Harvester-forwarder for logging in first-thinning stands

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Abstract. *The development project produced a new machine for harvesting wood from thinnings. This new machine is based on the concept of a harvester-forwarder. The concept of the harvester-forwarder is that felling and processing and forest haulage are carried out using the one and the same machine. The objective of this study connected to the project and conducted by Metsäteho Oy was to conduct an analysis of the structure of the time consumption, output and costs of the said harvester-forwarder based on a new harvesting technology and harvesting method when used in first-thinning pine stands and mixed stands. The harvester-forwarder involved in the study is a machine producing delimbed timber developed by the company S Pinomäki Ky. This report is based on Metsäteho Oy`s project report no 26.*

1 INTRODUCTION

It is quite evident that less first thinnings have been carried out in Finnish forests than is rational from the point of view of the wood production capacity of the country's forests resource. The profitable industrial use of wood from thinnings is a problem because of the high costs of harvesting it. The harvesting conditions when dealing with first-thinning timber are disadvantageous and work productivity is distinctly lower than in final fellings. The costs of harvesting thinning timber are 2-3 times greater than the costs of harvesting final-felling timber.

The problem is, how to make the wood from thinning more profitable for forest industry. Solving this problem requires the development of all stages in the process of converting wood from thinnings. One of the primary development targets is harvesting technology and innovative solutions connected to it.

In Finland, TEKES (Technology Development Center) provides funding within the framework of the HARJU Program for projects focusing on developing the various links in the conversion chain of wood from thinnings ranging from the stump to the mill. Ecologically sustainable utilization of the forests and the requirements this imposes on technology and action modes are taken into consideration when developing new technology.

One of the harvesting technology projects included in the HARJU Program is S. Pinomäki Ky's project titled "*Ensiharvennuspuun taloudellisen korjuun mahdollistavan laitteen kehittäminen*" (trans. "Development of a device enabling economically feasible harvesting of first-thinning wood"). The aim of the company S. Pinomäki Ky was to develop a harvester-forwarder appropriate for inclusion in the conversion chain of first-thinning wood. The implementation of the concept of a harvester-forwarder requires that the said technology can be made to function effectively and economically. To get information of new technology Metsäteho Oy conducted an analysis of the structure of time consumption, output and costs of the said harvester-forwarder based on a new harvesting technology and harvesting method when used in first-thinning pine stands and mixed stands.

2 PROJECT TASKS AND OBJECTIVES

The tasks of the project were, in cooperation with the machine manufacturer and its users:

1. To develop a harvester-forwarder producing delimbed and bucked wood,
2. To provide the harvester-forwarder with work methods and technology appropriate for first-thinning conditions
3. To conduct studies involving the harvester-forwarder in different first-thinning conditions in order to collect data on time consumption and output in harvesting
4. To produce information of the suitability of harvester-forwarder technology for inclusion in the conversion chain for first-thinning timber
5. To produce information of possible problems and development needs involving the harvester-forwarder
6. To perform calculations on the competitiveness of a single-grip harvester chain when compared to the harvester-forwarder system.

3 IMPLEMENTATION OF THE PROJECT

3.1 Organization

The project was launched in 1996. S. Pinomäki Ky were responsible for the technical development of the harvester-forwarder. The process of defining the requirements to be imposed on the machine were taking care by the project group in which S. Pinomäki Ky, Metsäteho Oy and forest-industry enterprises were participating.

In the course of the project, a forwarder was provided with a custom-designed and constructed harvesting head enabling the felling, processing, loading and unloading of timber in first-thinning conditions as inter-articulated work stages. By the end of 1996, S. Pinomäki Ky had developed and constructed the felling-processing-and-loading harvester-forwarder producing delimbed wood.

The machine's operating techniques and methods in first thinning operations were developed in connection with the first trials with the harvester-forwarder. The development of operating techniques and methods was carried out in cooperation with a logging entrepreneur on different thinning sites in connection with normal wood harvesting work.

Once the harvester-forwarder and its operating technique and methods in first thinning operations had been made functional and standard, it was time to implement the work study part of the project and the experiments conducted in conjunction with it.

3.2 Harvester-forwarder and its work method

When using a harvester-forwarder to carry out mechanized thinning, only one machine is needed instead of two. When using a harvester-forwarder, felling, processing and forest haulage are linked to form a seamless whole. The objective in having advanced inter-articulation of the work stages is to achieve higher outputs in wood harvesting. The second point in the development work was that using the harvester-forwarder the capital input required is reduced significantly and significant cost savings are obtained in harvesting.

In the course of the project, S. Pinomäki Ky have developed two harvester-forwarder versions; one produces undelimbed pulpwood and the other delimbed timber. This report examines the development of the harvester-forwarder producing delimbed timber and the experimental work done with it in first-thinning logging.

In first-thinning conditions, the method of operating the harvester-forwarder requires that it can open up its own strip roads within the stand and be able to operate on a strip road interval of 20 meters. This required modifications on the forwarder base and the hydraulic crane.

The study stage involved two harvester-forwarders based on the Pika 300 harvester head developed by S. Pinomäki Ky. The base machine for one was the Pika 728 T forwarder (Fig. 1) and Valmet 820 forwarder for the other.

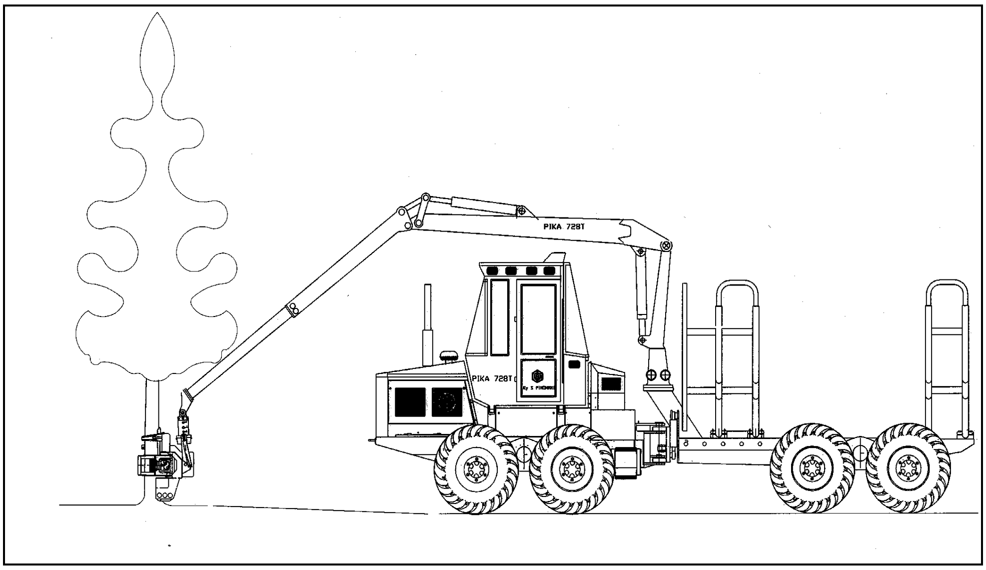

Figure 1. *Pika 728T/300 harvester-forwarder can operate the crane over the cab and open up a strip road.*

The method of operating the harvester-forwarder differs in many respects from the usual method of operating a wood harvesting chain including a single-grip harvester and forwarder (hereafter single-grip harvester chain). Harvester-forwarder technology can be adopted in all forwarder models in which it is possible to operate the crane over the cab of the machine and in so doing open up a strip road for the machine. The base machine must be sturdy enough for the harvester-forwarder technology to be efficiently utilized. In the experimental machines, the crane boom had a reach of ca. 10 meters on either side of the machine. In the direction of movement, its reach was ca. 4 meters and this corresponded to the extent to which the machine could be used to open up a strip road for itself at the one time. The said reach was observed to be sufficient from the point of view of operating the machine. The harvester-forwarder can be operated using a strip road spacing of 20 meters and the machine's normal strip road width requirement is 4 meters.

The harvester-forwarders working method consists of two stages (Appendix 1). In the first stage, the harvester-forwarder opens up the strip road. This is done by operating the crane-mounted harvester head over the cab with the machine moving on in the normal manner. The trees felled from the strip road are processed and bunched alongside the strip road. When opening up strip roads, the machine does not load timber, but a small "base load" is picked up in the early stages of opening up of the strip road in order to provide the harvester-forwarder with the necessary ballast to make it more stable. When opening up the strip road for the machine, a few trees alongside the strip road may also be harvested.

Once the strip road has been opened up, the operator turns the machine around at the end of the strip road, and the second stage begins, namely that of felling and processing trees between adjacent strip road stretches. When operating the machine to fell and process trees in the in-between area, the operator also loads on all the processed timber. From the point of view of output, it makes sense to add this timber into the same bunches with the timber produced from the strip road trees and then to load them together. The size of the bunches will then increase and improve the efficiency of the load-on stage as all the timber is loaded at the one time. The timber assortments are kept separate. Once the load bunk is full, the operator drives the harvester-forwarder to the roadside landing to unload the timber and then drives back to continue on from the most recent felling point.

3.3 Research method

The objective in data acquisition was to obtain time consumption, output and cost data for determining the competitiveness of the harvester-forwarder in first-thinning logging and to compare it with the single-grip harvester technology. Time study data were collected to determine the outputs of the harvest technologies compared, harvester-forwarder and single-grip harvester. The time study was conducted in compliance with the principles of comparative time study. The cost data were produced with harvesting cost calculation models where costfactors of the harvester-forwarder were included.

Comparing the economics of two different harvesting technologies requires that the output and cost data are collected on homogenous harvesting sites. In order to ensure adequate accuracy of the data on logging conditions, the time study was carried out applying a research method focusing on homogenous experimental plots and applying precise measurement techniques. The experimental plots and their growing stocks were measured before and after and each plot was allocated a certain harvesting technology. The aim was to ensure that both of the technologies being compared would accrue observations made in comparable conditions.

The experimental plots were 20 m x 100 m in size and they were marked out and located within the study blocks by measuring and their boundaries were set out with clearly visible flagging. Strip roads were placed down the middle of each experimental plot parallel with its lengthwise axis and these were marked out in advance to run straight. As a means of ensuring contiguous harvesting conditions, the pairs of plots to be compared were usually arranged to be side by side.

The study comprised three forest blocks within which networks of experimental plots were established. The time study data were collected from a total of nineteen experimental plots.

3.4 Research material

The time studies were conducted in first-thinning stands, which were chosen so that they complied with the conditions in the probable operating environments of this type of machine. Two kinds of first-thinning stands were selected as follows:

1. Mixed stands, share of dominant species about 50 – 70 %
2. Pine-dominated stands, share of mixed timber assortments less than 25 %

The harvester-forwarder was examined in operation on twelve experimental plots while the single-grip harvester was studied on seven experimental plots. No earlier research data was available on the harvester-forwarder whereas there is plenty of previous time study data on single-grip harvesters in first-thinning work. Metsäteho Oy has recently concluded extensive research on the rate bases for single-grip harvesters and this information was made use of in this study, e.g. in defining the time consumption structure and output and cost comparisons pertaining to single-grip harvesters.

The average stem size of the felled trees on the experimental plots was 0.081 m^3 and varied between 0.041 and 0.134 m^3. The corresponding stem number of removal per hectare within the experimental plots varied between 485 and 1520 stems/ha. The harvested removal on the experimental plots varied between 40 and 89 m^3. The basal area of the stands after harvesting was between 13 and 19 m^2, which complies with the retention-stand basal area requirement in Finland set out in thinning models currently in use. The research data contained sufficient variation in terms of first-thinning stand harvesting conditions.

3.5 Concepts applied in time study

Data acquisition work in the time study looking at the harvester-forwarder was divided into eleven stages. The effective-time consumption included gripping-felling-fetching and processing, driving with and without load, picking up load and unloading, moving, organizing, disturbances, and planning of work. The gripping-felling-fetching time includes taking the harvester head to the base of the tree, felling of the tree and fetching it to the processing place. Processing time includes delimbing and cross-cutting of the stem resulting in timber assortments. Moving, organizing, disturbances and planning of work were made to include the time consumption arising from felling and processing and forest haulage.

The concepts of both effective time consumption and consumption of operating time were used in the time study. Interruptions are not included in effective time consumption. When computing the consumption of operating time, all interruptions shorter than 15 minutes were added to the effective time consumption.

4 RESULTS

4.1 Time-study results for harvester-forwarder

The time consumption for the harvester-forwarder consists of cutting and forest haulage. In traditional studies focusing on mechanized wood harvesting it has been possible to keep these separate, but with a harvester-forwarder it is difficult to clearly distinguish between these stages. The factors affecting time consumption do not work the same way for a harvester-forwarder as they do for a harvester chain, for example.

4.1.1 Structure of time consumption for harvester-forwarder

The average structure of the time consumption actualized on the research stands is shown in Fig. 2. The cutting (= felling-and-processing) stage and the forest haulage stage are the harvester-forwarder's foremost operating stages. The harvester-forwarder's effective time consumed was divided as follows: 42 % in cutting and 46 % in forest haulage. Felling consisted of gripping the tree and felling it and processing consisted of delimbing and cross-cutting. Forwarding consisted of loading, driving with and without load, and unloading at the roadside storage pile. All machine movings connected to operating it were included in forest haulage stage. "Miscellaneous time", which comprised 12 % of the effective time, included organizing and disturbances and planning of work.

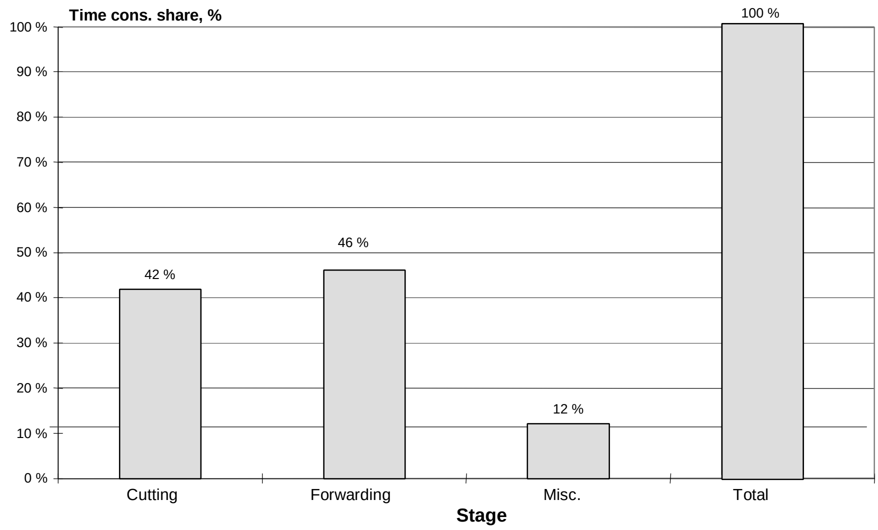

Figure 2. *Structure of the effective time consumption of the harvester-forwarder: All stages*

In the cutting stage, the harvester-forwarder used an average of 59 % of the effective time consumed in processing (=delimbing and bucking), while 41 % of the said time was consumed in gripping the trees and felling them (Fig. 3.). The ratio between the time consumption of the work stages in felling and processing is almost the same as what has been observed to apply to single-grip harvesters operated in similar first-thinning conditions.

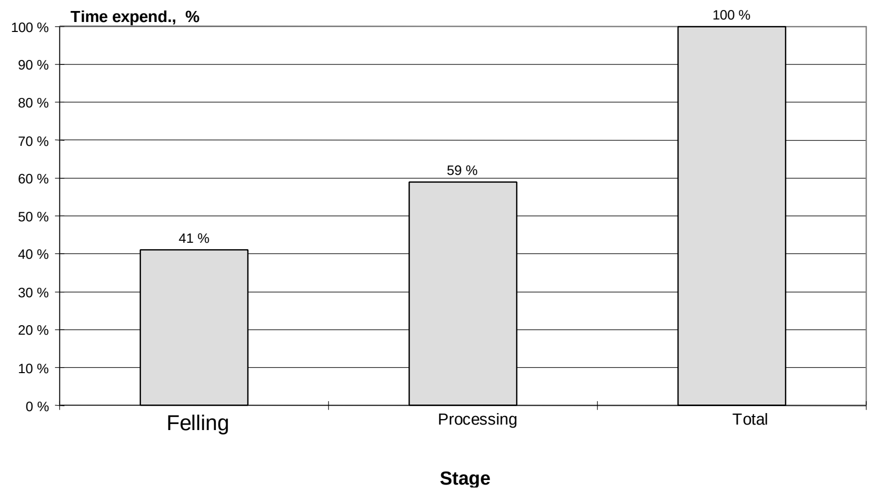

Figure 3. *Structure of the effective time consumption of the harvester-forwarder: Felling and processing.*

The share of processing time was 63 % at the stage of opening-up the strip road (Fig. 4.). The average gripping-felling-fetching distance shortens only to 4.2 meters, which shortens the time required to grip a tree. With a single-grip harvester, the gripping-felling-fetching distance in conjunction with opening-up of the strip road was only 2.7 meters. The difference in gripping-felling-fetching distance is due to the fact that the gripping-felling-fetching distance is determined from the crane's mast. The boom of the harvester-forwarder is located behind the cab and so the gripping-felling-fetching distances are greater.

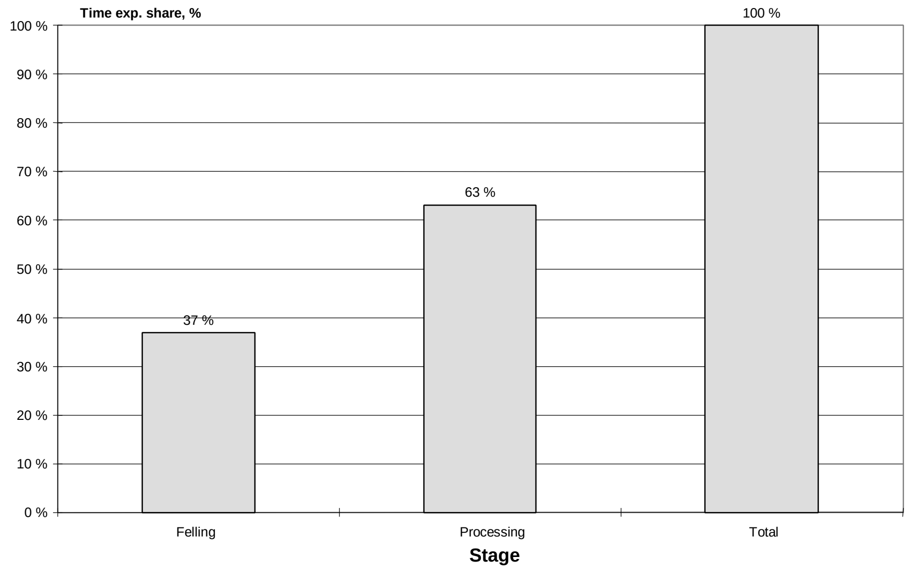

Figure 4. *Structure of the effective time consumption of the harvester-forwarder when opening up the strip road.*

When felling and processing trees within the in-between area (between adjacent stretches of strip road) there were no significant differences in the average results concerning the time consumption shares gripping-felling-fetching and processing times when using the harvester-forwarder (Fig. 5.). A small difference was caused in the time consumption shares when the gripping-felling-fetching distance increased from 5.5 m to 6.2 m.

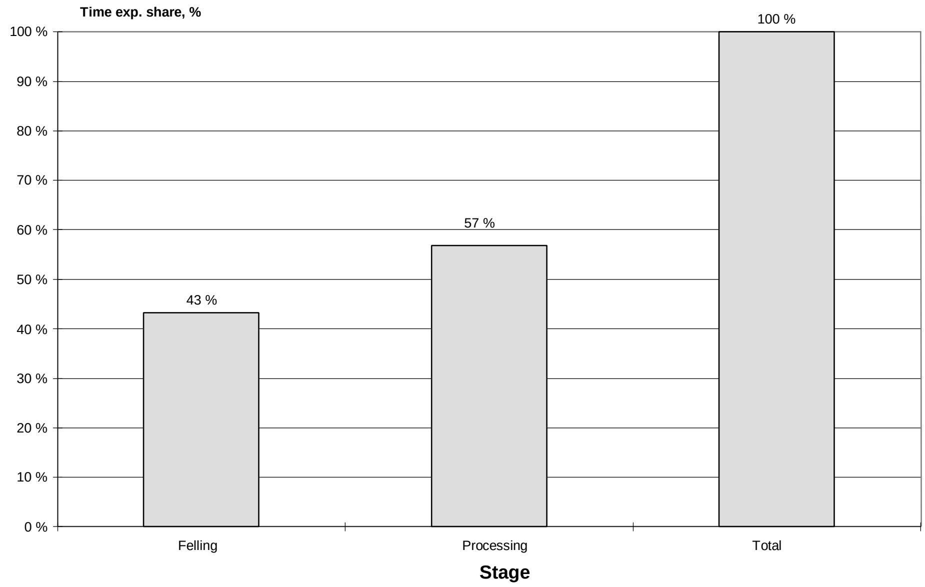

Figure 5*. Structure of the effective time consumption of the harvester-forwarder in dealing with trees in the in-between area (area between adjacent stretches of strip road).*

The forest haulage stage when using the harvester-forwarder took a little bigger share of the effective-time consumption than did the felling and processing stage. However, all movings have been computed into the forest haulage stage because it is not possible to define movings separately for felling and processing and forest haulage.

Moving when loading, the share of which averaged 29 % of the effective time consumed by the harvester-forwarder, is that very time factor which is keenly connected to the felling and processing stage when using the harvester-forwarder method (Fig. 6). It is the scarcity of movings that makes the harvester-forwarder method such an extremely efficient method. The harvester-forwarder consumed almost an equal amount of time for driving with load as without a load.

The share of the time required by loading was considerably high and loading was indeed one of the most time consuming stages. This is probably due to the lack of flexibility caused by the felling head in loading and unloading.

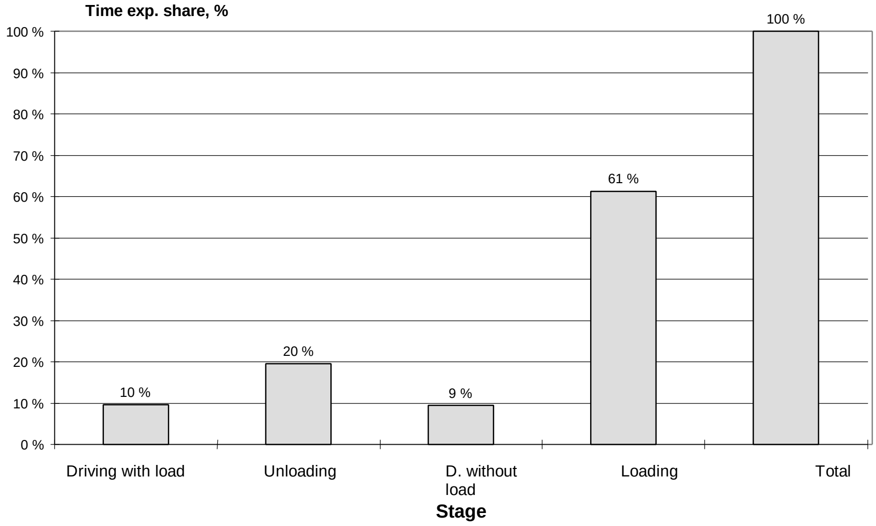

Figure 6. *Structure of the effective time consumption of the harvester-forwarder: Forest haulage.*

The average consumption of operating time on part of the harvester-forwarder when working on the experimental plots was 104.8 cm/stem (Fig. 7.). The average stem size was 0.081 m^3 and the average share of hardwood timber was 28 %. The share of organizing rose to 7.7 % of the operating time, which is explained by the merging of felling and processing and forest haulage. The machine operator prefers to make better bunches alongside the strip road so as to speed up the loading stage on returning.

Interruptions of less than 15 minutes accounted for 5.9 % of the time consumed. The ratio between operating time and effective time on the experimental plots was 1.08, which was a little less than that of the single-grip harvester and the forwarder. Operating time includes interruptions of shorter than 15 minutes, while these are not included in effective time.

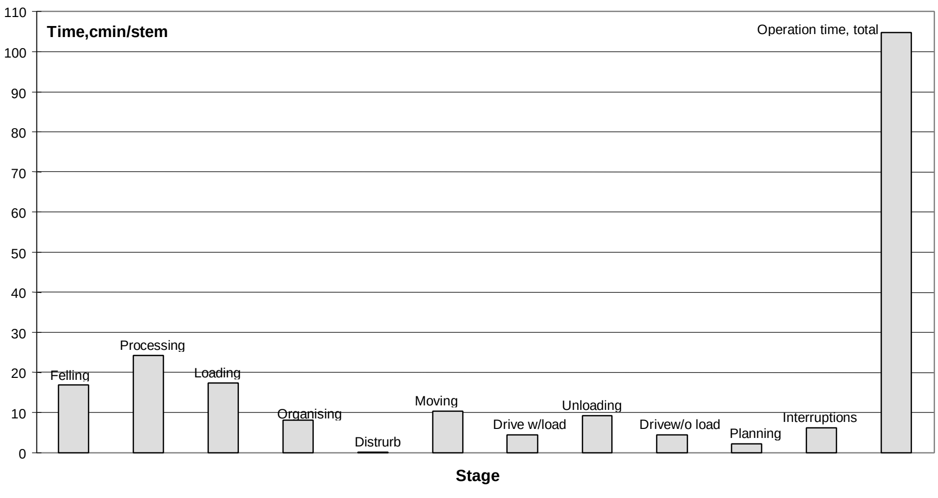

Figure 7. *Distribution of the time consumption of the harvester-forwarder among the work stages: All stages*

The consumption of operating time of the harvester-forwarder at the cutting stage was 63 cmin/stem when the average stem size was 0.081 m^3 (Fig. 8.) The time consumed by felling included gripping-felling-fetching and the processing time included delimbing and bucking. Other moments were organizing and disturbances, movings, and interruptions of shorter than 15 minutes. Interruptions were made to include the planning of work for the sake of comparison.

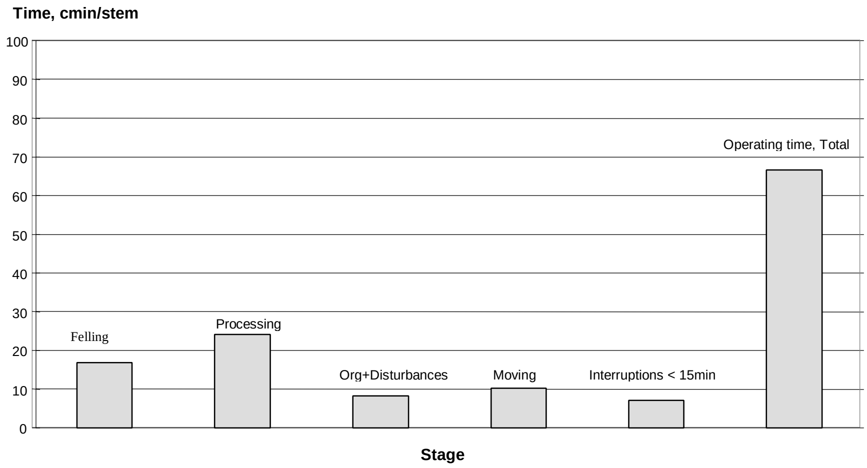

***Figure 8**. Time consumption of the harvester-forwarder in cutting, interruptions include planning.*

The harvester-forwarder's stem processing and felling times were a little higher than those of the single-grip harvester (Fig. 9.). For the same stem size, the single-grip harvester used 16 % less time in cutting than the harvester-forwarder. This was probably primarily due to the smaller size of the harvester head and the output capacity of the hydraulics system. The gripping-felling-fetching time is also influenced to some extent by the poorer visibility of the operator from the cab of the harvester-forwarder when compared to the visibility from the cab of the single-grip harvester, a machine constructed simply for felling and processing timber. The harvester-forwarder developed by S. Pinomäki Ky has better visibility from the cab than is the case with the Valmet 820 forwarder used in the study.

The share of disturbances of the harvester-forwarder's consumption of operating time remained small, which shows that the machine constitutes an operationally reliable whole. The share of movings for both machines was almost the same, but the harvester-forwarder movings also include forest haulage movings as mentioned before. The machines did not differ greatly in terms of interruptions, but again it is necessary to point out that the interruptions for the harvester-forwarder include all the work stages.

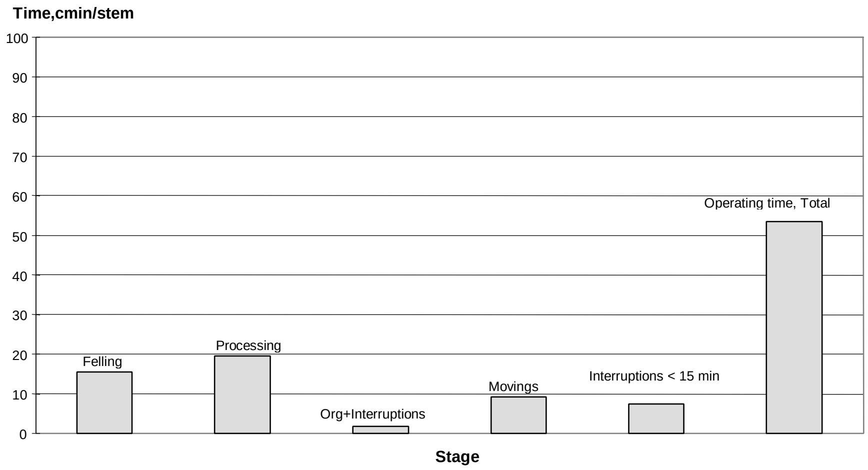

Figure 9*. The single-grip harvester's operating time in felling and processing, interruptions include planning.*

4.1.2 Time consumption and output

The most decisive factor explaining the time consumption of the harvester-forwarder was the stem size of the timber harvested. The number of trees per hectare to be harvested also affected the time consumption of the harvester-forwarder. The forest haulage distance affected the time consumption of the harvester-forwarder because the same machine was used also to carry out the forest haulage. According to the results of a productivity study dealing with thinnings, the most important factor affecting productivity is, however, the operator's knowledge and skill at work, and this also applies to the harvester-forwarder. The operators involved in this research project were skilled.

Time consumption in this study was examined as a function of stem size and dbh of the trees. The dbh classes continue to 25 cm and the stem size classes to 0.200 m^3 because stems above these dimensions are infrequent in the probable first-thinning sites where this machine will be used.

The average forest haulage distance for the entire study material was standardized to 250 m, the average stem size in the harvesting to 0.081 m^3, and the harvested stem number per hectare to 888 stems.

Time consumption for the harvester-forwarder was at its smallest in pure or almost pure stands of pines (Fig. 10.). The difference between pure and mixed stands in terms of time consumption when using the harvester-forwarder came out mainly when dealing with large stems. The difference in operating time consumption between a pine stand and a mixed stand was 3 % for stem sizes below 0.070 m^3, but it increased to 7 % when stem size increased to 0.200 m^3.

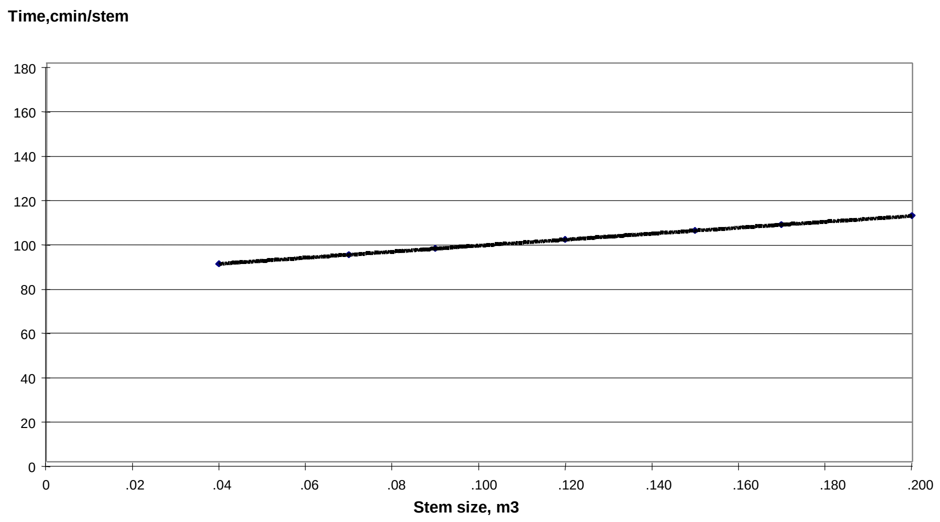

Figure 10*. Operating time consumption of the harvester-forwarder as a function of the stem size in a pine stand*

The difference with bigger trees was due to the slowness in processing the top sections of large birches because of their thick branches. The harvester head of the harvester-forwarder was not powerful enough to deal with them. Also, the species mix meant problems in the forest haulage stage of the harvester-forwarder. The loading of several timber assortment and unloading them into separate piles further increased the time consumption. This problem is the same in conventional forest haulage carried out using a forwarder.

The slopes of the time-consumption curves are far from steep, but one must remember that only the work done during the felling and processing stage cause an increase in time consumption connected to stem size. However, these stages comprise only 42 % of the machine's total time consumption. On the other hand, variation in stem size is depicted within the range of 0.040 - 0.200 m^3 within which range differences in time consumption do not yet rise very radically.

The time consumption at the felling and processing stage for the harvester-forwarder was indicative of the difficulty in handling large trees with the machine. When dealing with stems with dbh of 15 cm, the harvester-forwarder was 13 % slower than the single-grip harvester. However, the proportion of stems with dbh greater than this on those logging sites that the harvester-forwarder is intended for will be very small, and therefore the effect on productivity will be minor. As regards the gripping-felling-fetching times, the harvester-forwarder did not significantly differ from the times achieved using a single-grip harvester.

The time consumption in felling and processing when using the harvester-forwarder in opening up the strip road does not really differ from the average time consumption (Fig. 11.). When dealing with trees with dbh 15 cm, the harvester-forwarder was 14 % slower than a single-grip harvester. The difference between the machines is mainly explained by the fact that the harvester-forwarder is operated over the cab, which is a slightly more difficult method.

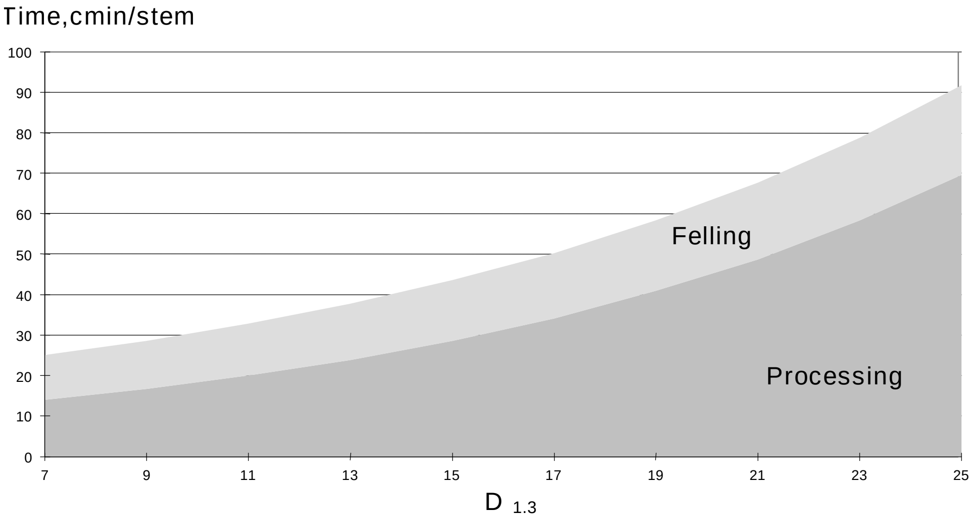

***Figure 11**. Time consumption in felling and in processing of timber when using the harvester-forwarder in opening up the strip road*

The differences between the harvester-forwarder and the single-grip harvester were small in thinning the area in between adjacent stretches of strip road; when dealing with trees with dbh 15 cm, the difference was just 5 % (Fig. 12.).

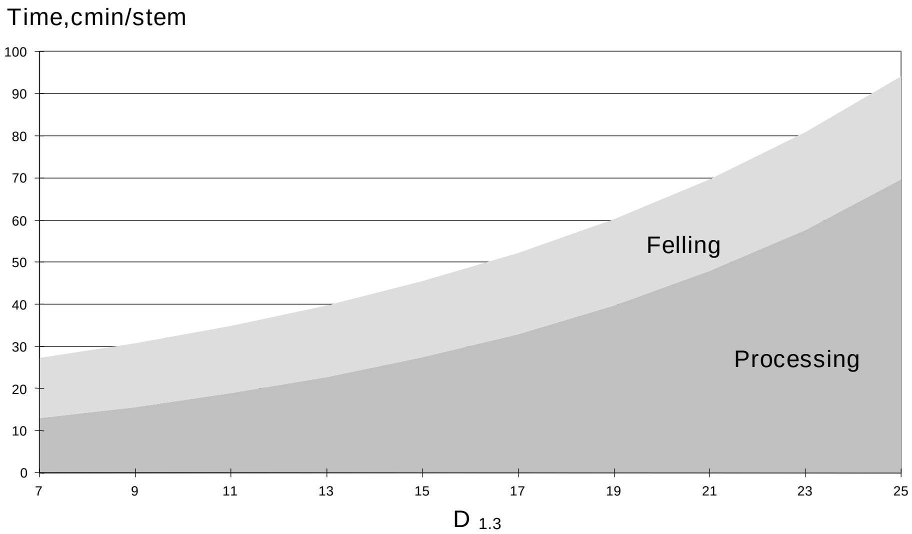

***Figure 12**. Time consumption in felling and in processing of timber when using the harvester-forwarder in thinning the area in between adjacent stretches of strip road*

When dealing with small stems, the output per operating hour achieved using the harvester-forwarder were almost the same for both pine-stand and mixed-stand plots (Figures 13 and 14). On the mixed-stand plots, outputs increased to levels even higher than on the pine plots when the average stem size was below 0.050 m^3. This was due to the lack of branches on the small-diameter birches and the abundance of such birches, which together increased the productivity of the machine on mixed-stand plots. When the average stem size on pine plots was 0.80 m^3, the harvester-forwarder's output per operating hour was 9.4 % higher than that achieved on mixed-stand plots. When the average stem size on pine plots increased to 0.200 m^3, the productivity was 23 % higher than that achieved in mixed-stand plots.

When dealing with the largest trees on the mixed-stand plots, the productivity of the harvester-forwarder was poorer than on pine plots.

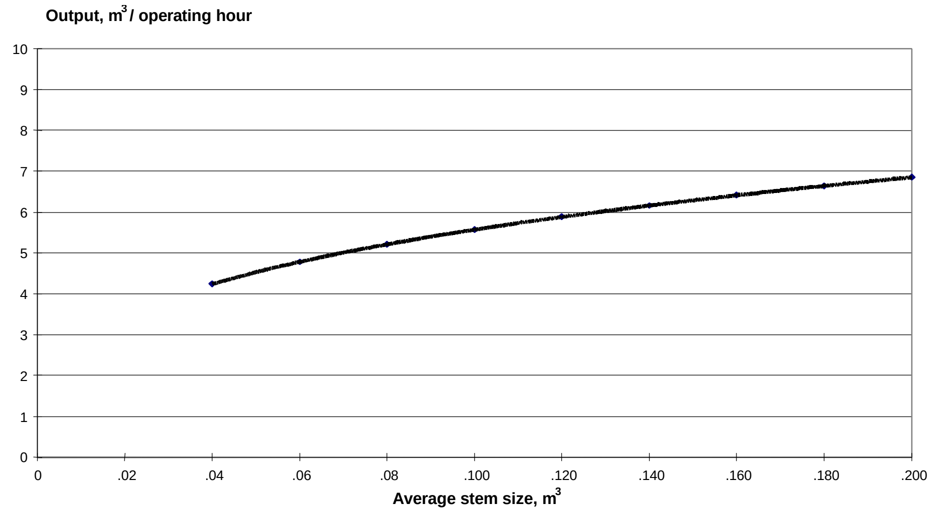

Figure 13. *Output per operating hour achieved when using the harvester-forwarder in a pine stand.*

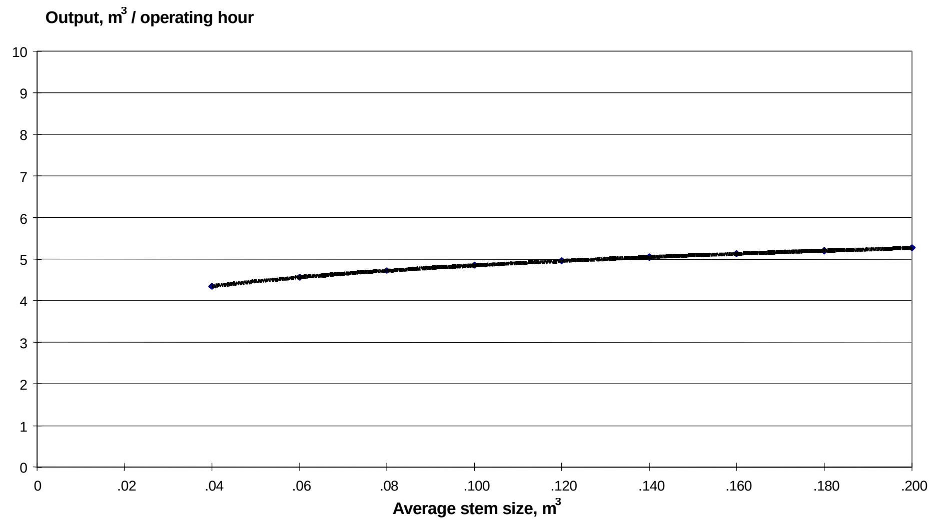

Figure 14. *Output per operating hour achieved when using the harvester-forwarder in a mixed stand.*

4.2 Time-study data on single-grip harvester

The primary single-grip-harvester data used in this study were the results of a productivity study on mechanized thinning recently completed at Metsäteho Oy. The purpose of the single-grip-harvester plots (seven of them) established in conjunction with the harvester-forwarder plots was to provide supportive data for the assessment of the single-grip-harvester chain. These results collected from seven experimental plots were compared with the results of the productivity study, which were used to ensure the equivalence of the circumstantial factors of the comparisons, for instance. This enabled maximum scope for the material base for the single-grip-harvester chain.

The data provided by the study itself was used also when comparing the time consumption of opening-up the strip road and thinning the area in-between adjacent stretches of strip road. These stages had not been separated in the productivity study, and therefore the data acquired in this study were used as the comparison data to enable comparisons.

4.3 Output of chain including single-grip harvester and forwarder

To facilitate comparison, the output of the single-grip harvester chain was determined with the help of harvesting models developed at Metsäteho Oy, and which embody output functions based on the latest rate bases studies. The tree-species compositions in the calculation for the single-grip-harvester chain were set to correspond to the tree species compositions on the harvester-forwarder plots.

The output per operating hour achieved when operating the single-grip harvester chain in a pine stand with average stem size being 0.070 m^3 was 5.42 m^3/h. This was 4 % higher than achieved in a mixed stand. The difference in output per operating hour between wood harvesting in a pine stand and in a mixed stand will not exceed 4 % even if the average stem size were to be raised to 0.200 m^3. This is due to the fact that time consumption when using a single-grip harvester does not rise to such extent as it does when using a harvester-forwarder when the stem size is 0.200 m^3. The output per operating hour of the single-grip harvester chain in a pine stand was 7.6 % higher than that of the harvester-forwarder in a pine stand with average stem size at 0.070 m^3. When the stem size increases to 0.150 m^3, the advantage of the single-grip harvesters chain over the harvester-forwarder solution increases to 13 %. In the light of this result, the competitiveness of the harvester-forwarder with respect to the single-grip harvester chain remains moderately good in pine stands with average stem sizes not exceeding 0.150 m^3.

The curve depicting the single-grip-harvester chain's output per operating hour as a function of stem size in a mixed stand was considerably steep when compared to that of the harvester-forwarder. The output per operating hour of the single-grip harvester chain operating in a mixed stand was 11 % higher than that of the harvester-forwarder when the average stem size was 0.070 m^3. When the average stem size increased to 0.150 m^3, the productivity of the single-grip harvesters chain was 22 % higher than that of the harvester-forwarder. The lack of capacity of the small harvester head of the harvester-forwarder becomes more evident with larger average stem sizes. The stem sizes occurring in thinning stands do not pose difficulties for single-grip harvesters.

5 COMPARISON OF LOGGING COSTS: HARVESTER-FORWARDER CHAIN VS. SINGLE-GRIP HARVESTER CHAIN

Output functions and cost premises for the harvester-forwarder were installed in Metsäteho Oy's harvesting-cost models to facilitate the computation of timber harvesting costs of the harvester-forwarder. In doing so, it was recognized that using a harvester-forwarder is not yet an established method. Consequently, the cost factors for the harvester-forwarder were determined applying the principle of caution. The base machine and the crane of the harvester-forwarder examined represented the smallest possible size class that can be built into the harvester-forwarder, with the consequence that the output level of the new method would not be overestimated.

When examining the timber harvesting costs of the harvester-forwarder, the output per operating hour applied was that obtained in this study, namely 4 m^3/h. For the chain including the single-grip harvester, the output functions applied were those obtained from a thinning productivity study. The average size of the logging operation for the harvester-forwarder was set at 200 m^3 because cost computation was based on the assumption the harvester-forwarder would be used only to carry out first thinnings.

The average logging operation size for the single-grip-harvester chain was set at 500 m^3, which significantly favors this chain in the cost comparison. The time consumed in moving the machines was made the same for the two methods although it is probable that it is distinctly shorter per logging operation for the harvester-forwarder.

The average stem size in thinning was 0.069 m^3 for the harvester-forwarder and 0.147 m^3 for the single-grip harvester chain, which again favors the single-grip harvester chain. The harvesting removal allocated to the harvester-forwarder was 60 m^3/ha while the single-grip harvester chain was allocated the of 80 m^3/ha.

The degree of utilization for the harvester-forwarder was cautiously set at 70 %. In practice, the degree of utilization will probably be higher. The corresponding for the single-grip harvester was 80 % and that for the forwarder 85 %.

All these differences favor the single-grip harvester chain in the cost comparison. The purpose of this procedure was to underscore the uncertainty always associated with new technology.

The costs associated with the two wood harvesting technologies clearly differ from one another (Fig. 15.). The costs resulting from using the harvester-forwarder were, on average, 85 % of the logging costs resulting from using the single-grip harvester chain in first-thinning operations. The harvester-forwarder was the cheaper alternative up to the average stem size of 0.150 m^3. When dealing with stems below 0.055 m^3 size, the harvester-forwarder achieved 18 % lower harvesting costs than the single-grip harvester chain. With average stem size at 0.100 m^3, the harvester-forwarder advantage was still of the order of 8 %. This cost comparison shows that the harvester-forwarder constitutes a competitive wood-harvesting technology in all thinnings in which the average stem size remains below 0.150 m^3.

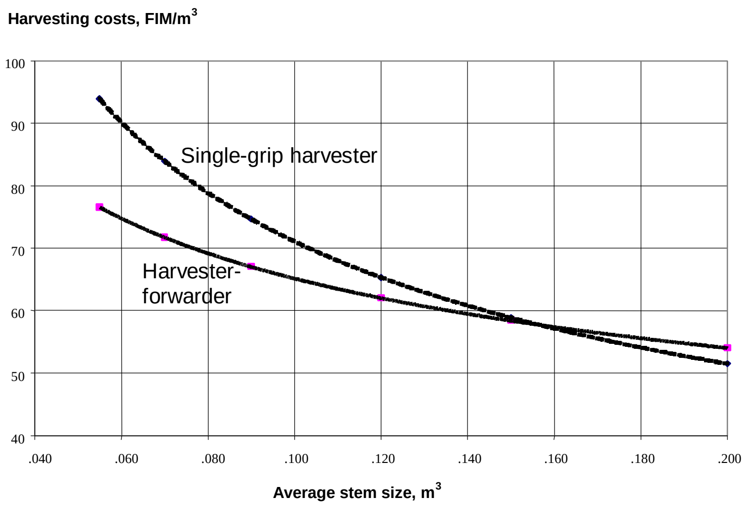

***Figure 15**. Costs resulting from timber harvesting using (i) the single-grip harvester chain and (ii) the harvester-forwarder.*

The purchase price used in the computations on the harvester-forwarder's harvesting costs included the measuring device under development and to be mounted on it. Its effect on the wood harvesting costs are minor and it was included in the computations. The development of the measuring device is important from the point of view of the adoption of the concept of the harvester-forwarder and it will enhance the possibilities for applying the method.

6 CONCLUSIONS

The harvester-forwarder developed in the course of the project to produce delimbed timber appears to constitute promising harvest technology for thinning operations involving stem sizes below 0.150 m^3. The harvester-forwarder technology offers a new alternative in the field of harvesting of thinnings timber. In the light of the present study, it is profitable for both the entrepreneur as well as industry using the wood.

The technology involved in the harvester-forwarder still have a lot of development and improvement potential. Increasing the capacity of the grapple head and the crane and improving the visibility from the cab will increase the machine's productivity, first and foremost, in harvesting of mixed stands and in handling large-diameter trees. Development work on the crane is necessary primarily to enhance the machine's capacity to open up the strip road. This stage is more time consuming with the present boom type than it is when using the single-grip harvester. It is, indeed, probable that we shall, during the next few years, see new machine solutions based on the concept of a harvester-forwarder become commercially available.

The harvester-forwarder concept is at its best for logging entrepreneurs, who already have a chain including a single-grip harvester. When first thinning harvesting is carried out using a harvester-forwarder and the chain including a single-grip harvester concentrated on large-diameter final-felling operations, the total economics of the logging business will improve. The harvester-forwarder is the most profitable alternative in thinnings where the use of a chain including the single-grip harvester is less profitable. The profitability of a single-grip harvester chain will, however, improve once the small-diameter first thinnings are relegated to a harvester-forwarder.

Also for the entrepreneur concentrating solely on forest haulage, the harvester-forwarder provides the opportunity to expand and intensify operations without a major investment being required.

The harvester-forwarder entrepreneur involved in this study was very satisfied with the functioning of the machine and working with it. The harvester-forwarder method makes the machine operator's work more variable by including both stages of wood harvesting. The variability of the job increases job satisfaction, work motivation, and most probably also the productivity of the work.

In the light of the present study, it can be said that the harvester-forwarder producing delimbed timber is a functional and successful concept even though it was developed relatively quickly. The harvester-forwarder is an alternative worthy of attention in terms of its output and timber harvesting costs in first thinnings. With some additional development work its properties can be further improved.

References

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