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Harwarders in Final Felling

A summary of the studies carried out by Skogforsk in collaboration with the Harwarder Group 2014-2020

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The concept machine, the Komatsu X19, switching from harvester head to forwarder grapple prior to unloading. The photo was taken outside Hökhult in Småland. Photo: Rikard Jonsson, Skogforsk.

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Foreword

This report summarises the current state of knowledge regarding the use of harwarders in final felling. The studies were carried out in collaboration with the Harwarder Group in 2014-2020. The Harwarder Group was formed in the 1990s as a forum where users could discuss specifications for new machine concepts and share relevant experiences and study findings. The work on developing a new harwarder concept for final felling started in 2007.

I wish to extend thanks to previous and current members of the Harwarder Group for their engagement and the knowledge they shared in the work, and to the machine operators who contributed with their experiences, creativity, and patience while participating in the studies. Finally, I wish to extend thanks to all colleagues who contributed to specific parts of the studies summarised in the report, and who played a role as sounding boards. All the knowledge presented in the report is a result of everybody's dedicated and comprehensive work.

Rikard Jonsson

Uppsala, 22 April 2021

Sammanfattning

Tvåmaskinsystemet (TMS) har dominerat avverkningsarbetet i svenskt skogsbruk de senaste fyra decennierna. Det har gjorts flera försök med enmaskinsystemet drivaren, en maskin som integrerar avverknings- och lastningsarbetet, men den har inte slagit genom på större skala. 2014 invigdes konceptmaskinen Komatsu X19 som byggts utifrån erfarenheter från äldre drivare. Syftet med denna rapport var att sammanfatta kunskapsläget utifrån de senaste 7 årens utvärderings- och utvecklingsarbete direkt eller indirekt kopplat till konceptdrivaren Komatsu X19.

Bland de mest centrala studieresultaten återfinns:

1) Snabbfäste och specialiserade redskap i Komatsu X19:s kranspets jämfördes med kombinationsaggregat och ledde till 17 procent sänkta drivningskostnader.

2) Mätnoggrannhet avseende längd och diameter för drivaren vid upparbetning över en nästan full lastbärare i relation till upparbetning över mark jämfördes, inga betydande skillnader noterades. Även kapsprickor jämfördes med liknande upplägg, men inga skillnader kunde konstateras.

3) Drivningskostnader analyserades över stamvolym och terrängtransportavstånd för X19 och TMS. Resultaten visade att båda systemen påverkades påfallande likartat av både stamvolym och terrängtransportavstånd, dock uppvisade drivaren en något högre känslighet för terrängtransportavstånd än TMS. Inget av systemen kunde uppvisa en tydlig generell dominans. Beträffande drivmedelsförbrukning kunde ingen skillnad mellan systemen konstateras.

4) Inverkan av nominellt antal sortiment per lass och lassets sortimentsfördelning på prestationen analyserades. Resultaten visade att nominellt antal sortiment per lass är en för abstrakt faktor för att kunna prediktera drivarens prestation. Drivarens prestation ökar snabbt ju större andel av lassets totala volym som koncentreras på de två största sortimenten.

5) Två metoder för enkelsidig avverkning med drivare jämfördes, en redan etablerad och en ny. Resultaten visade 3–4 procent besparing av drivningskostnader, där kort terrängtransportavstånd ledde till större besparing.

6) En workshop arrangerades där deltagarna formulerade idéer till tekniska och metodmässiga förbättringar. Förslagen med potential att spara tid analyserades efter workshopen och effekten på drivningskostnader bedömdes. Drivningskostnaderna bedömdes sänkas med ca 6 procent.

7) Drivararbete är mer kognitivt krävande än dito för skördare eller skotare vilket signalerar ett behov av automation samtidigt som de tekniska förutsättningarna är bättre än för TMS. Manuellt styrd och delautomatiserad drivare jämfördes i maskinsimulator och automatiken sparade tid i vissa moment.

Kunskapsbilden från dessa studier är att drivaren påverkas likvärdigt av varierande stamvolym som TMS, och gynnas av kort terrängtransportavstånd och små trakter. Sortimentens inverkan på drivaren i relation till TMS är inte lika tydlig, men vår tolkning är att drivaren gynnas mer än TMS av låg sortimentskomplexitet, med i huvudsak ojämn volymfördelning. För att ytterligare bygga kunskapsbilden vore det intressant med studier i grov skog och med hög sortimentskomplexitet. För kortare tidsspann kan sannolikt metodutveckling och tekniska justeringar ha stor betydelse för drivarens

konkurrensförmåga gentemot TMS. För längre tidsspann kan sannolikt automationsutveckling ge stor utväxling.

Summary

The two-machine (harwarder-forwarder) system (TMS) has dominated logging in Swedish forestry in the past four decades. Trials have been carried out using a one-machine system, the harwarder, which integrates the felling and the loading work, but this has not made a breakthrough on any large scale. In 2014, the Komatsu X19 concept was launched, based on the experiences from older harwarders. The aim of this report is to summarise the state of knowledge after the past seven years' work on developing and evaluating harwarders, directly or indirectly linked to the Komatsu X19 concept.

The most significant investigations and results included:

1) The quick hitch and specialised equipment (harvester head and grapple) at the Komatsu X19's boom tip were compared with the combination head. Logging costs were found to be reduced by 17 percent when the specialised equipment was used.

2) Measurement accuracy (log length and diameter) for the harwarder when processing above a nearly full load space was compared with processing over ground. No significant differences were recorded. Bucking splits were compared for the same setups, but no differences were observed.

3) The effects of stem volume and forwarding distance on logging costs were analysed for the X19 and the TMS. The results showed that both systems were affected in a similar way by stem volume and forwarding distance, but the harwarder was rather more sensitive to forwarding distance than TMS. Neither system could show a clear general dominance. No difference could be observed between the systems in terms of fuel consumption.

4) The effects of a nominal number of assortments per load and the assortment distribution in the load were analysed. The results showed that the nominal number of assortments per load is too abstract a factor to be of practical use in predicting harwarder productivity. Harwarder productivity increases rapidly when a greater proportion of the load's total volume is concentrated in the two biggest assortments.

5) Two methods for one-sided felling with the harwarder were compared, one an established method and the other new. The results showed 3-4 percent reduction in logging costs, where short forwarding distance produced greater savings.

6) A workshop was arranged in which the participants formulated ideas for technical and method-related improvements. The proposals with potential for saving work time were analysed after the workshop, and the effect on logging costs was assessed. Logging costs could be reduced by approximately 6 percent.

7) Harwarder operation is more cognitively demanding than harvester or forwarder operation, which signals a need for automation, while the technical potential is greater for the harwarder than for the TMS. Manually controlled and part-automated harwarders were compared in a machine simulator, and the automation saved time in certain work processes.

The knowledge generated in these studies is that varying stem volumes have similar effects on the harwarder and the TMS, but short forwarding distance and small logging

sites favour the harwarder. The effect of assortment on the harwarder and TMS is not as clear, but our interpretation is that the harwarder is favoured more than TMS by low assortment complexity, with a largely uneven volume distribution. Studies in forests with large trees and with a high assortment complexity could increase knowledge about this. In the shorter term, method development and technical adjustments will probably improve the harwarder's competitiveness in relation to TMS. In the longer term, automation development would probably have greater impact.

Introduction

The two-machine (harwarder-forwarder) system (TMS) has dominated logging in Swedish forestry in the past four decades. Trials have been carried out with a one-machine system, the harwarder, which integrates the felling and the loading work, but this has not made a breakthrough in practical use. Older harwarders have shown logging cost advantages over TMS in situations with small average stem volume, short forwarding distances, small harvesting sites, and few assortments. Older harwarders have mainly been designed for thinning and small-stem final felling. When the most recent harwarders disappeared from the market, greatest potential for harwarders was seen in final felling and using specialised equipment in the boom tip with a quick hitch arrangement, instead of the combination head that had been tested up to that point. (Jonsson et al. 2016)

In 2014, the Komatsu X19 concept machine was built, based on experiences from older harwarders, with input from representatives of machine manufacturers, forest companies, a forest owner association, and Skogforsk. The X19 was initially equipped with a combination head, but this was replaced with a quick hitch system, thereby enabling work with specialised equipment (Jonsson et al. 2016). The X19 has been developed and evaluated over approximately seven years.

When new machine systems are introduced, it is important that they perform better than the established system in one or more economic, social, and environmental aspects. Key economic aspects include logging costs and wood value, social aspects include operator experiences, and environmental aspects concern fuel consumption and ground damage through rutting.

The aim of this report is to summarise the state of knowledge after the past seven years' work on developing and evaluating harwarders, directly or indirectly linked to the Komatsu X19 concept machine.

The Studies

Specialised equipment better than combination head

Jonsson et al. (2016) studied time consumption and costs for the Komatsu X19, fitted with a) the 330DUO combination head, and b) the quick hitch and specialised equipment (Komatsu 365 head and a 0.36 m^2 grapple). The time study was carried out on four felling

sites in Västerbotten, with one operator. The setup with the quick hitch and specialised equipment reduced time consumption by 20 percent and logging costs by 17 percent compared with the combination head.

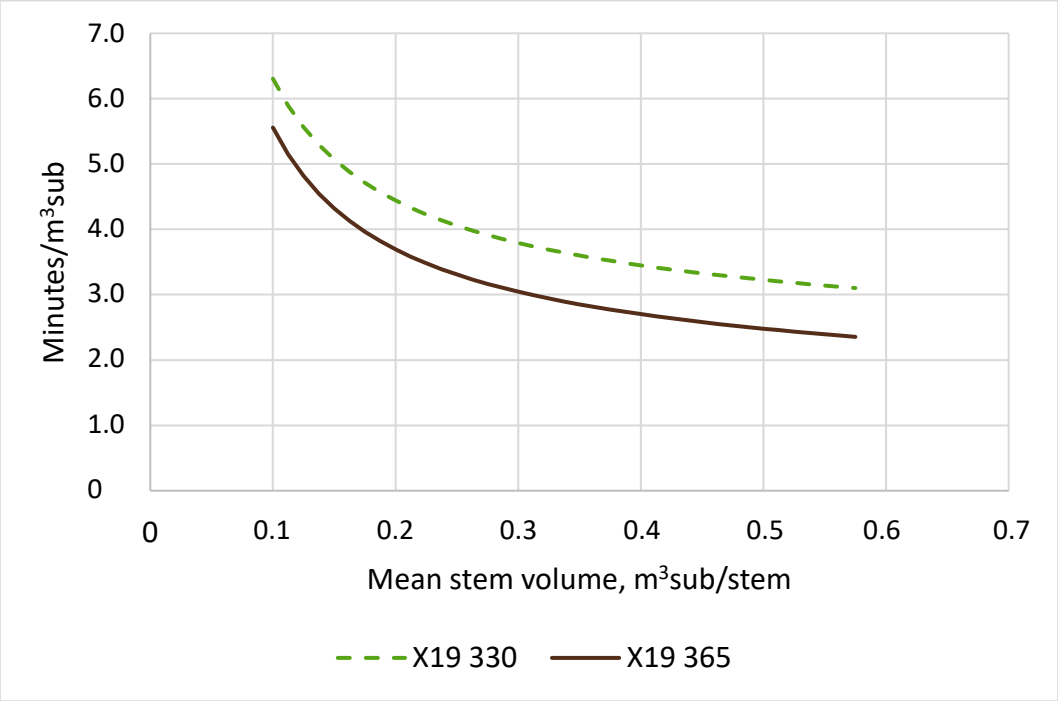

Figure 1. Harvesting productivity for the X19 with a combination head (X19 330) and with specialised equipment (X19 365). Figure taken from Jonsson et al. (2016).

Processing above load space and over ground gives equivalent wood value

Ågren et al. (2016) compared measurement accuracy (log length and diameter) for the harwarder when processing above a nearly full load bearer and when processing over ground, and found no significant differences.

They also examined the number of logs with bucking splits in the top half of the load bearer and in the bottom half, and bucking splits when the wood was processed over the ground. The study was carried out outside Sollefteå in Ångermanland. No noticeable difference could be established in bucking splits between the processing alternatives.

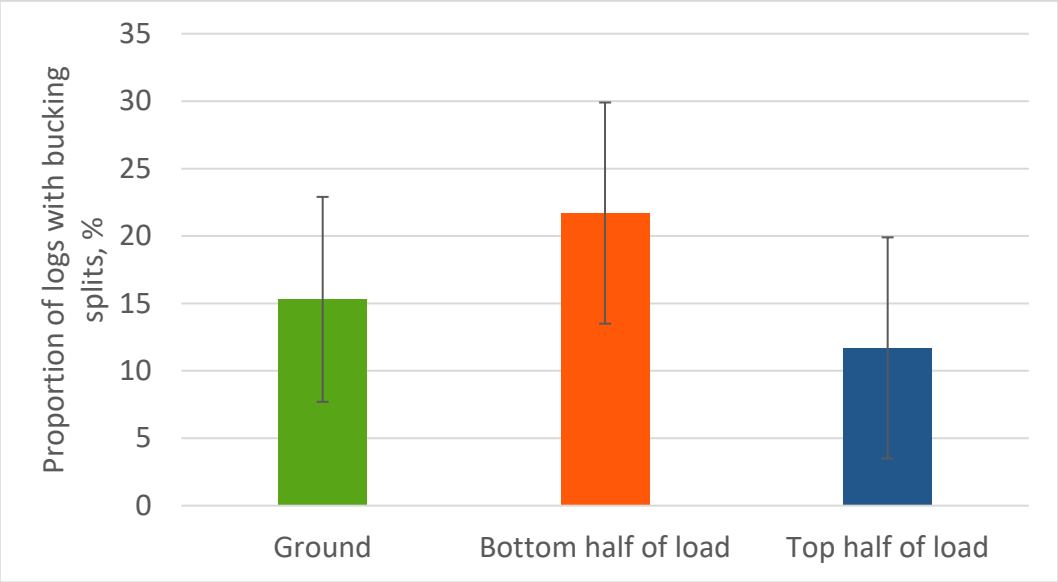

Figure 2. Proportion of logs with bucking splits in the bottom half of the load, in the top half of the load, and in processing over ground. The error bars indicate the 95-percent confidence interval. NB. No difference between treatments was statistically confirmed. Figure taken from Ågren et al. (2016).

Harwarder and two-machine system show equivalent logging costs

Manner et al. (2016) analysed the effects of stem volume and forwarding distance on logging costs for the X19 and the TMS. Both systems were affected in a similar way by stem volume and forwarding distance, but the harwarder was rather more sensitive to forwarding distance than the TMS. Consequently, existing knowledge that the harwarder is favoured over short forwarding distances could be confirmed, but the same did not apply to stem volume, as neither of the systems were favoured more than the other in the studied interval. Neither of the systems could show a clear general dominance.

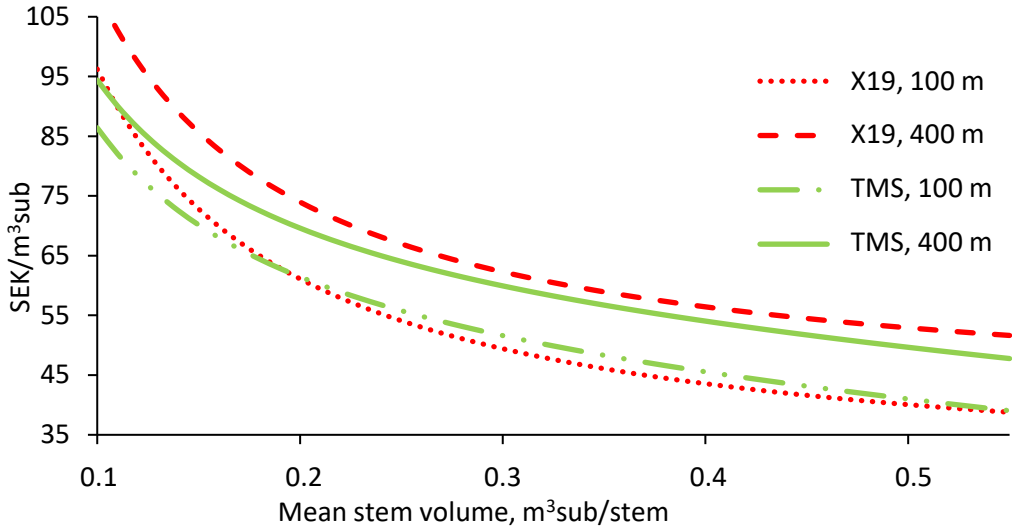

Figure 3. Logging cost of each system as a function of stem volume for forwarding distances of 100 and 400 metres. Figure taken from Manner et al. (2016).

No difference could be observed between the systems in terms of fuel consumption.

Volume distribution more significant than number of assortments

Manner et al. (2019b) examined how a nominal number of assortments per load and the assortment distribution in the load affect the harwarder's productivity. The results showed that the nominal number of assortments per load is too abstract a factor to be of practical use in predicting harwarder productivity, because the nominal number of assortments per load does not describe the load properties. Productivity is better predicted using the load's assortment distribution – either the proportion made up of the load's biggest assortment or the proportion made up of the load's two biggest assortments together. Harwarder productivity increases rapidly when a greater proportion of the load's total volume is concentrated in the two biggest assortments.

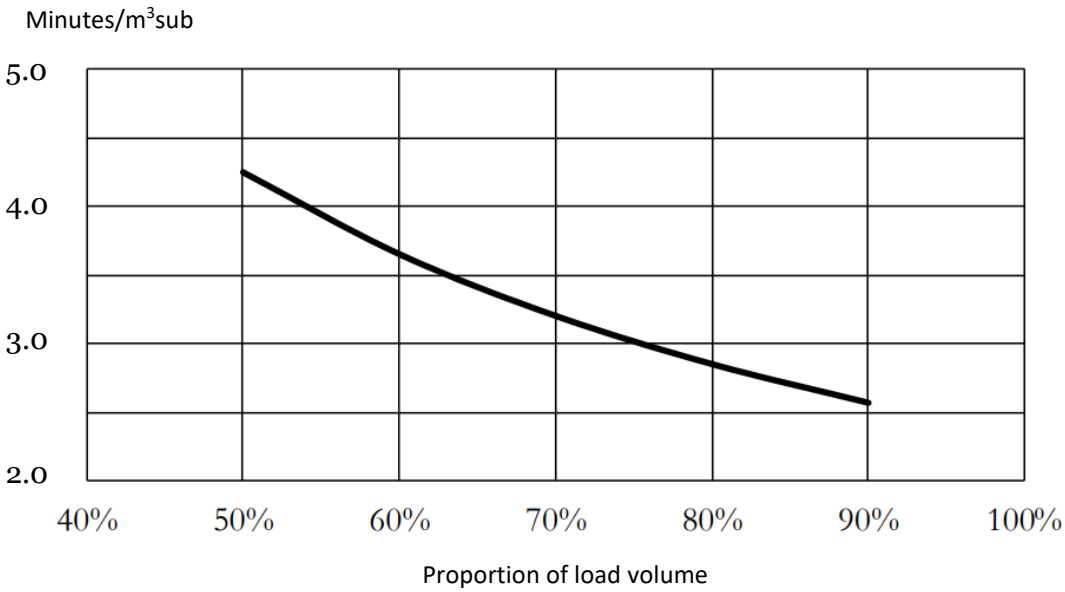

Figure4. Time consumption for the harwarder's terminal work (cutting and loading, and unloading) as a function of the proportion of the load volume comprising the two biggest assortments together. Figure taken from Manner et al. (2019b).

Felling from outside the stand edge more efficient than inside

Manner et al. (2020) compared two methods for one-sided felling with the harwarder. In the traditional method, the harwarder is driven inside the stand edge. The advantage of this is that more trees can be harvested per harvesting position. The broader cutting width makes the loading drive distance shorter, but driving the machine inside the stand edge has a negative effect on the crane work. In spatial terms, the trees must be felled less efficiently in relation to the load space, so the felled trees must be transported a longer distance to the load space before bucking can begin. In the alternative work method, the trees are felled from outside the stand edge, where the situation is the opposite. The narrower cutting width lengthens the loading drive distance. However, the crane work is made easier, because the trees are felled at an optimal distance to the load space; because of this, processing can begin soon after felling.

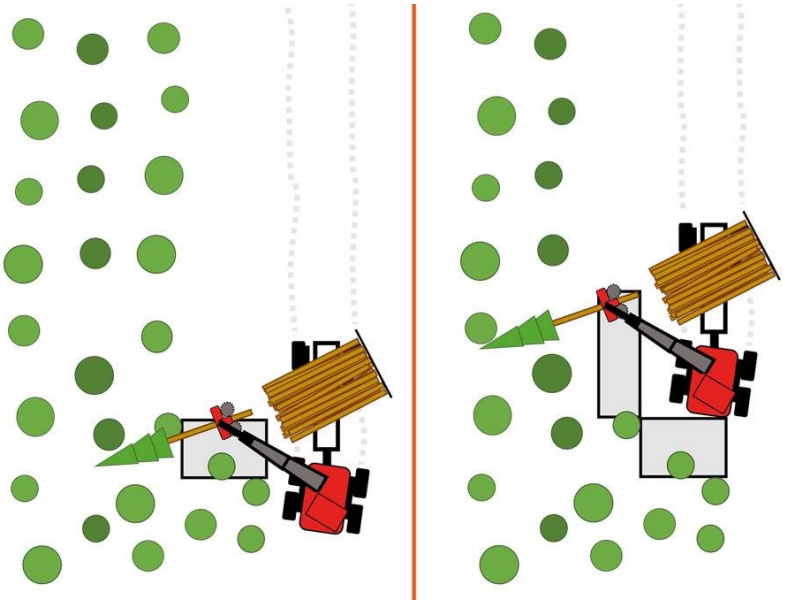

Figure 5. Driving outside the stand edge (left), which was the fastest method, and driving inside the stand edge (right). Figure taken from Manner et al. (2020).

The conclusion is basically a trade-off – simpler crane work against shorter loading drive distance. A comparative field study was carried out to determine which method is better. Two experienced operators drove the harwarder using both methods. The results showed that, when the machine was driven outside the stand edge, 8.9 percent G_0-time was saved in the felling-processing-loading work compared with driving inside the stand edge. When the entire logging work and costs were considered in the comparison, the results showed a 3-4 percent reduction in logging costs, where shorter forwarding distance gave a greater reduction in costs.

Immediate development potential of the harwarder

In 2019, Jonsson et al. (2020) arranged a workshop attended by operators who had driven the Komatsu X19, a forest administrative professional, and some researchers. The participants formulated ideas for technical and method-related improvements. The proposals with potential for saving time were analysed after the workshop, and the effect on logging costs was assessed.

The proposals that could reduce logging costs included the following technical changes: a new crane with flexible tilt pillar, assistance for driving between harvesting positions during felling-processing-loading, load space with automatic raising and lowering of separating stakes, break of harvester-head tilt when processing small stem dimensions, and faster break of the harvester head, making it easier to switch equipment at the harvesting site instead of at landings. A change in method was also identified, in that direct loading at the harvesting site would enable new driving patterns. The technical and methodological developments proposed were together estimated to lead to a time saving of 9.4 percent. The proposed improvements would entail an increase in total investment costs of SEK 0.6 million. Logging costs would be reduced by approximately 6.0 percent.

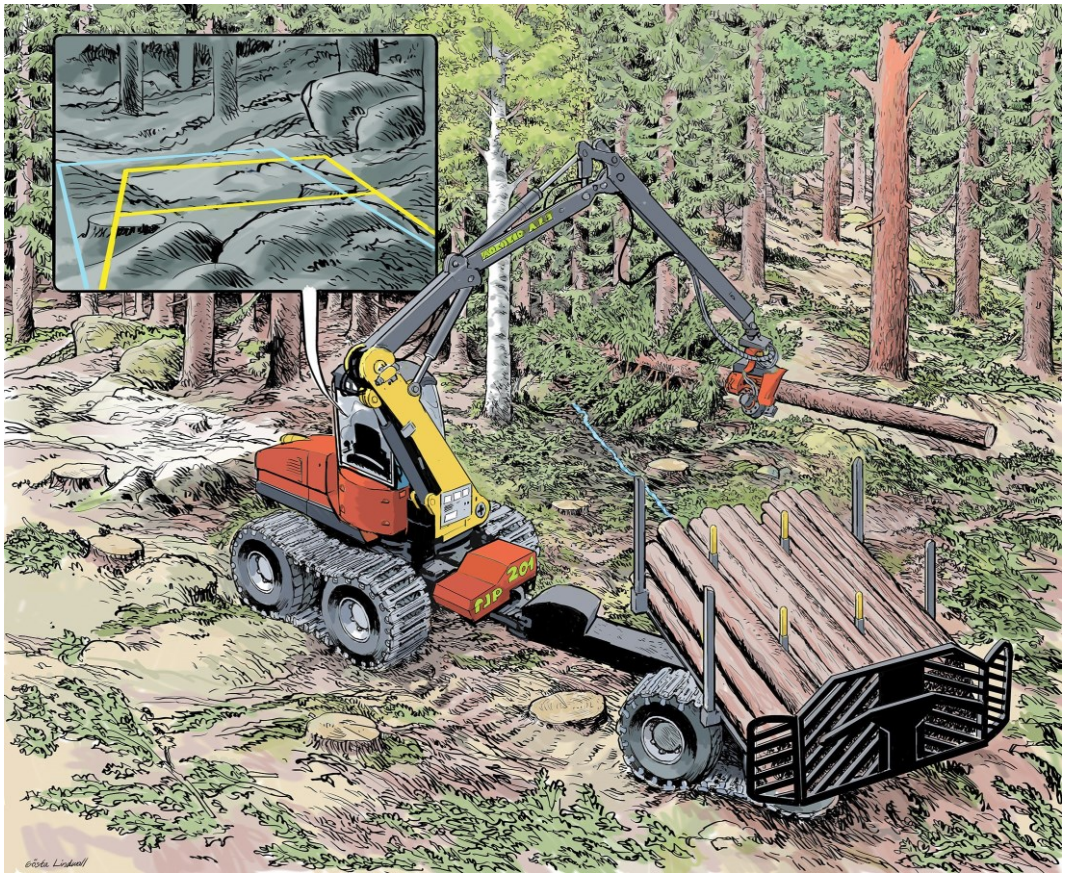

Figure 6. Illustration of final-felling harwarder during felling-processing-loading work. Proposed technical changes are highlighted in yellow. Illustrator: Gösta Lindwall.

Automation potential of the harwarder

A harwarder operator must be able to control more work elements simultaneously than a harvester operator. Through automation, the operator would need to control fewer machine functions in parallel, and could thereby possibly complete remaining tasks faster.

As with the need for automation, the technical potential for automation is greater for the harwarder than for today's harvester-forwarder system. The harvester places cut logs on the ground, which means that the forwarder must pick up the logs again. If a forwarder is robotised, picking up the logs is a difficult and complex task. The logs must be identified spatially before they can be picked up. The harwarder avoids this problem, because it cuts the logs directly above the load space. This gives the harwarder unique possibilities for automation.

Manner et al. (2019a) compared a manually controlled with a part-automated harwarder in a machine simulator. The aim was to analyse whether harwarder productivity could be increased by automating certain work elements. The results showed there was no general difference in productivity between a manually controlled harwarder and one equipped with automatic functions. However, statistically significant differences were found when the impact of the automation was analysed by individual work element. During automated operation, the time taken during the work element felling of the tree increased. In contrast, time was saved by automation when felled stems were collected

and the load space rotated. However, the measured time differences were relatively small, and also varied somewhat between the two operators who took part in the study. More significant time savings would require considerable development work, such as operator-specific machine settings.

Figure 7. Ongoing harvester work in a virtual forest. As an extra operator support, the recommended felling area is marked with a red frame on the ground. This support was available all the time, regardless of whether or not automatic sequences were used. Figure taken from Manner et al. (2019a).

Discussion

This report is a summary of the studies carried out by Skogforsk in collaboration with the Harwarder Group in the period 2014-2020. The studies were mainly focused on evaluating the harwarder in relation to the TMS, or on developing the harwarder as a machine system. Productivity using the harwarder is similar to that of the TMS, and no clear difference could be observed in terms of logging costs or wood value. The earlier state of knowledge was that the harwarder would be favoured in relation to the TMS by:

1) Small stem volume – this could not be confirmed, as the systems showed equivalent results for different stem volumes.

2) Short forwarding distance – this was confirmed, because the harwarder as a transport machine is more expensive than the forwarder.

3) Small sites – this was confirmed. The fact remains that relocation costs for one machine instead of two have even greater impact on small sites, where the relocation cost comprises a greater proportion of the total cost.

4) Few assortments – this was not confirmed, as the number of assortments as a factor is a poor predictor of time consumption, while the volume distribution of assortments per load is a better predictor. The state of knowledge here can be simplified. Both harwarder and TMS are favoured by low assortment complexity (uneven volume distribution between assortments, few assortments, uneven spatial distribution on the harvest site), but the harwarder is favoured more.

Development of the harwarder showed potential to reduce logging costs. The development potential can be divided into method and technology. The method adjustment in the felling-processing-loading work led to a clear reduction in logging costs, and our impression is that method development is an important area in the harwarder's potential that can further reduce the costs. In the studies and in the trials carried out by the forest companies and the forest owner association, a total of eight operators participated and contributed with their experiences and creativity to ensure that the harwarder could work as efficiently as possible. More potential could be realised if more harwarders were available and thereby more operators who could contribute to the development. This potential is assessed to be available in the near future.

Technological adjustments, which were a key discussion topic in the workshop on the development potential of the harwarder, showed clear potential to reduce logging costs in the near future. Together with method development, technological improvements could be an important contribution. Looking further ahead, automation of harwarder use could reduce logging costs considerably – assuming that sufficient development resources are allocated.

Over these years, several studies have been carried out, generating new knowledge, but more can be done. The conditions under which the harwarder shows greatest potential, mainly short forwarding distances and small harvesting sites, are found in many areas in southern Sweden. The time and cost analyses concerned relatively small stem volumes and average to low assortment complexity, so future studies of harwarders and the TMS in large-stem forest with high assortment complexity would be interesting. A handful of operators participated in the studies, generally with a great interest in development and with a high level of productivity. It would be interesting to study more 'everyday' operators in future studies, to better capture the breadth in the machine operator population.

Different variants of harwarders have been tested over the years, and because of earlier unsuccessful introductions to the market, views differ regarding their potential in the sector. If the harwarder is to take a significant proportion of the market, a large-scale system analysis is needed that can quantify the potential on the basis of current knowledge. Broad communication activities are also needed to ensure that old knowledge patterns are replaced by new, and more development resources are also needed. As the harwarder's work patterns are relatively fixed compared with the TMS, and the work can be based on information about where the logs are situated on the load carrier – in contrast to the harvesting site as is the case with the TMS – the harwarder's potential for automation is assessed to be greater than for TMS. In the shorter term, method development and technical adjustments can probably have greater significance, while in the longer term, development of automation can probably be beneficial.

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