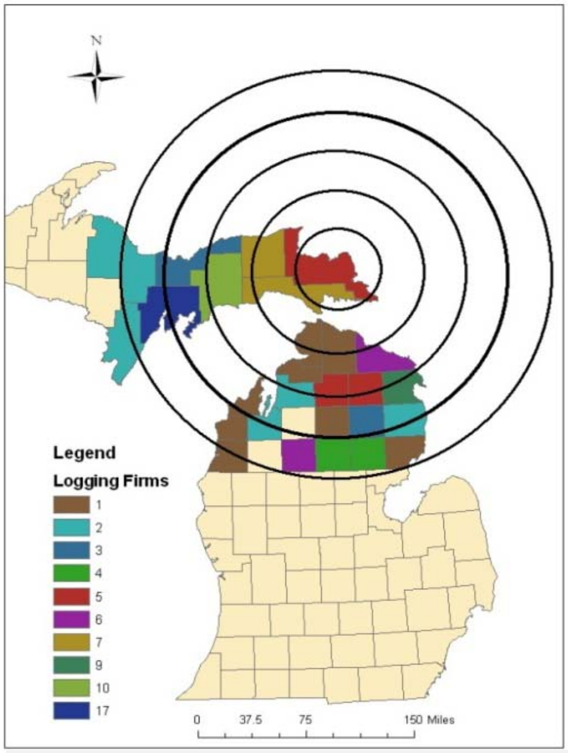

Figure 3.2. Distribution of logging firms based on survey results.

Table 3.1. Geographical distribution of respondents by county.

County	Responses	County	Responses	County	Responses
Alcona	2	Delta	17	Menominee	2
Alger	3	Emmet	1	Missaukee	6
Alpena	9	Grand Traverse	2	Montmorency	5
Antrim	2	Iosco	1	Ogemaw	4
Benzie	1	Leelanau	1	Oscoda	3
Charlevoix	1	Luce	7	Ostego	5
Cheboygan	1	Mackinac	7	Presque Isle	6
Chippewa	5	Manistee	1	Roscommon	4
Crawford	1	Marquette	2	School Craft	10

Business Details of Logging Firms

The following tables include data relative to the type of logging operation, number of employees, the type of forest products produced and product destination:

Table 3.2. Ownership

Type of Operations	%
Owner and Operator of a Logging Firm	88%
Owner but not operator of a logging firm	9%
Operator but not owner of a logging firm	4%
Response Rate	95%

Table 3.3. Employment

Number of Employees		
	In 2009	Normally
Average	4.6	5.7
Maximum	32	50
Minimum	1	1
Response Rate		91%

Table 3.4. Products

Products	Responses
Saw Log	95%
Pulp Wood	91%
Chips	34%
Response rate to question is 90%	

When respondents were asked about the types of facilities they delivered material to in 2009, they provided the following responses:

Table 3.5. Product destinations

Different destination	Responses	Percentage of production
Hardwood sawmill	73	25.8 ± 23.7[a]
Softwood sawmill	54	21.9± 23.3
Veneer mill	45	7.6 ± 11.7
Pulp mill	62	50.7 ± 28.1
Particle board, med. density fiberboard, other panel mill	21	20.1 ± 24.0
Oriented strand board mill	22	27.5 ± 26.3
Wood pellet fuel mill	10	13.0 ± 31.3
Direct-fired wood power generator	12	8.5 ± 15.3
Truck or rail landing	16	14.5 ± 25.9
Other – mostly firewood	20	47.8 ± 41.8

[a] Numbers following ± represent standard deviations

When respondents were asked about the size of their harvesting operations in 2009, it was obvious that most responses were in the smaller acres. They provided the following responses:

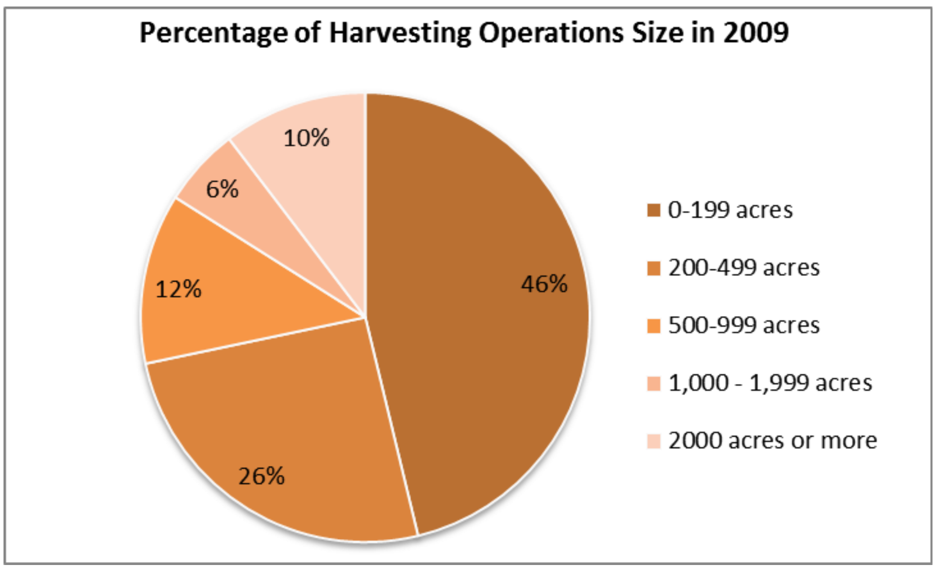

Figure 3.3 Size of logging operations in the Kinross region

When respondents were asked about the smallest volume operations they would be willing to harvest combined with smallest areas they were willing to harvest, they responded as follows:

Table 3.6. Size of operation

Units	Min	Max
Cords	25	6000
Tons	300	1000
MBF	8	50
Acres	1	400

Respondents were asked about 1) how long their firm had been in business; 2) what percentage of their operations were run by equipment they own; 3) what percentage of their operations were run by equipment they subcontract; 4) their operating capacity; and 5) whether they purchased stumpage, they responded as follows:

Table 3.7. Business details

Questions	Responses	Min	Max	Average
Number of years in Business	98%	1 year	90 years	31 years
Equipment Ownership	95%	1%	100%	89%
Subcontracted Equipment	47%	1%	100%	19%
Operating Capacity in 2009	86%	0%	100%	86%
Purchased Stumpage	87%	0%	100%	62%

Available Logging Equipment

The following table includes equipment available for logging in the 150-mile radius of Kinross, MI.

Table 3.8. Available logging equipment in the 150-mile radius from Kinross, MI

Equipment type	Number Reported	Model year (responses)	Total machine hours (responses)	Fuel use in gallons/hr (responses)
Cut-to-length processor	96	2003 ± 4.6[a] (68)	9943 ± 7471 (77)	5.1 ± 2.1 (77)
Feller-buncher	34	1995 ± 9 (22)	9042 ± 4444 (27)	7.0 ± 2.7 (25)
Forwarder	140	1997 ± 8.9 (81)	10534 ± 6079 (91)	3.3 ± 2.4 (89)
Chainsaws	260	2004 ± 7 (34)	835 ± 1191 (11)	0.7 ± 0.5 (11)
Grapple skidder	49	1995 ± 8.3 (28)	11832 ± 6130 (17)	4.7 ± 2.2 (18)
Cable skidder	10	1975 ± 11.9 (8)	9333 ± 3055 (3)	2.7 ± 0.6 (3)

Loaders	24	1994 ± 8.7 (13)	6708 ± 4466 (11)	3.7 ± 2.0 (13)
Grinders	3	1994 (1)	9000 (1)	10 (1)
Slashers	11	1998 ± 5 (4)	9802 ± 6933 (7)	3.5 ± 1.8 (10)
Chippers	16	1996 ± 9.4 (13)	7843 ± 5991 (11)	16.3 ± 8.3 (12)
Bulldozers	54	1991 ± 14.6 (31)	5217 ± 3224 (41)	3.7 ± 2.3 (34)

[a] Numbers following ± represent standard deviations, based on number of responses in parentheses

Logging Equipment Configuration
When respondents were asked to provide a snap shot about their logging configurations, the following information was provided. However, based on a comparison between responses analyzed and the exact entries in the mailed in surveys, there seemed to be a few errors that were removed. For example, respondents might answer that they would use a unique equipment configuration, however, when this was compared with the equipment they owned, it would not match. This means they might, for example, mark a configuration of a processor and forwarder, but in their responses they only indicated they owned a forwarder. Nevertheless, responses were analyzed and the following is the presentation of the received responses:

Table 3.9. Logging equipment configuration preferred by loggers in the Kinross region.

Logging configuration	**Responses**	**Percent of Operations using This System**
Full processor/Forwarder	56	83.9 ± 24.4[a]
Feller-delimber/Grapple skidder / Slasher	6	31.2 ± 34.3
Feller-buncher/Grapple skidder / Delimber / Slasher	10	60.6 ± 39.5
Feller-buncher/Topper / Grapple skidder / Slasher	2	22.5 ± 3.5
Feller buncher with leveling cap/Grapple skidder with winch / Slasher	1	5
Feller-buncher / Forwarder	2	30 ± 14.1
Feller-buncher / Grapple skidder / Slasher / Chipper	4	43.8 ± 39.0
Feller-buncher / Full processor / Forwarder	2	51.5 ± 61.5

[a] Numbers following ± represent standard deviations

Table 3.10. Averaged harvest productivity values for different equipment configurations

	Averaged harvest productivity (tons/hr)		
Equipment configuration	30% Selective	70% Shelterwood	Clear-cutting
Full Processor	8.54	9.95	13.42
Feller-buncher	8.58	11.06	13.95

Table 3.11. Reported productivity estimates for different logging equipment configurations

Full Processor/Forwarder							
		1 Harvester - Productivity (cords/ hr)			2 Harvesters - Productivity (cords/ hr)		
Treatment	Forest Type	N	Average	Std. Dev	N	Average	Std. Dev
30% Cut (Selective)	Hardwoods	14	3.78	1.31	8	6.13	1.46
	Softwoods	10	4.5	2.42	7	7	1.91
	Mixed	12	4.16	1.47	7	6.43	1.4
70% Cut (Selective)	Hardwoods	12	4.58	1.93	6	6.83	2.48
	Softwoods	6	5.5	2.43	5	7.4	1.52
	Mixed	10	5	1.94	5	7.6	2.07
Clear-cutting	Hardwoods	13	6.23	2.62	3	8.66	3.06
	Softwoods	9	7.22	2.39	3	8.67	2.31
	Mixed	13	6.43	2.48	5	8.8	1.92

Table 3.12. Reported productivity estimates for different logging equipment configurations

Feller-buncher/Grapple Skidder/Slasher							
		1 Harvester - Productivity (cords/ hr)			2 Harvesters - Productivity (cords/ hr)		
Treatment	Forest Type	N	Average	Std. Dev	N	Average	Std. Dev
30% Cut (Selective)	Hardwoods	4	3.75	1.71	2	7	4.24
	Softwoods	3	3.67	0.58	2	7	4.24
	Mixed	4	4	0.82	2	7	4.24
70% Cut (Selective)	Hardwoods	3	5.33	1.52	2	7	1.41
	Softwoods	3	4.67	0.58	3	11	4.58
	Mixed	4	5	0.82	2	8	2.83
Clear-cutting	Hardwoods	4	7	2.45	1	10	--
	Softwoods	2	5	0	1	10	--
	Mixed	4	6.75	3.5	1	10	--

Production Volume

When respondents were asked to provide estimates for the average production rates of their more productive equipment configuration, under various harvest conditions, the following information was provided:

Table 3.13. Production volume

Type of product		**Responses**	**Average production volume**	**Range of reported volumes**
Logs	Hardwood	42 29	97,810 MBF 1,075 Cords	3-1,200,000 MBF 20 – 4500 Cords
	Softwood	15 36 3	8,118 MBF 2,312 Cords 6,427 Tons	5- 100,000 MBF 20 – 15,000 Cords 300 – 19280 Tons
Pulpwood	Hardwood	63 9	3,059 Cords 7,167 Tons	25 – 30,000 Cords 1,000 – 17,000 Tons
	Softwood	57 7	2,516 Cords 5,229 Tons	30 – 45,000 Cords 2,000 – 12,000 Tons
Chips	Hardwood	10	18,225 Tons	25 – 50,000 Tons
	Softwood	10	10,930 Tons	20 – 50,000 Tons

Logging Methods

When respondents were asked about their logging methods as far as it involved leaving or removing logging residue, they provided the following responses:

Table 3.14. Summary of logging methods

Different practices (residues, etc.)	**Responses**	**Percentage**
Clearcut – residues left on site	61	43.1 ± 33.7[a]
Clearcut – residues removed	24	37.9 ± 30.1
Partial cut – residues left on site	72	69.8 ± 31.3
Partial cut – residues removed	17	43.5 ± 33.0
Other	3	100 ± 0

[a] Numbers following ± represent standard deviations

Land Ownership and Terrain

When respondents were asked about the ownership of the properties they harvest, they provided the following responses:

Table 3.15. Land ownership summary

Ownership type	**Responses**	**Percentage**
Non-industrial private	94	63.6 ± 36.7[a]
Forest industry or timber management org.	21	51.2 ± 32.3
State forest	55	44.4 ± 29.5
National forest	17	23.4 ± 23.9
Other public	6	8.5 ± 4.9
Tribal	0	--
Don't know	1	100 ± 0

[a] Numbers following ± represent standard deviations

Table 3.16. Operations in different terrain types

Terrain type	**Responses**	**Average**
Low ground	70	28.9 ± 23.5[a]
Flat	82	40.0 ± 21.6
Rolling	78	38.8 ± 19.3
Steep hilly	48	16.1 ± 9.6

[a] Numbers following ± represent standard deviations

When respondents were asked to explain about the percentage of the cost increase in their operations from one terrain to the other, one cut type to another and one species to the other, the following information was provided:

Table 3.17. Effect of terrain, harvesting prescription and forest type on harvesting cost

Scenario	Responses	Increase in costs (%)
Regular → difficult terrain	87	28.5 ± 18.7[a]
Clearcut → selective cut	85	20.2 ± 16.0
Softwood → hardwood stands	81	17.0 ± 16.6

[a] Numbers following ± represent standard deviations

Discussion

We learned that a significant majority of logging firms were owner operators and a very small percentage were owners but not operators. The size of logging firms varied from employing only one employee to a maximum of 32. However, employment was generally down in 2009 from other years. The main product was saw log and pulp wood with wood chips constituting about one third of their business. Naturally, saw mills were the primary destination of timber followed by pulp mills and veneer mills. Very few loggers supplied biomass to pellet mills or wood fired power generators. A large fraction (46%) of the loggers surveyed harvested less than 200 acres whereas only 16% harvested over 100 acres. Loggers indicated that they would be willing to harvest as little as 1 acre and as much as 400 acres. On an average logging firms were in business for over 30 years while some as long as 90 years. Most of the firms owned their equipment and operated their equipment at about 86% capacity in 2009. A majority of loggers purchased stumpage.

A large majority of logging firms owned cut-to-length harvesters (96 units) followed by feller-bunchers (34 units) in the Kinross region. They owned 140 forwarders, 49 grapple skidders and 24 loaders. Therefore, cut-to-length processor and forwarder was the preferred configuration by those that responded to the survey followed by feller-buncher/grapple skidder/delimber/slasher. The average harvest productivity ranged from 8.54 tons/hr for 30% selective cutting to 13.42 tons/hr for clear-cutting. Productivity numbers for feller buncher were comparable to those of full processor. A large majority of loggers were leaving residue on site. This makes sense since biomass market has not been fully established. A large majority of loggers harvested in non-industrial private forests (94) followed by state forests (55). Only 17 loggers reported harvesting in national forests. A large number of loggers harvested in flat terrain followed by rolling terrain. Only 48 reported harvesting in step hilly terrain. They reported increase in harvesting cost when went from regular to difficult terrain, from clear-cut to selective cut and from softwood to hardwood.

The survey gave us a good snapshot of the state of the logging industry in the Kinross region, equipment configuration used and their age, machine productivity, and type of forests and terrain. This information was useful in computing harvesting cost.

ECONOMIC ANALYSIS OF HARVESTING OPERATIONS

Introduction
This section covers the cost analysis of harvesting log products. To compute harvesting system costs we were interested in identifying a model that could be adapted to Michigan conditions and would allow cost calculations for the various equipment systems commonly used by Michigan loggers. A literature review was carried out to identify the best available model that would determine the cost of harvesting biomass from natural forests and plantations. The review was structured into two phases; the first offered a literature summary of abstracts that was organized into three categories: Modeling Fuel Reduction/Forest Harvesting, Timber Harvest Outputs/Supply Chain, and Economics/Market Impacts. The second phase was based on extensive discussions with national forest harvesting experts. The models that were of particular interest to the project were those that required customized inputs based on Michigan particular conditions. Three models were found. These are a Virginia Tech model (http://cnre.vt.edu/harvestingsystems/logcost9.html), an Auburn Harvesting Analyzer model developed at Auburn University and modified by R. Visser (http://cnre.vt.edu/harvestingsystems/costing.htm#auburnharvester) and a Fuel Reduction Cost Simulator (FRCS) model developed by Bruce Hartsough and Dennis Dykstra. The VT and Auburn models require user to input all values whereas the FRCS model has many built-in default features. To use this model successfully it is critical that built-in features as well as input data flexibility allowed was to be clearly understood and input parameters for Michigan conditions clearly determined. The logger's survey played an important role in our developing an understanding of the region's logging industry and in determining input parameters for cost calculations.

Methodology
There are two elements to calculating logging cost:
1) hourly rate of logging equipment; and
2) harvesting system production cost.

<u>Hourly rate of logging equipment</u>: Machine hourly rate is expressed in \$/SMH, whereas SMH = scheduled machine hours. Machine hourly rate in \$/SMH can be converted to \$/PMH (PMH = productive machine hours) by dividing productive machine hours by scheduled machine hours (PMH/SMH). Once cost in \$/PMH is determined, cost in \$/GT (GT=green ton) is determined by dividing this number by machine productivity (GT/PMH). Machine productivity can either be determined by conducting time-and-motion studies or estimated using published data. Machine productivity is highly dependent of site and terrain conditions (stand density, slope etc.) and the type of harvesting operation i.e. partial cutting or clear cutting. In this report we used the available Forest Inventory Data (FIA) to estimate stock and stand data.

Machine hourly cost has three primary components:

1. Fixed (Ownship) cost. This is the cost of owning the machine and includes depreciation, interest on investment and cost of taxes, insurance and housing of the machine. These costs are calculated as follows:
   a. $D = (P-S)/(N \cdot SMH)$, where
      D is Depreciation in \$/SMH
      P is Purchase price in \$
      S is Salvage value in \$
      N is Machine economic life in years
   b. $AAI = (P - S) \cdot (N + 1)/(2\,N) + S$, where
      AAI is Average Annual Investment in \$

c. (Int + Ins + T) = % rate · AAI /SMH, where
Int + Ins + T is the total cost for interest, insurance, and tax in $/SMH

2. Variable (Operating) cost. This cost is incurred when machine is operated and includes fuel and lube, tires and tracks, and repairs and maintenance. Fuel and lube cost depends on the rated fuel consumption of the machine and fuel and lube costs. Repair and maintenance cost can be estimated based on records if available or obtained from literature.
   a. Repairs and Maintenance ($/PMH) = Depreciation x Repair and maintenance factor (%/Depreciation)
3. Labor. This cost includes hourly labor rate and labor fringe benefits (%) expressed in terms of $/SMH.

Harvesting system cost: Once costs of each machine used in logging operation is determined in terms of $/SMH it is possible to compute harvesting system production cost in terms of $/GT. Harvesting system cost depends upon the logging system used such as cut to length (CTL) or whole tree (WT) harvesting. The following are harvesting system cost components:

1. Harvesting or felling (felling-processing). Cost of felling depends, in addition to the type of machine used to perform felling operation, upon the type of harvesting operation such as partial cutting (thinning) or clear cutting. It also depends on the type of forest (hardwood, softwood or mixed), tree size, and stand density.
2. Forwarding or skidding. This operation is necessary to bring cut trees to the landing for loading onto trucks for hauling or for further processing such as delimbing, bucking, and chipping. The cost of skidding depends primarily upon skidding distance, terrain conditions, skid trail layout, and average turn volume.
3. Loading. This operation represents loading logs onto truck for hauling to their final destination. Please note that in this portion of the study hauling cost is computed elsewhere in the report under a separate section.
4. Move-in costs. This cost represents deployment of harvesting, forwarding, and processing equipment to the tract and depends upon tract size, moving time, and distance from home. It also depends on site preparation including roads to be built and to establish entrances. In this study we did not include any site preparation cost and assumed that all tracts were already prepared.
5. Support cost. This cost includes pickups, chain saws, foreman, and overhead. This cost is generally expressed as $/cord and then converted to $/GT.

Therefore, total harvesting cost is computed by adding all above costs in terms of $/GT.

Results and Analysis

Based on the Logger's survey the most common systems used in Michigan are:

1. Whole tree system (WT) - Felling and skidding with and without chipping at landing
2. Cut to length (CTL) system - harvesting and forwarding with and without chipping at landing

The following tables list the assumptions made to compute machine costs (Table 3.18), machine hourly rate intermediate calculations (Table 3.19), and machine hourly rate calculation results (Table 3.20).

Table 3.18: Machine cost assumptions and survey-based variables

	Small F-Buncher	**Small Skidder**	**Small Slasher**	**Small Harvester**	**Small Forwarder**
Purchase price as of Dec 02, P ($)	150,000	140,000	350,000	350,000	240,000
Machine power rating (hp)	150	120	120	120	110

Machine life (n, years)	5	5	5	5	5
Salvage value, S (% of P)	20	20	20	25	25
Utilization rate (%)	75 [a]	75 [a]	75 [a]	75 [a]	75 [a]
Repair and maintenance (% Depr)	50 [b]	50 [b]	50 [b]	50 [b]	50 [b]
Interest rate (%)	8	8	8	8	8
Insurance and taxes (%)	7	7	7	7	7
Fuel consumption rate (gal/hp-h)	0.026	0.029	0.022	0.028	0.025
Fuel cost per gallon ($/gal)	3.228	3.228	3.228	3.228	3.228
Lube and oil (% of fuel cost)	37	37	37	37	37
Crew size (persons)	1	1	1	1	1
Crew wage ($/SMH)	19.43	19.43	19.43	19.43	19.43
Crew fringe rate (%)	40%	40%	40%	40%	40%
Scheduled machine hours (SMH/year)	1650 [a]	1650 [a]	1650 [a]	1650 [a]	1650 [a]

[a]: Survey-based variables. Winter (6 winter months per year in survey area): 35 SMH/week; Summer: 33 SMH/week

[b]: Reference: (Warren, 1977), and http://www.fao.org/docrep/T0579E/t0579e05.htm#3.5%20operating%20costs

Table 3.19. Machine hourly rate intermediate calculations

	Small F-Buncher	**Small Skidder**	**Small Slasher**	**Small Harvester**	**Small Forwarder**
Salvage value (S, $)	30,000	28,000	70,000	70,000	48,000
Annual depreciation ($)	0 [a]	0 [a]	0 [a]	0 [a]	0 [a]
Average yearly investment	30,000	28,000	70,000	70,000	48,000
PMH	1,237.5 [b]	1,237.5 [b]	1,237.5 [b]	1,237.5 [b]	1,237.5 [b]

[a]:When a piece of equipment is completely depreciated, the annual depreciation is 0.
[b]:Survey-based productive machine hours.

Table 3.20. Machine hourly rate calculation results

	Small F-Buncher	**Small Skidder**	**Small Slasher**	**Small Harvester**	**Small Forwarder**
Owning costs:					
Interest cost ($/year)	2,400	2,240	5,600	5,600	3,840
Insurance and taxes($/year)	2,100	1,960	4,900	4,900	3,360

Yearly owning cost ($/year)	4,500	4,200	10,500	10,500	7,200
Owning cost per SMH ($/SMH)	2.73	2.55	6.36	6.36	4.36
Owning cost per PMH ($/PMH)	3.64	3.40	8.48	8.48	5.81
Operating costs:					
Fuel cost ($/PMH)	12.59	11.23	8.52	10.85	8.88
Lube cost ($/PMH)	4.66	4.16	3.15	4.01	3.28
Repair & maintenance cost ($/PMH)	9.70	9.05	22.63	22.63	15.52
Operating cost per PMH ($/PMH)	26.94	24.44	34.30	37.49	27.68
Labor costs:					
Labor ($/SMH)	19.43	19.43	19.43	19.43	19.43
Benefits ($/SMH)	7.77	7.77	7.77	7.77	7.77
Labor cost per SMH ($/SMH)	27.2	27.2	27.2	27.2	27.2
Machine hourly rate:					
Machine hourly rate in SMH ($/SMH)	42.37	40.31	51.52	53.91	44.55
Machine hourly rate in PMH ($/PMH)	56.49	53.74	68.69	71.88	59.40

Harvesting System Productivity based on Logger's Survey. The following table includes harvesting system productivity data as determined from logger's survey.

Table 3.21. Summary of survey-based production rate (GT/PMH) of WT and CTL harvesting systems

		Whole tree system		**Cut-to-Length system**	
		1 Feller-buncher	**2 Feller-bunchers**	**1 Harvester**	**2 harvester**
30% cut	**Hardwood**	8.63	16.10	8.69	14.10
	Softwood	8.44	16.10	10.35	16.10
	Mixed	9.20	16.10	9.57	14.79
70% cut	**Hardwood**	12.26	16.10	10.53	15.71
	Softwood	10.74	25.30	12.65	17.02
	Mixed	11.50	18.40	11.50	17.48
Clearcut	**Hardwood**	16.10	23.00	14.33	19.92
	Softwood	11.50	23.00	16.61	19.94
	Mixed	15.53	23.00	14.79	20.24

Survey-based production cost ($/GT)

Table 3.22 shows the production cost of roundwood products in terms of $/GT as they are delivered and processed at the landing in a WT harvesting system. For the equipment combination of one feller-buncher plus one skidder, the total production costs ranged from 11.11 $/GT to 21.20 $/GT for different forest types and harvesting prescriptions; while this cost range for the equipment combination of two feller-bunchers plus one skidder was 9.30 $/GT to 14.62 $/GT.

Table 3.23 shows the production cost of roundwood products in $/GT as they are delivered to the landing in a CTL harvesting system. For the equipment combination of one harvester plus one forwarder, the total production costs range from 7.91 $/GT to 15.10 $/GT for different forest types and harvesting prescriptions; while this cost range for the equipment combination of two harvesters plus one forwarder is 10.04 $/GT to 14.41 $/GT. Similar to the cost change trend in a whole tree harvesting system, with the increase of removal amount, the production cost of a CTL system will be reduced in both equipment combinations.

For both whole tree and cut-to-length harvesting systems, results in Tables 21 and 22 present a clear trend that with the increase of removal amount the production cost will be reduced. It is also clear that in the whole tree system, the equipment combination of two feller-bunchers plus one skidder systematically achieves lower production cost than the equipment combination of one feller-buncher plus one skidder (Table 21). However, this cost difference is not reflected in the different machine combinations in the cut-to-length system (Table 22). Compared with a whole tree harvesting system, a cut-to-length system features less number of machines as a harvester combines the functions of a feller-buncher and a slasher, which makes the entire harvesting system productivity less constrained by system balancing.

Table 3.22. Production cost ($/ton) for whole trees delivered at the landing using a WT harvesting system

		One Feller-buncher				**Two Feller-bunchers**			
		F.-buncher	**Skidder**	**Slasher**	**Total**	**F.-buncher**	**Skidder**	**Slasher**	**Total**
30% cut	**Hardwood**	6.55	6.23	7.96	20.74	7.02	3.34	4.27	14.62
	Softwood	6.69	6.37	8.14	21.20	7.02	3.34	4.27	14.62
	Mixed	6.14	5.84	7.47	19.45	7.02	3.34	4.27	14.62
70% cut	**Hardwood**	4.61	4.38	5.60	14.59	7.02	3.34	4.27	14.62
	Softwood	5.26	5.00	6.40	16.66	4.47	2.12	2.72	9.30
	Mixed	4.91	4.67	5.97	15.56	6.14	2.92	3.73	12.79
Clear cut	**Hardwood**	3.51	3.34	4.27	11.11	4.91	2.34	2.99	10.24
	Softwood	4.91	4.67	5.97	15.56	4.91	2.34	2.99	10.24
	Mixed	3.64	3.46	4.42	11.52	4.91	2.34	2.99	10.24

Table 3.23. Production cost ($/ton) for log products using a CTL harvesting system

		One Harvester			**Two Harvesters**		
		Harvester	**Forwarder**	**Total**	**Harvester**	**Forwarder**	**Total**
30% cut	**Hardwood**	8.27	6.83	15.10	10.20	4.21	14.41

	Softwood	6.94	5.74	12.68	8.93	3.69	12.62
	Mixed	7.51	6.21	13.72	9.72	4.02	13.74
70% cut	**Hardwood**	6.82	5.64	12.46	9.15	3.78	12.93
	Softwood	5.68	4.70	10.38	8.45	3.49	11.94
	Mixed	6.25	5.17	11.42	8.22	3.40	11.62
Clearcut	**Hardwood**	5.02	4.15	9.16	7.22	2.98	10.20
	Softwood	4.33	3.58	7.91	7.21	2.98	10.19
	Mixed	4.86	4.02	8.88	7.10	2.93	10.04

FRCS Model simulation

Repeated runs were performed per batch data using different harvesting methods within identified radius scenarios. Data is depicted for small diameter hardwood species analyzed for Frontier particular analysis criteria only. No chip trees or large trees (volume > 80 ft^3/stem) are included. Simulation results are summarized in Table 3.24. The FRCS model predicted costs of employing a whole tree harvesting system ranged from 17 to 38 $/green ton, averaged 29.36 $/green ton. The model projected cost for using a cut-to-length system was from 11 to 13 $/green ton, averaged at 11.86 $/green ton. A comparison between survey-based production cost and FRCS model projected production cost (Table 3.25) showed that the FRCS model predicted WT system production costs were significantly higher than survey-based results, however, the model prediction for CTL system costs fall in the range of survey-based results.

Table 3.24. FRCS model predicted production cost ($/ton) for WT and CTL harvesting systems

	Average production cost ($/GT)	**Min production cost ($/GT)**	**Max production cost ($/GT)**	**Sample size**
WT harvesting system	29.36	17	38	14
CTL harvesting system	11.86	11	13	14

Table 3.25. Production cost ($/GT) comparison between survey-based results and FRCS model predicted results.

	Survey-based cost ($/GT)	**FRCS predicted cost ($/GT)**
WT harvesting system	11.11 – 21.20	29.36
CTL harvesting system	7.91 – 15.1	11.86

Sensitivity Analysis

Sensitivity analysis was performed to determine the effects of different variables on the production cost, while keeping all the other variables constant. Results comparisons and scatter plots showed how the production cost changed with the corresponding value changes in the tested variables, which included buying new machines, machine economic life, and diesel fuel price.

<u>Effect of purchasing new equipment on production cost</u>

Purchasing new equipment will cause high upfront depreciation, which will be reflected in the machine hourly rate and production cost. Table 3.26 shows the machine hourly rate of a CTL harvesting system with a new harvester and a new forwarder. The machine hourly rate when investing in new equipment increased to 137.49 $/PMH and 104.40 $/PMH for a harvester and a forwarder, respectively; whereas the machine hourly rates were 71.88 and 59.40 $/PMH when using a completely depreciated harvester and forwarder (Table 3.20).

Table 3.26. Machine hourly rate calculations when purchasing **new** equipment (Assumptions in Table 3.18 applied)

	Small Harvester	**Small Forwarder**
Salvage value (S, $)	70,000	48,000
Annual depreciation ($)	56,000	38,400
Average yearly investment	238,000	163,200
PMH	1,237.5	1,237.5
Owning costs:		
Interest cost ($/year)	19,040	13,056
Insurance and taxes($/year)	16,660	11,424
Yearly owning cost ($/year)	91,700	62,880
Owning cost per SMH ($/SMH)	55.58	38.11
Owning cost per PMH ($/PMH)	74.10	50.81
Operating costs:		
Fuel cost ($/PMH)	10.85	8.88
Lube cost ($/PMH)	4.01	3.28
Repair & maintenance cost ($/PMH)	22.63	15.52
Operating cost per PMH ($/PMH)	37.49	27.68
Labor costs:		
Labor ($/SMH)	19.43	19.43
Benefit ($/SMH)	7.77	7.77
Labor cost per SMH ($/SMH)	27.20	27.20
Machine hourly rate:		
Machine hourly rate in SMH ($/SMH)	103.12	78.30
Machine hourly rate in PMH ($/PMH)	137.49	104.40

Using the existing survey-based equipment productivity, the harvesting production costs are summarized in Table 3.27 for CTL systems with one harvester and two harvesters, respectively. Production cost comparison in Table 3.28 shows that with the use of completely depreciated equipment the production cost of the equipment combination of one harvester plus one forwarder will be reduced from 14.57-27.82 $/GT to 7.91-15.10 $/GT, and for the equipment combination of two harvesters plus one forwarder the production cost will be reduced from 18.74-26.91 $/GT to 10.04-14.41 $/GT. Results in Table 3.28 also indicated that when performing a 30% partial cut, the use of depreciated machine has the strongest effect on production cost reduction, because the production rate in the prescription of 30% partial cut is the lowest, which amplify the effect of using depreciated machine on production cost.

Table 3.27. Production cost ($/GT) of a CTL system when purchasing **new** equipment

		One Harvester			**Two Harvesters**		
		Harvester	**Forwarder**	**Total**	**Harvester**	**Forwarder**	**Total**
30% cut	**Hardwood**	15.81	12.01	27.82	19.50	7.40	26.91
	Softwood	13.28	10.09	23.37	17.08	6.48	23.56
	Mixed	14.37	10.91	25.28	18.59	7.06	25.65

70% cut	**Hardwood**	13.05	9.91	22.96	17.51	6.65	24.15
	Softwood	10.87	8.25	19.12	16.16	6.13	22.29
	Mixed	11.96	9.08	21.03	15.73	5.97	21.70
Clear cut	**Hardwood**	9.60	7.29	16.88	13.81	5.24	19.05
	Softwood	8.28	6.29	14.57	13.79	5.24	19.03
	Mixed	9.30	7.06	16.36	13.59	5.16	18.74

Table 3.28. Production cost ($/GT) comparison between using new and depreciated equipment

	Forest type	**1 harvester & 1 forwarder total**		**2 harvesters & 1 forwarder total**	
		New machine	**Depreciated machine**	**New machine**	**Depreciated machine**
30% Cut	**Hardwood**	27.82	15.10	26.91	14.41
	Softwood	23.37	12.68	23.56	12.62
	Mixed	25.28	13.72	25.65	13.74
70% Cut	**Hardwood**	22.96	12.46	24.15	12.93
	Softwood	19.12	10.38	22.29	11.94
	Mixed	21.03	11.42	21.70	11.62
Clear cut	**Hardwood**	16.88	9.16	19.05	10.20
	Softwood	14.57	7.91	19.03	10.19
	Mixed	16.36	8.88	18.74	10.04

<u>Effect of machine economic life on production cost</u>

To test the effect of machine economic life on production cost, the scenario of 70% partial cut of hardwood using a CTL harvesting system was used, as this was determined to be the most representative forest type and harvesting system used currently in the project region. The production cost change by adjusting machine economic life in the other scenarios has been tested to follow the similar pattern shown in Table 3.29.

Sensitivity analysis showed that with an increase of machine economic life from 4 years to 8 years, machine hourly rate will decrease, resulting in a final production cost reduction from 25.81 $/GT to18.69 $/GT. Results in Figure 3.4 also shows that the change of production cost has an exponential trend, indicating that with an increase in machine economic life, the production cost will be less sensitive to the machine economic life. This strengthens the importance of machine maintenance work at the beginning stage of its life when machine life has a stronger effect on production cost.

Table 3.29. Production cost ($/GT) and machine hourly rate ($/PMH) change of a CTL harvesting system when applying different machine economic life (Years)

Machine economic life (Years)	**Harvester hourly rate ($/PMH)**	**Forwarder hourly rate ($/PMH)**	**Total production cost ($/GT)**
4	155.31	116.61	25.81

5	137.49	104.4	22.96
6	125.61	96.25	21.06
7	117.13	90.43	19.70
8	110.76	86.07	18.69

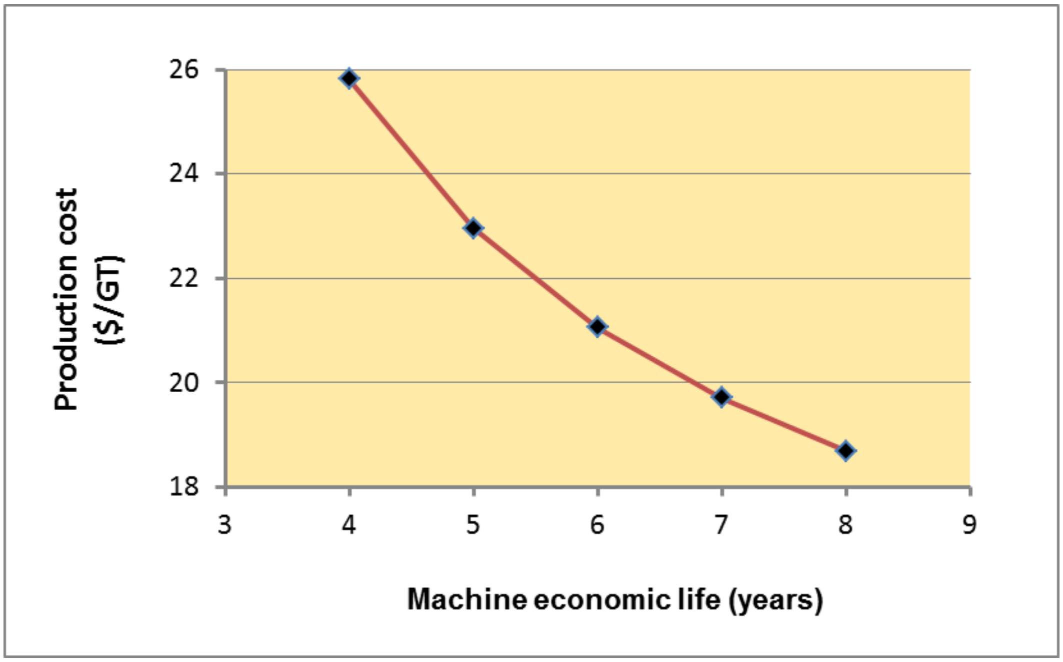

Figure 3.4. Effect of machine economic life (years) on total production cost ($/GT)

Effect of diesel price on production cost

Diesel price is the most concerned factor during harvesting operations, as once the harvesting equipment is purchased and harvesting site is laid out, the daily fluctuated diesel price becomes the most variable part for the harvesting cost control. Diesel price will affect machine operating cost, which will be reflected in the production cost. To test the effect of diesel price on production cost, the scenario of 70% partial cut of hardwood using a CTL harvesting system was used again. Results in Table 3.30 shows that with an 1$/gal diesel price increase, the production cost will increase by 0.79 $/GT. Figure 3.5 shows a straight line in production cost change, indicating the effect of diesel price on production cost is constant, at some point when diesel price is high enough, the total production cost will be inflated to a level that would make the entire operation cost prohibitive.

Table 3.30. Production cost ($/GT) and machine hourly rate ($/PMH) change of a CTL harvesting system when applying different diesel price ($/Gal)

Diesel price ($/Gal)	Harvester hourly rate ($/PMH)	Forwarder hourly rate ($/PMH)	Total production cost ($/GT)
2.00	66.22	54.78	11.49
3.00	70.83	58.54	12.28
4.00	75.43	62.31	13.08
5.00	80.03	66.08	13.87

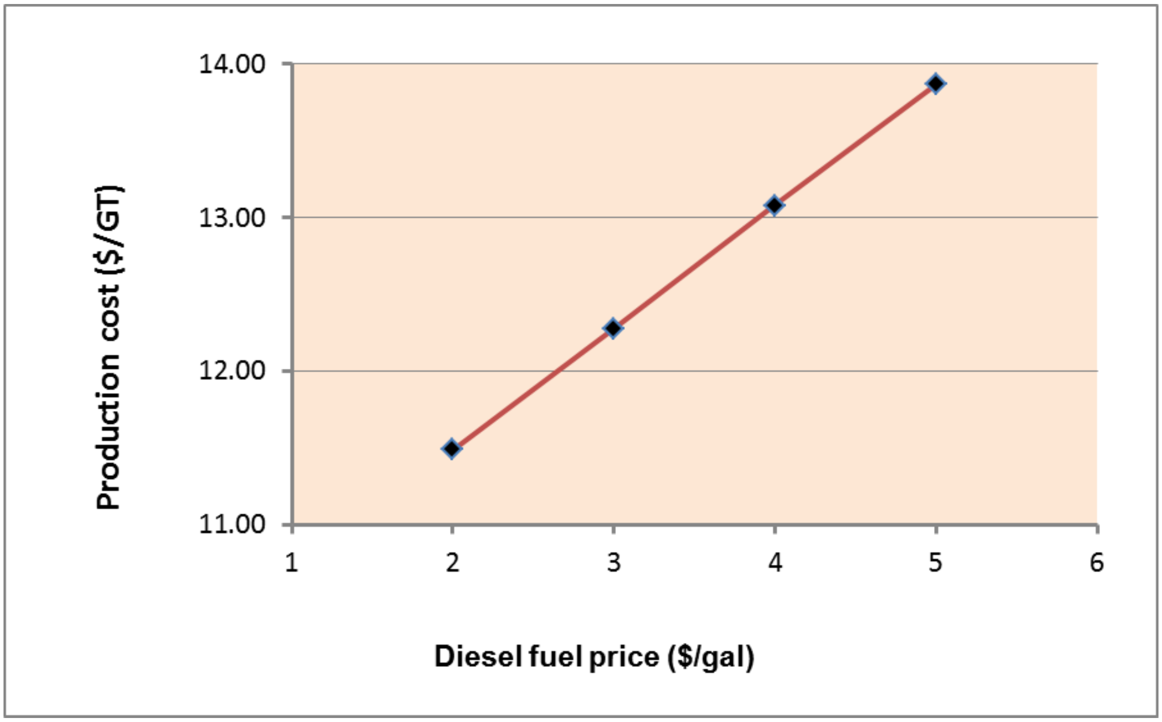

Figure 3.5. Effect of diesel price ($/gal) on production cost ($G/GT)

Discussion

Whole tree and cut-to-length harvesting systems are the most widely used in Michigan's forest harvesting operations. Although our survey-based study did not show that cut-to-length system is more economically advantageous when compared with whole tree harvesting, a cut-to-length system features less number of machines, less operators, simpler system organization, and less soil disturbance, which makes it more popular these days. Whole tree harvesting systems, nevertheless, should receive more considerations when biomass recovery is a component of prescription, as tree limbs and tops, by-products of the whole-tree harvesting operation, would be available at landing without any added cost.

Our survey results showed that in the study region a whole tree harvesting system with two feller-bunchers the production rate ranged from 16.10 to 25.30 green tons per PMH; while this range for a cut-to-length system with two harvesters was 14.10 to 20.24 green tons per PMH. With current yearly PMH of 1237.5 hours, a whole tree harvesting system can produce 19923.75 to 31308.75 green tons wood, and a cut-to-length has a production capacity of 17448.75 to 25047 green tons. To meet Mascoma plant's feedstock requirement of 0.5 million tons roundwood per year, at least 16 whole tree harvesting systems or 20 cut-to-length harvesting systems need to be employed for feedstock supply. To reduce the number of harvesting systems required, harvesting operations need to be better organized to improve system utilization rate. Longer scheduled working time also can be considered, as survey results showed that average daily scheduled machine hours were only 6.6 hours in the study region.

Harvesting production cost comparison between our survey-based results and FRCS model predicted values showed that FRCS model always has a higher production cost. FRCS model is a forest harvesting and processing cost projection model originally developed in western United States. It has been recently updated by adding location variants to make it work for the northern states, including Michigan. However, FRCS model still has limitations. For example, when simulating a WT harvesting system in Michigan, the FRCS model relevance weights information indicated that the model used nine past studies in California hardwood plantations and southern pine plantations for production cost prediction, partially because harvesting production cost information was not well documented for Michigan although the state has a long history of logging activities. The significant difference in site and terrain conditions between Michigan and other regions suggests high risks in such model predictions, especially when western mountainous areas are usually associated with higher harvesting costs.

SUMMARY AND CONCLUSIONS

We learned, from the loggers' survey, that a significant majority of logging firms were owner operators and a very small percentage were owners but not operators. The size of logging firms varied from employing only one employee to a maximum of 32. However, employment was generally down in 2009 from other years. The main product was saw log and pulp wood with wood chips constituting about one third of their business. Naturally, saw mills were the primary destination of timber followed by pulp mills and veneer mills. Very few loggers supplied biomass to pellet mills or wood fired power generators. A large fraction (46%) of the loggers surveyed harvested less than 200 acres whereas only 16% harvested over 100 acres. Loggers indicated that they would be willing to harvest as little as 1 acre and as much as 400 acres. On an average logging firms were in business for over 30 years while some as long as 90 years. Most of the firms owned their equipment and operated their equipment at about 86% capacity in 2009. A majority of loggers purchased stumpage.

A large majority of logging firms owned cut-to-length harvesters (96 units) followed by feller-bunchers (34 units) in the Kinross region. They owned 140 forwarders, 49 grapple skidders and 24 loaders. Therefore, cut-to-length processor and forwarder was the preferred configuration by those that responded to the survey followed by feller-buncher/grapple skidder/delimber/slasher. The average harvest productivity ranged from 8.54 tons/hr for 30% selective cutting to 13.42 tons/hr for clear-cutting. Productivity numbers for feller buncher were comparable to those of full processor. A large majority of loggers were leaving residue on site. This makes sense since biomass market has not been fully established. A large majority of loggers harvested in non-industrial private forests (94) followed by state forests (55). Only 17 loggers reported harvesting in national forests. A large number of loggers harvested in flat terrain followed by rolling terrain. Only 48 reported harvesting in step hilly terrain. They reported increase in harvesting cost when they went from regular to difficult terrain, from clear-cut to selective cut and from softwood to hardwood.

The survey gave us a good snapshot of the state of the logging industry in the Kinross region, equipment configuration used and their age, machine productivity, and type of forests and terrain. This information was useful in computing harvesting cost.

The roundwood production costs (subtotal up to logging truck) ranged from $7.91 to $21.20 per green ton for different forest types, harvesting prescriptions, and harvesting systems, as calculated based on survey data. Increasing the amount of removal from 30% cut to clear cut significantly reduces cost for both whole tree and cut-to-length systems. In whole tree harvesting, a machine combination of two feller-bunchers plus one skidder showed much lower production costs than one feller-buncher plus one skidder combination. This trend is not reflected in the cut-to-length system. Overall, our data analysis indicated that harvesting costs are highly variable and dependent upon forest type, stand condition, harvesting prescription, type of equipment, and harvesting system used.

The FRCS model predicted costs of employing a whole tree harvesting system ranged from $17 - 38 per green ton with an average of $29.36 per green ton. The model projected cost for using a cut-to-length system was from $11- 13 dollars per green ton, averaged at $11.86 per green ton. Generally, the whole tree harvesting system cost resulted from FRCS model prediction were higher than those provided by the loggers' survey, however, the model prediction and survey results for cut-to-length system costs were comparable.

Management factors affecting cost were found to be initial investment, machine economic life, and diesel fuel price. Sensitivity analysis showed that with the use of completely depreciated equipment the production cost can be reduced significantly. The testing for the factor of machine economic life indicated that with an increase of machine economic life, machine hourly rate will decrease, resulting in a final production cost reduction. Finally, with a 1 $/gal diesel price increase, the production cost was found to increase by $0.79 per green ton.

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