

HUMAN-MACHINE INTERACTION IMPROVEMENTS OF FOREST MACHINES

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In times when forest operations have been fully mechanized, we are entering a new era where it is crucial for people and technology to work as a harmonic unit. The higher work tempo of today combined with the many qualified decisions that the operators must make, contribute to a greater mental and physical load. Skogforsk has conducted comparative studies in a forest machine simulator and in field regarding fidelity, automation and human-machine interaction. The studies clearly demonstrate that automation of forestry machines and measures of HMI are feasible ways to increase productivity and to improve the working conditions of operators.

Keywords: Automation, boom-tip control, head-up display, human-machine interaction, mental workload

1 Introduction

A new era in forestry has been entered where it is crucial for people and technology to interact. That is to continuously increase productivity but also to improve the working conditions of the machine operator. Work to reduce the physical stress to which operators are subjected has been done successfully over the years. However, little research has focused on the cognitive aspects of the work. Skogforsk has done studies in various fields to direct the development of forest machines into efficient and human-adjusted solutions.

2 The development of forestry

In all time people in Sweden have used the resources of the forest for building material and fuel, just about for the same purposes as today. But during the last 60 years the evolution of the mechanization system has exploded. This has led to a great increase in felling and now the forest industry is one of the prime export industries in Sweden. The development started in the 1950s with the introduction of the chain-saw. Until that time, the horse had been used for extraction work but then it was largely replaced by small crawler tractors. A decade later, heavier machines were introduced. In the 1970s the forerunner to the harvester was introduced – the processor – which was followed by the feller-buncher. Soon the big boom in mechanization of final felling was a fact, and many loggers thought that the evolutionary era of machine progresses had come to an end. But parts changed places and the first two-grip harvester entered the forest. Together with the forwarder they became an efficient combination in final felling operations. For thinning, however, the two-grip harvester was too big. The breakthrough came in the early 1980s when the single-grip harvester was developed. Today the dominant system in both thinning and final felling is a single-grip harvester together with a forwarder. But the evolution of forest machines is still taking steps forward. The 'Beast' is an unmanned harvester that is controlled remotely from the forwarder. The 'Harwarder' is a combination between a harvester and a forwarder and has the advantage of being equipped with an integrated grip and felling unit, allowing processing of the wood directly onto the load unit without putting any wood on the ground. At the end of the 1970s, many of the large forest companies turned into making

use of independent entrepreneurs for logging instead of having their own machinery and employees. In the middle of the 1980s, 32 % of the forest machines were owned by entrepreneurs and in the beginning of the 1990s this proportion had reached 70 % (Lindén, 1994, cited by Hultåker et al., 2003). Since that era, this tendency has continued in the same direction.

In conjunction with the mechanization of the forestry, the forest machines have also been equipped with increasingly advanced information technology. The operation of the machine has become digital. Data about the tree are continuously compared automatically with the wanted lengths and volumes. Mobil communication between operators is widely spread. The computerization of the forestry opens a broad spectrum of possibilities. Within logistics, for example, it is of great interest to be able to match the wood supplies in the forest with the demands of the sawmills to cut transport costs.

2.1 Effects of the development

The technical evolution in forestry has in many ways facilitated the work for the human being. The amount of heavy and strenuous work tasks has decreased considerably. But at pace with the transfer of the operator from ground into cabin, other types of problems have become visible. Especially ache in the neck and shoulders are common. A tree takes less than 1 minute to process and during that time the operator uses in average 24 functions and makes 12 decisions. That can be compared to the work conditions of a fighter pilot with the difference that a forest machine operator works up to 10 hours a day. Along with the technical evolution, more tasks have been put on the shoulders of the operators. Besides being a skilled machine operator and mechanic, the operators are nowadays to some extent also expected to act as trained computer users. The contractor needs to be all that, plus a manager of his company. Altogether, the working conditions put operators under high pressure, both physical and mental.

Compared to the size of the productivity-increasing steps that were taken in the beginning of the mechanization, the steps of today are relatively small. Yet further increases are demanded. Since the 1980s, considerable ergonomic improvements in forest machines have been made. There are, however, strain injuries whose cause do not lay within badly suited steering levers but in the information environment. It is therefore essential to focus more on the cognitive demands and the interaction between humans and the machines.

3 Objectives

One of Skogforsk's missions is to help Swedish forestry to increase the productivity and improve the mental work environment in the forest machines. This paper is to give a summary of the projects that Skogforsk has conducted to contribute to this objective.

4 Human machine interaction improvements of forest machines

To find further possibilities to increase the productivity and at the same time improve the working conditions of the machine operators, Skogforsk has conducted various studies within the field of human-machine interaction. These studies are presented below together with the most recent research project.

4.1 Fidelity

All the following studies have to some extent been conducted in the Skogforsk forest machine simulator. In such studies it is of great importance to be able to apply the results

to the real world. Therefore Löfgren (2007) did an initial study to compare the results from the simulator to those from the field. An experienced operator of a harvester got to fell a real forest stand. The work was measured by time, functions used on the harvester and all the trees were marked by their coordinates. Based on these data the stand could be reconstructed in the simulator, and after some simulator training the same operator got to fell the same trees virtually. The differences in performance between the real world and the simulator were small, $\pm 4\%$. This result shows that results from coming tests in the simulator are possible to transfer to the real world.

4.2 *Automation*

A reason to why logging-machine operators are put under such great pressure, both mentally and physically, is that they have to deal with large pieces of information at the same time as they have to operate the machine. This includes making crucial decisions regarding for example the quality of the tree and the position of the machine. Automation of machine operations could be one possibility to increase the important micro pauses, pauses longer than 3 s, that give exposed muscles time to recover (Eriksson, 1995) and also extend the time for quality rising decisions. In other words, automation could be a way out to reduce that pressure.

4.2.1 *Automation of a single grip harvester*

In the study by Brander and Eriksson (2004) the objective was to evaluate which of the functions in the boom operation that could be beneficial to automate, but also how the work with the automated functions affected the subjective experience of the mental and physical load.

Through an analysis of the work pattern of an experienced operator together with how different functions were connected to decisions taken, a number of work elements were found to be suitable for automation. Five automated functions were implemented in the forest machine simulator and tested by four students at a vocational school for natural resource use. The students had previous knowledge from operating a forwarder but not a harvester. Each student got to carry out various tasks, partly with the conventional boom control, partly with the automated functions activated. The operational maneuvers were recorded and the subjective estimation of the workload was registered through a NASA-TLX form (Human System Integration Information Analysis Center, 2006). The result showed that the use of the joystick functions decreased with about 60 % in the semi-automated control compared with the conventional control and also the total work time was reduced with almost 30%. The subjective estimation showed over all positive results for the automated functions, in other words, the workload was believed to be lower.

In a subsequent study by Brander and Nordén (2004) a very skilled operator carried out the same test as the students and the results were compared. It turned out that the semi-automated functions contributed to decrease the productivity gap between the inexperienced students and the skilled operator. With the conventional control the students needed 74% more time than the experienced operator to perform the same task, with the automated system the corresponding number was 21%.

The study by Eriksson and Oscarsson (2005) pointed at additional advantages of automation. Through a cognitive task analysis problem areas for workload were mapped. One of these was a sorting function. Two automatic sorting function concepts were

developed and implemented in the simulator. The concepts were then evaluated by an experienced machine operator concerning productivity (time consumption), subjective estimation (NASA-TLX form) and the use of instruments (maneuver registration). The use of levers was lower for the automated concepts than the conventional system. This increased the number of micro pauses in the work. On the other hand, the total amount of time for felling had increased for the concepts and the workload was estimated a bit worse compared to the conventional system.

4.2.2 Automation of a forwarder (Boom-tip control)

An important part of the work with the forwarder is operating the boom. To manage the physical and mental workload that comes with the intense work, semi-automated functions have been seen as a solution. In the study by Egermark (2005) the boom-tip control effects on the learning process are evaluated, both regarding speed, precision and subjective workload. Boom-tip control means that each movement of the tip of the knuckle boom is generated by one single movement of a joystick or button, so that it avoids all simultaneous commands that obstruct the muscles to rest. It also means that all movements are corresponding to each other so a downward movement with the joystick generates a downward movement of the tip. Vocational school students for natural resource use without previous experience of forest machines took part in the test that was carried out in the Skogforsk forest machine simulator. The students had to move the boom to five different places around the forwarder as fast as possible without hitting obstacles or the forwarder itself. If they hit something, extra time was added to the final result. Half of the students carried out the test with conventional boom control, and half with the boom-tip control. Each group was practicing in total 14 hours divided on 7 occasions during a two month period. The result showed that the boom-tip control group performed better both regarding speed and precision than the reference group and they also estimated the workload as lower. But the most interesting result was in the learning curve where the boom-tip control group showed greater improvements over time while the reference group stayed almost on the same level.

4.3 Human-machine interaction

During felling, the harvester operator gets a large amount of information input from the surrounding environments, both outside and inside the machine. The main source of this visual information is the head-down display with bucking information, placed in the lower parts of the cabin windshield, and the boom-tip that is operating several meter outside the cabin. This means that there is a continuous competition between the two information sources and to change focus the operator has to reposition his or her head and accommodate the gaze. This is a cause to tensions in the neck and shoulder musculature and also a source to mental workload.

Lundin et al. (2005) made a study on how to improve the way visual information is displayed to the operator and also to suggest alternative interface concepts. The pilot study showed that the current interface contained too much alphanumeric information and that the position of the display was too low. Three concepts for head-up displays were designed, this means that the information is projected directly on the windshield and gives the illusion of floating in the air next to the boom-tip. The benefit of the head-up display is that the operator does not have to refocus and that the head-down display becomes available for less critical information as machine data. One concept was designed similar to the current interface, while the two others used more symbols. The concepts were

evaluated subjectively in the Skogforsk forest machine simulator by an experienced harvester operator. All the three head-up display concepts were more appreciated than the conventional head-down display, especially the two where alphanumerical information had been exchanged to symbols.

Based on Lundin et al. (2005) further interface concepts for head-up displays were developed and evaluated in two subsequent studies by Järrendal and Tinggård Dillekås (2006 and 2007). In the latter, tests were carried out both in the simulator and in field. Focus was on whether or not the workload could be reduced by the usage of a head-up display, but also refinement of interface concepts from the study by Järrendal and Tinggård Dillekås (2006). The workload was measured through a NASA-TLX test. It turned out that the bucking time was reduced for the head-up display concepts both in the simulator test and the field test, compared to the head-down display alternative. Regarding the estimated workload, this was lower in the simulator test for the head-up display concepts and unchanged in the field test.

The most recent study by Skogforsk (Norén et al., 2007) is with regard to bucking information interfaces. In this study, four interfaces of different brands were evaluated considering visual ergonomic principles. How the operators were interacting and using the bucking information was examined during a field study. Guidelines about how bucking information should be presented were formed together with a compilation of what the operators thought were the most relevant information during bucking. Finally, two concept interfaces were created to exemplify the guidelines.

4.4 *Mental workload assessment*

Forest machine constructors today do not have knowledge or experience about human-machine interaction to meet the complex demands of the forest machine environment. In addition, it is lacking basic studies about what information a forest machine operator needs and how the information is received today. Most of the research that has been done on the work environment in forest machines has focused on physical workload. Few studies have been carried out with regard to cognitive aspects of forest machine operators' work environment. Previous studies by Skogforsk on workload have been conducted with a NASA-TLX test where six classes are estimated and weighted by the subject. One of the classes is *mental demands*. To get a greater and more holistic perspective on mental workload Skogforsk has in the spring 2007 started a project to develop a 'tool-box' with methods to verify and validate various system solutions, not only from subjective estimations of mental workload but from methods conditioned by physical and performing measurements. The project comprises studies in the Skogforsk forest machine simulator as well as in field. The project also contains a mapping and evaluation of forest machine operators' information needs and how they obtain information. Together, this can be expected to give an incentive for bringing the development of the new generation of forest machines forward – adjusted to both the demands of the industry and those of humankind.

5 Discussion

The various studies by Skogforsk demonstrate that automation of forest machines is a feasible way to increase productivity and improve the working conditions of the machine operators. Automation should be directed to knuckle boom operations as well as processing functions. Today it is very costly to recruit new operators since they work less efficient than the experienced ones. Therefore it is of great interest to shorten the learning

period. Boom-tip control could be one possible solution since the major advantage over conventional boom steering is that it is faster to learn. Another aspect is that the future forest machine operators will be recruited from a generation that has grown up with TV- and computer games and will be familiar with that sort of navigation and controls. Moreover, actions within human-machine interaction have shown to ameliorate cognitive input and reduce mental and physical workload. This include new ways to present information such as through interface design that is rooted in usability guidelines and visual ergonomic principles, but also through new mediums like head-up displays.

In a continuously expanding industry it is not realistic to put all efforts on one side of the coin if the objective is to carry on in the same direction. With a tool that can describe technology from the perspective of mankind, the development of forest machines will reach a new level, generating more comprehensive improvements.

6 Conclusion

Human-machine interaction is a fairly new area within forestry. As can be seen from the studies described, there are potentials for enhancement in quite a few fields. It is therefore of importance to continue to accomplish further research within the area of human-machine interaction.

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