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Research Article

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Comparative Time Study of Conventional Cut-to-Length and Integrated Harvesting Method - A Case Study

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Abstract

This study compares two harvesting methods i.e., conventional cut-to-length (CTL) followed by harvesting residuall extraction for energy and integrated harvesting method combining CTL with harvesting residual pre-pilling by harvester followed by extraction of both timber and logging residual for energy. The study was carried out in spruce stands (Picea abies) in South Moravia (Czech Republic) at the Pozořice and Kuničky locations. Two methods conducted by harvesters and forwarders were compared. The first case was a conventional CTL method when trees are felled, delimbed, and cross-cut by harvester. The resulting logs are pre-pilled and then transported by forwarder. In this case, the harvesting residual remains in the stand. It was not about using harvesting residual as brash mat on the strip roads, but extracting them independently of harvesting later for energy. In the second case, the resulting harvesting residual were piled up by harvester, later to be extracted by forwarder. Such extracted harvesting residual are stored at the roadside for seasoning and future comminution. The aim was to obtain input data for internal analysis of a private entity contracting in logging operation. The client demanded measuring the increase in time needed to produce one timber unit with simultaneous harvesting residual preparation. In our case integrated harvesting was 33% more time demanding of harvesters and 16% less time demanding of forwarders during harvesting residual extraction, which might result in about 8% higher total operational time of complete operation.

Keywords: CTL; Harvester; Forwarder; Time study; Harvesting residual; Biomass

Introduction

Forests are important carbon repository in terms of its global balance [1]. In context with the Kyoto Protocol, it is necessary to consider forestry as a possible tool to mitigate the increase of Green House Gasses (GHG) in the atmosphere. However, each of the country accepted different strategies how to mitigate carbon. Therefore, it is important to work also with data on forest biomass at a regional level [2]. Traded quantity of biomass products does not match its amount in the stands. Several studies on this topic have been published with the almost same results; it means high amount of biomass is left in the stand, which is positive from nutrient point of view [3].

Necessarily increasing mechanization of logging and timber transport leads to an intensive change in this sector supporting high efficiency. One option is to apply fully mechanized technology such as harvesters and forwarders [4]. When applied, the machines are used not only to produce timber, but also for the processing and transport of biomass for energy [5].

If logging residues are to be used for energy then the logging methods should be adapted to this fact. If the harvesting operation is not adjusted to subsequent processing of harvesting residual, the quality of the biomass is very low and costly. Conventional logging residual cannot dry out as uniformly because logging machines usually run over it and therefore logging residual are in higher contact with soil, absorb moisture of soil and are contaminated by the soil and stones. Contamination increases wear of chipper knives during comminution, reduces fuel efficiency, causes troubles in combustion process and increases the percentage of ash [6].

However, devoting a part of the harvester performance for logging residual preparation will affect its productivity related to primary product, in this case the timber assortments. This was the incentive to carry out a time study describing, without using software-equipped machines, the effect of integrated harvesting on time consumption. It was thus necessary to make comparative study of basic and integrated logging operation in as much as possible uniform conditions.

According to nomenclature [7] in this case is a comparative study comparing two variants trying as much as possible controlling other factors. As reported by Ref. [8], the aim of a comparative study is to evaluate the influence of the examined factor on productivity when other factors are almost fixed, such as the influence of worker's experience. The method of the study was subject to the requirements of the client, who was interested in information leading, after further processing, to the increase of productivity and improvement of the economics of studied logging technology. This is in accordance with the findings by Ref. [9] about the focus of time studies. However, in intensive time studies, it is necessary to take into account the skills and experience of the observer [10]. In this study, observers adopted method and recommendations from Ref. [7].

Materials and Methods

Study area

The study was carried out in parts of the Drahanská Highlands in the Czech Republic. The first site was located near to Pozořice - stand A (GPS: 49.2193728N, 16.8274086E), where the harvester Rottne H11c operated together with forwarder John Deere 1110D (JD). The second part of the measurements took place in Kuničky - stand B (GPS: 49.4637433N, 16.6883100E), where the John Deere 1270 was accompanied by John Deere 1110E forwarder.

The representative stands were chosen according to CTL recommended conditions in the Czech Republic. Areas with slopes up to 5°, with 95% to 100% dominated by Norway spruce (Picea abies), aged around 90 years, with an average tree volume 1.3 cubic metres and an average stock volume of 380 cubic metres per hectare were chosen. In all cases the clear-felling was used with no seed trees left. The contractor operating machinery ensured that at the selected locations will operate fixed crew. This enabled us during the data collection to focus on the studied factors, and not to deal with the effects of the operator. The average extraction distance was 700 m at the first site and 1000 m at the second one, respectively.

Time study

The study was designed and carried out according to the recommended procedure by [7], which is shown on Figure 1.

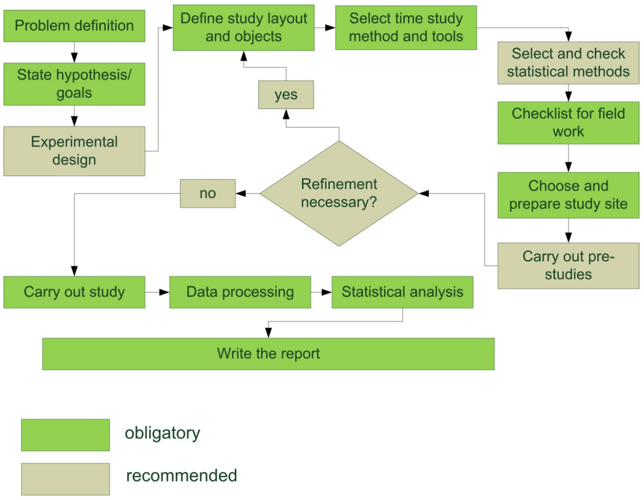

Figure 1: Diagram of steps in the development of the intended study [7].

Setting hypothesis/goal

In accordance with the assignment and the expected utilization of the study results, we have set the hypothesis and aim as follows: “Time consumption of the integrated logging operation is not significantly different from time consumption of commonly used CTL logging operation. Therefore, the application of integrated method is more effective. which will be confirmed/ rejected using the time study method finding out the difference of time consumption per unit of production i. e. cubic meter solid volume measured over the bark (o.b). The logging residual as a side product of timber harvesting are not set as a unit of production, only time spent in logging residual extraction is taken into the consideration”.

Experimental design

The study was conducted at two harvesters and forwarders. Harvesters Rottne H11c and John Deere 1270 were operated by the operator a and c. Forwarders John Deere 1110D and John Deere 1110E were operated by the operator b and d. We have not assessed individual performances of each operator through evaluation of individual productivity [11]. We have not standardized individual performances between harvester’s operator a and c and forwarders operators b and d, because normalizations or corrections may introduce new errors and uncontrollable variability into the measurement data files and operation of variant purposely built machines makes is significantly different [12]. Nevertheless, the experience of the operators was considered representative for the conditions of the study areas. Their skills and experience were declared very similar and for all involved, it was longer than three years. This should ensure sufficient validity of the results of the comparative study. Influence of the operator experience may have a significant impact on the performance of the machine. Nonetheless, it was shown that it has a greater influence in early intervention (treatments) in younger stands, but slightly smaller in the extraction of larger trees, as is the case in this study [13]. Note: From the results, the proportion of time spent in harvesting operation was equal to each other. The same result was found also in forwarding operation.

	Stand A	**Stand B**
Integrated	Rottne H11c+John Deere 1110D Operator a+c	John Deere 1270+John Deere 1110E Operator b+d
Conventional	Rottne H11c+John Deere 1110D Operator a+c	John Deere 1270+John Deere 1110E Operator b+d

Table 1: Experimental design of the study.

Due to the combinations of two stands and two type of operation, we have carried out the measurements in four variants. However, the other factors have to be confirmed as not influencing results i.e., operator and machine make and model, therefore eight combinations had to be studied in Table 1. In practice, it is not possible to achieve the entire exact value of measured phenomenon. To achieve desired results with an acceptable level of confidence, it was necessary to determine the sample size that is the number of measured cycles. The sample size (number of cycles) required for a reliable mean value was calculated using a statistical formula. We took the variance and the median of a particular population parameter (s^2) from previous similar studies with an accent on the knowledge of the contractor. Subsequently, the sample size required for a reliable estimate of the mean diameter may be calculated according to the following formula [13,14]:

$$n=\frac{t^2\times(S_X\%)^2}{(E\%)^2} \qquad (1)$$

$$S_x\%=\frac{S_X\times 100}{\bar{X}} \qquad (2)$$

Where:

n - sample size,

t - value of normal distribution (example: t = 1.96 for the used 95% confidence interval),

Sx - standard deviation,

E - error tolerance for the 10% confidence interval,

$\bar{X}$Where:

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- average value of time consumption from the preliminary estimate.

This gave us necessity of at least 10 of the cycle repetitions. Due to the cycle time consumption, the harvesting operation was measured in 180 of the repetitions and forwarding operation in 24 repetitions.

A following continuation of the work would be usually the creation of a regression model, as other authors have done. List of authors who have used linear models include [15,16]. Authors who designed quadratic models were for example Wang et al. [17] Kärhä et al. [13], and Nurminen et al. [18]. However, this study was carried out as a case study ordered by the contractor and limited by the budget. The budget limitation usually plays again the quality and accuracy of the study and following steps based on Mousavi [19], Nurminen [20] were never conducted i.e., data collection with the detailed time study to determine the productivity of both conventional CTL harvesting operation and integrated system in the study, the statistical analyses consisted of linear regression for predicting cycle times, verification of the. accuracy of regression models and testing the factor of impact using F-test, testing of the individual measurement samples separately by the t-test and finally confirmation or rejection of the null. In case, the null hypothesis is not true the differences in time consumption arises as a result of random effects [19-21]. Due to the lack of the statistical analysis of the data, the results can be presented only in descriptive form.

Division of working elements

We have used the following elements of the operation for the harvester in this study:

Felling: machine stops, the hydraulic boom moves, the tree being felled is gripped, cut, directed, and if it is suspended by other trees then released and pulled down. Before it hits the ground the trunk may be released to reduce wear of hydraulic boom and gripped again.

Delimbing and bucking: a tree is held by a hydraulic crane horizontally. It is delimbed by knives, movement of the stem is controlled by feeding rollers of the head. At the same time a boom moves it toward the temporary storage of logs. Here, individual logs are pilled. In case of logging residual for extraction preparation the delimbing is preferably situated on one place for easier future manipulation.

Preparation of logging residual: the whole machine rolls back, picks up brushwood, tops of the trees and possibly other parts of the stem, such as around breaks or fork and pile those on for later extraction suitable place.

Moving to the next position (repositioning): machine moves to a place where it will stand during felling of the next tree.

We have used the following elements of the forwarding:

Piled slash/timber loading: is a set of cyclically repeated movements and grips of hydraulic crane/grapple, leading to the uploading the forwarder either by logs or logging residual after harvester preparation.

Free slash loading: is a set of cyclically repeated movements and grips of the hydraulic crane/grapple, consisting of on the harvesting area randomly placed slash concentration (piling) following with uploading the forwarder by logging residual. This slash was not prepared by harvester.

Unloading: is a set of cyclically repeated movements and grips of hydraulic crane/grapple, leading to unloading of the forwarder, including maneuvering during stacking and/or trimming the pile.

Driving loaded: is a drive of the loaded machine from the stand to the road side, defined by turning the operator's cab seat from work to transport position.

Driving empty: the machine drives empty back to the stand.

In assessing the performance of the skidding technology [22] concluded that the size of the load and transportation distance affects productivity the most. This work aims on the differences arising due to the logging residual processing. Nevertheless, we can still use the time studies as an instrument for defining the influence of various factors on technology productivity.

The operation was recorded in sections using a digital video camera Sony HDR-CX11E with a resolution of 10.2 megapixels. The detailed time study was conducted in the office by reviewing field operations recorded by the camcorder. We have played the records on a VLC player and the software Time Study was used for recording vehicle cycle times. Operation of the machine was divided into work elements that were considered typical of the harvesting process of each machine. Thus, we have monitored only periodically recurring operations during operation, which matched with the scope and goals of the project. The operation was measured in Productive Machine Hours (PMH). For example, relocation (moving between working sites) would still last the same length of time regardless of whether the logging residual were being prepared or not. We have exported the recorded time measurement data into MS Excel editor 2013 for processing.

Results and Discussion

In total, more than 40 hours of operations were recorded and evaluated. Tables 1-4 contain the measured results for the studied options, broken down by system, machine model and operator.

Stand	Machine make and model	Option	Felling			Delimbing and bucking			Logging residual preparation			Moving to the next tree			Total time per cycle Ø
			Ø	Min	Max	Ø	Min	Max	Ø	Min	Max	Ø	Min	Max	
A	JD 1270	integrated	50.6	22	144	92.8	71	103	41.2	12	54	14.6	8	30	199.2
A	JD 1270	integrated	52	26	70	95.2	72	111	42.4	16	50	13.8	8	24	203.4
B	Rottne H11c	integrated	46	22	66	101.6	76	108	49.4	24	70	10.4	4	22	207.4
B	Rottne H11c	integrated	49.8	12	84	90.4	59	116	39.8	10	72	11.8	6	24	191.8
A	JD 1270	conventional	51.6	20	76	69	50	98				13.8	6	26	134.4
A	JD 1270	conventional	49.8	22	70	70.4	52	94				14.4	10	30	134.6
B	Rottne H11c	conventional	45.4	30	62	75.2	50	102				12	6	26	132.6
B	Rottne H11c	conventional	47	18	68	73.8	46	98				11	4	20	131.8

Table 2: Time consumption (s) in harvesting operation.

Stand	Machine make and model	Option	Loading			Unloading			Driving loaded			Driving empty			Total time per cycle Ø
			Ø	Min	Max	Ø	Min	Max	Ø	Min	Max	Ø	Min	Max	
A	JD 1110E	integrated	521	498	543	265	230	277	852	841	873	685	652	706	2323
A	JD 1110E	integrated	536	502	564	243	222	262	846	839	862	697	669	712	2322
B	JD 1110D	integrated	499	471	516	183	162	195	1147	1121	1189	917	901	930	2746
B	JD 1110D	integrated	528	460	554	196	167	203	1138	1120	1184	923	897	937	2785
A	JD 1110E	conventional	1135	993	1217	272	237	281	863	851	880	674	661	693	2912
A	JD 1110E	conventional	1098	830	1252	247	229	268	839	822	857	682	671	708	2902
B	JD 1110D	conventional	897	760	1003	179	153	211	1097	1032	1147	915	899	925	3062
B	JD 1110D	conventional	1011	864	1082	188	162	201	1152	1127	1179	931	912	945	3237

Table 3: Time consumption (s) in logging residual forwarding operation.

Stand	Machine make and model	Option	Loading			Unloading			Driving loaded			Driving empty			Total time per cycle Ø
				Min	Max	Ø	Min	Max	Ø	Min	Max	Ø	Min	Max	
A	JD 1110E	integrated	775	713	821	717	653	736	740	727	755	691	658	720	2923
A	JD 1110E	conventional	712	692	747	781	702	816	762	733	803	688	663	713	2943
B	JD 1110D	integrated	745	723	798	761	729	824	983	956	1013	908	889	921	3397

B	JD 1110D	conventional	763	508	783	770	711	803	972	954	998	912	901	925	3417

Table 4: Time consumption (s) in timber forwarding operation.

The results clearly revealed the following trends for harvesters

1. The monitored machines were parametrically entirely comparable. The machines were similar both in concept (6x6 all-wheel drive machines with rotating cab, positioning of the crane in front half-frame in front of the cabin) and engine output power (JD 170 kW at 1900 RPM, Rottne 164 kW at 1800 RPM) and a reach of the hydraulic crane (JD 10 m and for Rottne 10.3 m).
2. The Rottne harvester was newer and had a lower failure rate. We could not demonstrate the influence of a more modern operator's working environment and software environment on the machine's performance.
3. The difference in the time required for felling and delimbing by different machine was not statistically significant, as well as the influence of the operators, as we have expected due to the fact that it was designed this way.
4. Preparation of logging residual did not influence the time required for felling and moving machines to a new position.
5. In addition to time consumption for the direct preparation of brushwood, we have detected an increase of time in the delimbing and bucking operation. The operator had to manage not only the location of the logs, but also the brushwood. This was hampering the work element by an average of 23.5% compared with delimbing and bucking in case of conventional harvesting operation.
6. Overall, the preparation of harvesting residual increased time consumption per cycle by 33%, which is equal to 67 seconds per cycle.

The results clearly revealed the following trends for forwarders

1. The effect of the operator was again negligible. The difference between the cycle times of both machines is negligible and statistically insignificant. We can assume that in long-term measurements, the difference in performance of operators would be zero, which corresponds to the records of their employer.
2. Both monitored machines - John Deere 1110D and 1110E - differed only in engine output power (120 kW at 2000 RPM versus 136 kW at 1900 RPM) and a rotating cabin. We have not detected an impact of the engine power on the performance during the study thanks to the nearly ideal working environment. According to the information of the operator of the machinery, the more modern machine 1110E has in the long run lower fuel consumption (which can be attributed among other things, to the difference in overall condition and age of the machine) and it has a better performance in difficult conditions.
3. The used tires differed only in the tire pattern height. The type and size were identical, just like the hydraulic crane, as well as the size and spacing of stanchions.
4. The loading and unloading of logging residual compare to timber extraction takes less time (71%), although the load occupies a greater load-carrying space volume. The difference in the time of unloading brushwood for various forwarders (255 and 190 s) was caused by the fact that the first piled brushwood onto the tall pile when the harvesting residual kept several times falling down and had to be adjusted. The second just established the pile on the road-side, therefore the pile hasn't been needed to be adjusted. After the experience gained during the measurement, the time needed for unloading brushwood onto a pile up to the cabin high, was around the average values actually measured, that is around 220 seconds.
5. Bulky volume of harvesting residual affects the time consumption in element of driving loaded. The time spent for logging residual extraction was about 15% greater than the time necessary for the transportation of logs. Bulky and not providing easy survey load transported by a forwarder forces the operator instinctively to be more careful and reduce the driving speed. We have recorded this fact in all four cases. The average speed of driving loaded by the harvesting residual was about 3.9 km/hour while driving loaded by logs 4.3 km/hour.
6. The driving empty back to the stand always took the same time regardless of the formal cargo, which is logical. Empty forwarder has driven 5.7 km/hour in our study. We have tested the possibility of potential differences due to the style of arriving into the position for loading and unloading as well as due to possible collecting of logging residual lost during the driving loaded. We could not confirm this assumption.
7. The forwarders were transporting in average about 8.5 cubic meters of timber in the 4 m long logs. We have estimated the volume of the transported logging residual by the size of loading area to be about 20 cubic meter bulk volume. In total to extract all of the material from the stand one journey with harvesting residual to three journeys with logs was necessary.
8. In case the forwarder was collecting freely spaced harvesting residual the time necessary for uploading was in average about 8 minutes (484 s) longer compare to the by harvester pre-piled option. However, the freely spaced material after CTL method is better concentrated compare to the motor-manual method (harvested and delimbed by power chain saw).

Productivity and time consumption are the first steps necessary for setting up the strategy of the contractor and are one of the most important information necessary for cost analysis and further decision making. With the arising number of new machinery (technological development) such studies arises in frequency too. This could be demonstrated by studies of Ref. [23] or Ref. [24].

In the logging operation within this study, the average theoretical performance of a harvester without any delays was detected to be 35 m^3s.v/PMH (cubic meter solid volume per productive machine hour) of timber or 23.5 m^3s.v/PMH of timber plus 16,45 m^3b.v/PMH (cubic meter bulk volume per productive machine hour) of pilled logging residual in the integrated operation.

Comparing machine performance leads to taking a lot of factors into the consideration. Generally, the productivity of the harvester per productive machine hour varies between 13 up to 42 m^3s.v/PMH [24].

The main factors affecting productivity are average tree volume [25], number of harvested trees [26], terrain conditions and soil bearing capacity [27] and/or operator skill [28], respectively. Based on the literature review, the results of this study with respect to productivity are comparable.

In the case of this study, productivity was calculated to time without any delays. Describing the real-life deployment of machines, the utilization of the machines needs to be measured. After all, it was a work in almost ideal conditions, with high stem volume of harvested trees, a minimum slope of the terrain, as well as dry and firm ground. The real machine performance according to their operators is considerably lower. In addition, in calculating the performance, we have not taken into account the impact of downtime, repairs, necessary breaks, and so on. For example, Mizaras et al. note in their work the breakdown of the working time as follows: Some 73.7% spent on working operations, such as felling, delimbing, and cross-cutting [29-34]. It took another 6.7% of the time to position the whole machine and 19.6% was reported as the time needed for other operations. According to this breakdown, the calculated performance would have to be decreased by almost 20% [35].

The performance of a forwarder was about 16.32 m^3s.v/PMH in timber extraction [36-38]. This matches with the data presented by Dvořák [30], who declares (in the Czech Republic conditions) that the forwarder performance ranges between 7.7 m^3s.v/PMH and 16.7 m^3s.v/PMH depending on the average log volume and extraction distance [39]. In case of logging residual extraction pre-pilled by harvester the average productivity was 27.5 m^3b.v/PMH, in case of freely spaced logging residual the average forwarder productivity was 23.1 m^3b.v/PMH. Many authors displaying similar results measured in case studies carried out in similar conditions, i.e., 6.0 - 23.4 m^3b.v/PMH [40].

The main objective, comparison of common CTL method with integrated harvesting method, is calculated based on operation time of both harvester and forwarder in the stand described above.

In the first option, i.e., conventional CTL method the total operation time necessary for timber and logging residual harvesting and extraction was 45.6 hours (harvesting without pilling 10.8 hours, timber extraction 23.3 hours, harvesting residual extraction 11.5 hours). In the second option, i.e., pre-pilling of harvesting residual by harvester the total operation time necessary for timber and harvesting residual harvesting and extraction was 49.4 hours (harvesting including pre-pilling 16.2 hours, timber extraction 23.3 hours, harvesting residual extraction 9.7 hours).

Conclusion

According to this case study, the integrated harvesting method is less effective compare to conventional CTL method followed by logging residual extraction. The authors can only speculate that only in case of harmonizing the operation time of both harvester and forwarder is this strategy valuable. The ratio between time spent by harvester and forwarder is for conventional method 1:3 but for the integrated method 1:2. This could be used for better balancing the number of machines applied to be able to reduce the transportation cost. The individual transportation of the vehicles may increase overheads cost for management and may increase non-operation supporting time necessary for servicing.

Better performance of the forwarder may be increased by using grapple purposely designed for logging residual manipulation or at least the versatile grapple useable for both round wood and logging residual manipulation. However, this was not confirmed by this study.

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