

Project Summary:

Application of a Trailer-Mounted Slash Bundler for Southern Logging

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Introduction

The John Deere bundler was originally designed to collect material behind a cut-to-length (CTL) operation, where the biomass feedstock is distributed across the harvested site. While the occurrence of a CTL operation is common in Europe, it is rarely used in the southern United States. Southern logging typically involves a tree-length operation, where the whole tree is skidded to the landing for processing. Therefore, the residual portions of the tree (primarily limbs and tops), which can be used as a biomass feedstock, are already located on the landing and available for the market.

Efficiently transporting this material requires some kind of densification practice. Some loggers are using small residue chippers for this process. However, some markets would prefer the biomass in larger form to facilitate handling and drying. Chippers also have high variable costs for fuel and knives. Bundling offers an alternative to chipping, but a mobile machine like the John Deere 1490E is an expensive option to consider.

The idea of mounting the bundling unit to a stationary trailer was conceived to reduce the capital cost of the machine and allow easier integration into a southern logging operation. A meeting was held in Auburn, Alabama in June, 2008 to develop the project. Auburn University was the lead on the project, with funding from the USDA Forest Service and in-kind support from John Deere in the form of the bundler and knuckle-boom loader. Cutting Systems, Inc. (CSI) also participated by donating one of their motorized trailers for use during the project.

Machine Build

To facilitate the schedule of the project, the bundler was mounted on a motorized trailer provided by Cutting Systems, Inc. (CSI). CSI's rugged trailer design, out riggers, and grapple loop made it ideal for in-woods use. The self-contained trailer features a 102 hp, John Deere diesel engine. The fixed displacement pump was replaced with an Oilgear, model PVM098, variable displacement pump.

The bundler's mounting configuration was modeled after the newest design of the John Deere 1490. Three, one inch steel plates were welded at intervals on each side of the trailer directly over the axle. Two, four inch schedule 40 steel tubes were welded onto the plates for mounting. Some additional bracing was welded into place for added security, and the B-380's mounting pedestal was then lifted into place. After fastening the pedestal to the rail system, the bundler was mounted securely atop the trailer.



Figure 1. Trailer mounted bundler prototype.

The trailer was then plumbed and the reservoir was filled with hydraulic fluid. To satisfy the higher voltage required by the bundler, a small amplifier was installed to convert the 12 volt battery power to 24 volts. While the original plan was to have a remote control system, there were too many challenges with the software system. As a result, a 75 foot extension was attached to the wiring harness to ensure operator safety during testing.

Field Testing

Field testing was performed on five different sites to evaluate the machine. The sites were located in east central Alabama and north central Florida. Each contained different stand conditions. The initial four sites were test and demo sites with the fifth being the production study site.

Auburn Test Site

Tim West, Mike Schmidt, and Bryon Neumann were on site to assist in the initial testing which was performed on Auburn University property. The source for the whole tree material used for bundling was an 18 year old loblolly pine plantation. The trees averaged 50 feet tall and 6 inches at breast height (dbh). Bundling took place for 1 ½ days; functionality was normal, and the machine performed well. There were no significant problems bundling the material. While no formal data was recorded, processing time for an eight foot bundle ranged between 90 and 100 seconds.



Figure 2. Initial testing of the bundler in Auburn, Alabama.

Midway Test Site

The Midway, Alabama site contained mature pine timber with a significant amount of mature bottomland hardwoods. The bundler and loader were setup in close proximity to the active logging deck. The cooperating logger operated a two loader, two skidder, and one feller-buncher system. Skidder operators used a gate to delimb the trees before bringing them to the

deck. Due to the large timber and use of the gate, the material was not ideal for bundling. The material contained a large proportion of 6 – 12” diameter woody stems with very little foliage. Bundles broke apart due to the lack of outward pressure that small limbs and foliage provide.

The unit was proven capable of bundling smaller hardwood tops; however, mature hardwood tops with crooks and forks led to problematic bundling. After being compressed, one crooked limb was thrust upward and broke the bundle hold down bar. Several times the material would pinch the saw bar. This complication in severing the bundle led to a couple of bent saw bars. A visit by Brian Reimer of John Deere resulted in some changes to the software defaults that enhanced the bundling operation. The changes enabled the number of wraps, distance between wraps, and bundle length to be altered.

Although bundling is possible in the Midway conditions, it is not ideal. A harvesting system that would bypass the gate and delimb at the deck using a pull-through delimber would provide a better mix of material.



Figure 3. Bundling hardwood slash at the Midway test site.

Live Oak Demo

This demo was put together by the US Forest Service and Auburn University, and locally hosted by the North Central Florida and the Suwannee River RC&D Councils. More than 120 politicians, power company personnel, loggers and landowners attended the Live Oak, Florida demonstration which showed a slightly different application of the machine. The demo site was a recently clearcut stand that contained piled logging residue. The operation was set up

adjacent to a large slash pile composed of mostly pine limbs and tops. Although the material had been sitting for weeks, the bundling operation processed the biomass with minimal problems.

Notasulga Test Site and Demo

The Notasulga, Alabama site consisted of two significantly different stand conditions. The operation piggybacked a logger that was clearcutting a 23 year old loblolly stand and thinning a younger loblolly pine plantation on the same tract. The cooperating logger, Caldwell Logging, utilized one loader, two skidders, and a single feller-buncher. The bundling operation was set up in close proximity to the active logging deck. Skidders transported slash from the loader's pull-through delimeter to the bundling operation. The operation did not use a gate to delimb the trees; consequently, both the clearcut, and thinning material compressed and bundled well.



Figure 4. Bundling operation in Notasulga, Alabama.

Bundling efficiency is greatly affected by the capabilities of the loader operator. An experienced operator from Caldwell Logging mastered the in-feed operation in a very short period of time. The operator went on to assist in the bundling demo which was attended by approximately 50 loggers, mill personnel, foresters, equipment dealers, and government personnel. Bundling went extremely well and the material mix was ideal.

Production Study

The Roanoke, Alabama site, a 90 acre clearcut, consisted of a large loblolly pine component with a small number of hardwood trees. Bundling productivity data was collected for one week on a 25 acre portion of the tract. The stand was inventoried prior to harvesting. In addition, work study data was collected on skidder performance to assess any changes in productivity. Time study data was collected on the bundling operation and delays were recorded for post processing.

Stand Conditions and Inventory

The gently sloping 25 acre stand was a naturally regenerated loblolly pine stand. It contained 121 tons per acre of total merchantable timber with the vast majority being pine sawtimber. The following volume table shows the breakdown by species and product class. Sixteen, 1/10th acre plots were measured to provide an estimate of standing inventory.

	Tons per Acre
Pine Sawtimber	86
Pine Pulpwood	22
Hardwood Sawtimber	2
Hardwood Pulpwood	11
Residue Available	32.5
Residue Harvestable	22.75

Table 1. Roanoke Site Stand Inventory

The residue availability estimates and merchantable weights are based on *Georgia Forest Research Paper 60 and 79*.

Logging System and Work Study

The tree-length logging operation, Sanders Logging, consisted of two loaders, two skidders, and one feller-buncher. Typically, the feller-buncher would maintain a one half to a full day buffer ahead of the skidders. Before bundling commenced, skidders would delimb the trees using a gate on approach to the logging deck. By delimiting in this manner, the skidders would have to clean slash from both the gate and the pull through delimiters on the deck.

During bundling operations, delimiting was performed strictly on the deck with pull through delimiters. This alteration in the operation produced a higher concentration of slash at the

deck and potentially affected the skidders' productivity. In order to quantify the change in productivity caused by bundling and the adjustments in the delimiting process, a work study was performed on the skidders.

The study's work sampling noted the skidder's operation every 4 minutes. Four days of skidder data was collected while the operation was using the gate to delimit trees. On average, gate delimiting consumed about 7% of total productive skidding time. The pre-bundler data also showed that slash movement away from the deck consumed an average of 11% of total productive time. On the other hand, during the bundling operation when gate delimiting was not utilized, slash movement only consumed approximately 7% of total productive skidding time. This indicates that bundling should not interfere with skidder productivity and may even enhance it.

Bundler Productivity

Bundler productivity was collected over a one week timeframe. The number of loader turns and saw bar cuts were collected as independent variables for cycle time equations. Delays were noted for data analysis and machine evaluation. Cycles were timed from the severing of one bundle until the severing of the next.

Measured production levels showed the prototype unit was capable of producing an average of 33.4 eight foot bundles per hour (15.9 tons/hr) with no delays. Accounting for minor operational delays that were observed during the production study (such as extra saw cuts and feeding delays), the average production for the bundling operation was 30.8 eight foot bundles per hour (14.6 tons/hr). A string repair occurred every 2.6 hours of run time with an average repair time of 12 minutes. To maintain proper functionality, saw chains were changed every 2.2 hours with a standard repair time of 14 minutes.

A limited number of 12 foot bundles were produced during the study. Without any delay considerations, 25.5 twelve foot bundles per hour (17.2 tons/hr) were produced. Minor delays slightly decreased production to 24.2 bundles per hour (16.4 tons/hr). String and saw chain repair delays were estimated to be equivalent to those that occurred during 8 foot bundle production.

Of the two lengths, the 12 foot bundles proved to be the most conducive to a production bundling operation in the study conditions. Twelve foot bundles generated between 5 and 10 percent more tons per hour in production. Twelve foot bundles also trailered better for safe transportation. Based on our observed average bundle weight, three bunks of twelve foot bundles at fifty percent moisture content would weigh approximately 27 tons.

Economic Analysis

Capital investment, variable costs, and revenue streams are uncertain with this prototype. Reasonable estimates have been applied to a *DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS SPREADSHEET*, developed by Dr. Robert Tufts of Auburn University, to determine some of the economics surrounding a trailer mounted bundling operation.

Two different options were considered for the loader cost analysis. An older, used loader was evaluated with a lower initial price, but higher fuel consumption and maintenance costs. The second option was a new, small loader with lower fuel consumption and maintenance costs. The two options produced similar costs and purchasing a small new loader for bundling seemed the most logical decision.

A 75% utilization rate (1500 PMH/2000 SMH/yr) is assumed for both the loader and the bundler. Fuel consumption for both the loader and the bundler averaged 2.5 gallons per hour. For analysis purposes, we assumed 3 gallons per hour, a fuel cost of \$2.50/gal, and a lube cost of \$2.50/ hr (total fuel and lube was \$10/PMH). Maintenance and repair costs for the bundler were based on conclusions from the field study. The operation consumed 1 roll of twine per 25 eight foot bundles. At a cost of \$23 per roll, twine costs equated to roughly \$2 per ton. Chains for the chainsaw consumed another large portion of the maintenance costs. Assuming 5 sharpenings per chain, and an effective chain cutting life of ½ day, chain costs total approximately \$12,500 per year or \$0.60 per ton. Allowing for some repair costs, total maintenance and repair was estimated to be \$50/PMH. The tables on the following pages show the economic analyses of eight, and twelve foot bundling operations.

The annual equivalent cost (AEC) is the cost per year to own and operate the piece of machinery over its entire lifespan. Assuming a life span of four years, the eight foot bundling operation cost estimates totaled \$12.85 per ton to produce bundles. Twelve foot bundles totaled \$11.25 per ton to operate the loader and trailer mounted bundling unit. By adding \$6 per ton for trucking, \$2 per ton profit for the logger, and \$1 per ton for stumpage to the land owner, bundles could potentially be delivered to a facility within 50 miles for approximately \$20-\$22 per ton.

Because the purchase price of the trailer mounted bundler is unknown, sensitivity analysis was performed at \$200,000, \$250,000, and \$300,000. \$7.44, \$8.08, and \$8.71 were the respective cost per ton of eight foot bundling. Twelve foot bundling cost per ton was \$6.51, \$7.07, and \$7.62 respectively. An increase in the purchase price by \$50,000 would constitute a 50-60 cent increase in cost per ton for bundling.

Loader Analysis (8 ft bundle operation)					
Purchase price	\$150,000			Discount rate	6.00%
Trade-in	\$0			Finance APR	10.00%
BV of trade-in	\$0			Marginal tax rate	15.00%
Down payment	\$0			Amount financed	\$150,000
Number of payments	48			Monthly payment	\$3,804
Expense Option	\$0			Adjusted basis	\$150,000
Hours per day	8.00			Expected life, years	4
Days per year	225			Residual value end of life	40.00%
Fuel & Lube	\$10.00			Inflate F&L	5.00%
Maint & Repair	\$10.00			Inflate M&R	15.00%
Labor rate	\$15.00			Inflate labor	5.00%
Fringe benefit %	30.00%			Utilization	75.00%
Insurance & taxes	4.00%			Production (tons/PMH)	14.00
AEC		(\$102,557)	(\$98,737)	(\$95,276)	(\$92,245)
Cost per ton		(\$5.43)	(\$5.22)	(\$5.04)	(\$4.88)
		Year 1	Year 2	Year 3	Year 4
Salvage value		114,000	87,000	69,000	60,000
ACRS Dep		30,000	48,000	28,800	17,280
Book value		120,000	72,000	43,200	25,920
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		15,000	17,250	19,838	22,813
Labor		35,100	36,855	38,698	40,633
Insurance		6,000	4,560	3,480	2,760
Total Expenses		71,100	74,415	78,553	83,570

Table 2. Loader Economics (8 ft bundles)

Bundler Analysis (8 ft bundle operation)					
Purchase price	\$250,000			Discount rate	6.00%
Trade-in	\$0			Finance APR	10.00%
BV of trade-in	\$0			Marginal tax rate	15.00%
Down payment	\$0			Amount financed	\$250,000
Number of payments	48			Monthly payment	\$6,341
Expense Option	\$0			Adjusted basis	\$250,000
Hours per day	8.00			Expected life, years	4
Days per year	225			Residual value end of life	20.00%
Fuel & Lube	\$10.00			Inflate F&L	5.00%
Maint & Repair	\$50.00			Inflate M&R	15.00%
Labor rate	\$0.00			Inflate labor	5.00%
Fringe benefit %	30.00%			Utilization	75.00%
Insurance & taxes	4.00%			Production (tons/PMH)	14.00
AEC		(\$172,203)	(\$164,630)	(\$158,066)	(\$152,646)
Cost per ton		(\$9.11)	(\$8.71)	(\$8.36)	(\$8.08)
		Year 1	Year 2	Year 3	Year 4
Salvage value		170,000	110,000	70,000	50,000
ACRS Dep		50,000	80,000	48,000	28,800
Book value		200,000	120,000	72,000	43,200
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		75,000	86,250	99,188	114,066
Labor		0	0	0	0
Insurance		10,000	6,800	4,400	2,800
Total Expenses		100,000	108,800	120,125	134,230

Table 3. Bundler Economics (8 ft bundles)

Loader Analysis (12 ft bundle operation)					
Purchase price	\$150,000			Discount rate	6.00%
Trade-in	\$0			Finance APR	10.00%
BV of trade-in	\$0			Marginal tax rate	15.00%
Down payment	\$0			Amount financed	\$150,000
Number of payments	48			Monthly payment	\$3,804
Expense Option	\$0			Adjusted basis	\$150,000
Hours per day	8.00			Expected life, years	4
Days per year	225			Residual value end of life	40.00%
Fuel & Lube	\$10.00			Inflate F&L	5.00%
Maint & Repair	\$10.00			Inflate M&R	15.00%
Labor rate	\$15.00			Inflate labor	5.00%
Fringe benefit %	30.00%			Utilization	75.00%
Insurance & taxes	4.00%			Production (tons/PMH)	16.00
AEC		(\$102,557)	(\$98,737)	(\$95,276)	(\$92,245)
Cost per ton		(\$4.75)	(\$4.57)	(\$4.41)	(\$4.27)
		Year 1	Year 2	Year 3	Year 4
Salvage value		114,000	87,000	69,000	60,000
ACRS Dep		30,000	48,000	28,800	17,280
Book value		120,000	72,000	43,200	25,920
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		15,000	17,250	19,838	22,813
Labor		35,100	36,855	38,698	40,633
Insurance		6,000	4,560	3,480	2,760
Total Expenses		71,100	74,415	78,553	83,570

Table 4. Loader Economics (12 ft bundles)

Bundler Analysis (12 ft bundle operation)					
Purchase price	\$250,000			Discount rate	6.00%
Trade-in	\$0			Finance APR	10.00%
BV of trade-in	\$0			Marginal tax rate	15.00%
Down payment	\$0			Amount financed	\$250,000
Number of payments	48			Monthly payment	\$6,341
Expense Option	\$0			Adjusted basis	\$250,000
Hours per day	8.00			Expected life, years	4
Days per year	225			Residual value end of life	20.00%
Fuel & Lube	\$10.00			Inflate F&L	5.00%
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Labor rate	\$0.00			Inflate labor	5.00%
Fringe benefit %	30.00%			Utilization	75.00%
Insurance & taxes	4.00%			Production (tons/PMH)	16.00
AEC		(\$172,203)	(\$164,630)	(\$158,066)	(\$152,646)
Cost per ton		(\$7.97)	(\$7.62)	(\$7.32)	(\$7.07)
		Year 1	Year 2	Year 3	Year 4
Salvage value		170,000	110,000	70,000	50,000
ACRS Dep		50,000	80,000	48,000	28,800
Book value		200,000	120,000	72,000	43,200
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		75,000	86,250	99,188	114,066
Labor		0	0	0	0
Insurance		10,000	6,800	4,400	2,800
Total Expenses		100,000	108,800	120,125	134,230

Table 5. Bundler Economics (12 ft bundle)

Recommended Deck Configuration

When the project was initially discussed, we considered integrating the trailer mounted bundler directly into a two loader system. After running the operation in the field, our initial presumptions have been altered. With the slash volumes we encountered during field tests, a separate loader needs to be allocated specifically for bundling. In this production study, we found the ratio of slash loads to roundwood loads to be around 1:5. For a 15 loads a day roundwood operation, producing 25-30 bundles/hr, an operator would be bundling for 6-7 hours per day.

The bundling operation should be within close proximity to the active logging deck in an effort to not affect skidder production during slash delivery. Forest residues should be deposited at the rear of the loader. Slash should be fed into the bundler from left to right so that the boom does not alter the operator's line of sight. Using set-out trucking and loading finished bundles directly onto a trailer would limit handling and increase production.

The figure below is the most efficient bundling deck configuration found during the trial period. The bundler position enables smooth feeding, and extraction of bundles. Positioning the loader in this fashion allows the operator effective reach of all necessary elements.

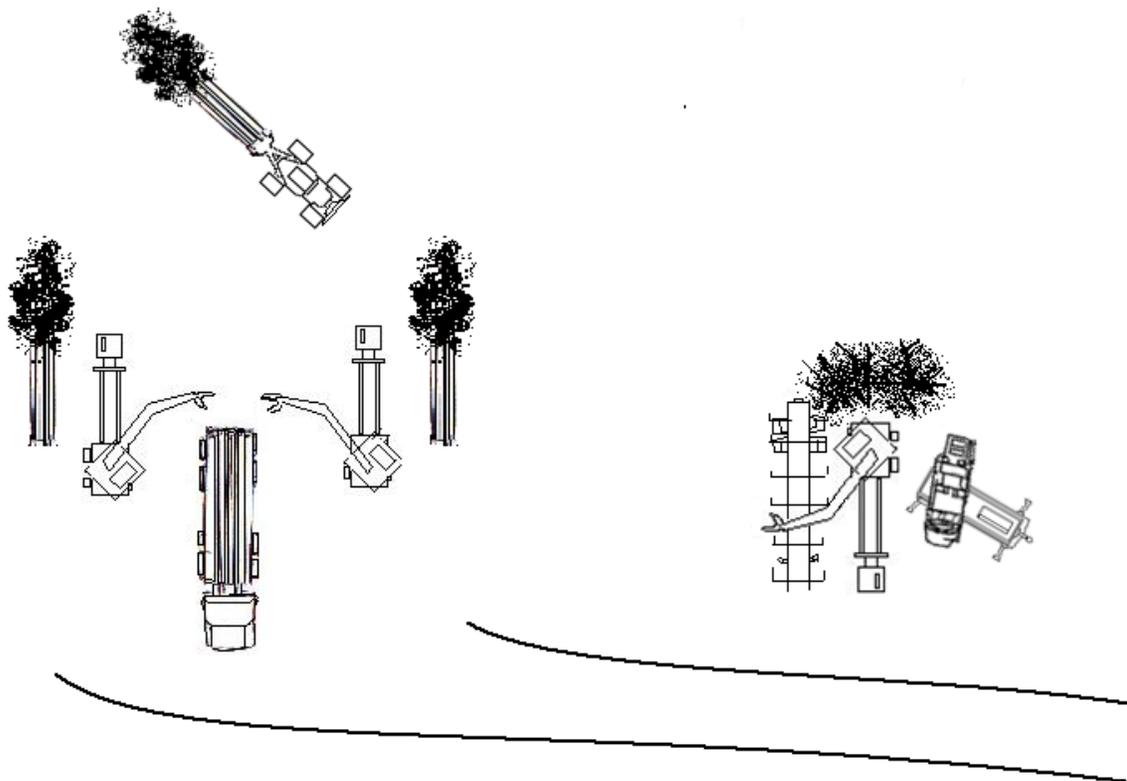


Figure 5. Optimal Deck Configuration

Recommended Improvements to the Prototype Trailer-Mounted John Deere Slash Bundler Unit

After conversations with Mike Schmidt, Tim West and others, the following suggestions are experience-based propositions that will make the trailer mounted slash bundler a more marketable addition to southern logging systems.

1) *Rotation configuration*

The piston driven rotation configuration within the turnstile needs to be redesigned. A gear based design seems much more effective. The middle “dead zone”, when the piston is fully extended, renders the rotation function useless. When not in use, the unit occasionally drifts around and could potentially cause damage to the loader or bundler.

2) *Cutting configuration*

In our studies, the cut off saw was to be one of the biggest sources of operational delays. The chainsaw hangs up without completely severing the bundles. At times, the saw bar will cycle down 2-5 times before cutting through the bundle entirely. Chain life is also an issue. Chains seem to have an effective cutting life of 2-4 hours. The chain will cut for a longer period of time; however, the saw delays become more prevalent. Some of these problems could possibly be reduced by issuing pressure recommendations for the hold down arm and saw bar depending upon bundle length.

3) *In-feed configuration*

For the most part, feeding the material into the machine was not a huge concern. After a short period of time, feeding slash comes naturally to a loader operator. A chain in-feed tray on the bottom seems like a viable option to aid the forward movement of the slash. Extending the vertical rollers would enable the bundler to grasp material more effectively.

4) *Protection for the hold down bar*

The hold down bar is a must; however, on multiple occasions a crooked or forked stem has maneuvered itself into a position to bend the bar. These incidents, although sparse in number, are extremely costly both monetarily and in productivity. Extension of the protective steel guide is recommended in order to steer the bundles away from this critical part.



Figure 6. Location of the hold down bar protection.

5) **Overall heightened protection**

- A) The valve bank is protected by a piece of sheet metal. The cover should be reinforced and have some type of metal stops instead of resting on hydraulic hoses at the bottom.
- B) With such an extensive hydraulic system, the numerous hoses are inevitable. Hoses should be more protected in various areas.
- C) Encase or extend protection of exposed hydraulic fittings. Both compactor 2 and 3 have some exposed fittings that could be covered by simply extending existing protective pieces.

6) **Remote control**

Remote control is crucial for this unit's success. A lone loader operator must be able to feed and bundle to make bundling safe and economical. The remote must be able to operate all the functions; however, remote operation of the display and bundle configuration options is not required.

7) **Display and bundle length**

The unit's display needs to be in English units for ease of operation. During eight foot bundling operation, bundle length varied from 254 cm to 272 cm. Length variation could cause problems when hauling bundles crossways on the trailer.

Trailer modifications

Although the CSI trailer was adequate, it was utilized because of the project's timeline. A purpose built trailer should be constructed with the following suggestions in mind.

8) ***Power requirements***

The 102 hp diesel engine used to power the unit was adequate. The only power issue with the tested unit existed in low temperatures when the hydraulic oil was more viscous than normal. This problem could be minimized by installing a pre-heater for the hydraulic oil or by running a lower viscosity oil.

9) ***Height of the unit***

Height is a valid concern for a trailer mounted unit. The prototype trailer mounted unit is 13 feet, 6 inches tall. The production unit must have a lower center of gravity to ensure safe transportation. Lowering the unit would also give the operator a better line of sight during loading. On the other hand, in order to conserve bundling integrity, the unit must be high enough that bundles can freely drop after being severed. Examination of the proto-type reveals many opportunities to reduce the height, including different mounting configurations as well as lowering the height of the trailer's metal housing.

10) ***Axle(s)***

The current unit does not meet DOT standards for transport on a single axle trailer. The bundler, including the mounting configuration, weighs approximately 9 tons. The CSI trailer weighs nearly 6 tons. A tandem axle trailer setup would not only legally bear the weight, it would also aid in the stability during travel on the highway and on rough in-woods roads.

11) ***Maintenance***

In order to ensure the safety of workers, a maintenance deck should be built into the production model. Climbing on oily, slick surfaces is a safety hazard. A trailer mounted collapsible or folding platform would aid in the ease of maintenance for this machine.

12) ***Outriggers***

Outriggers assist in the leveling of the unit on uneven surfaces. The production model trailer should feature outriggers because the added stability aids in safe and efficient bundling.

13) ***Towing***

The trailer and tongue weight of the trailer mounted bundler should be within the towing capabilities of a heavy duty service truck for transportation. The pintle hook setup should protrude further from the grapple loop to ensure a more conducive towing configuration. The grapple loop is essential for in-woods transportation by skidders.

14) ***Additional transport considerations***

A tie down system should be adapted to the trailer in order to ensure the bundler does not rotate in transit.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]