ARBETSRAPPORT

FRÅN SKOGFORSK NR 728 2010

Human factors in forest harvester operation

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Keywords: Human Factors, HMI, Mechanized forestry, work environment, Repetitive Stress Injury, Harvester operator.

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ISSN 1404-305X

Abstract

In forestry, as in many other industries, technical solutions have been the mean to enhance productivity as well as safety. This has proved to be successful in forestry, both in terms of productivity and safety. Technological development nevertheless introduce a change in the nature of work (Hollnagel & Woods, 2005) and the main limiting factor of productivity in forest harvesters is by now, according to Gellerstedt (1993a), no longer the workers physical abilities but their cognitive abilities. The work has changed "from doing to thinking" (Hollnagel & Woods 2005, p. 37).

One still cannot exclude the physical properties entirely. The main problem regarding physical ergonomics in mechanised forestry work, as seen today, are neck and shoulder pains. This is a product of a complex set of different interacting variables where vibration, mental- and physical work load probably are the most important ones. The solution to the problem is therefore multifaceted and requires a holistic view on the problem.

This paper presents a state of the art description of Human Factors, with emphasis on cognitive and physical ergonomics research in mechanised forest work in the Nordic countries, Sweden primarily. The research is also discussed in relation to theories and experiences from other domains considered complex. Existing literature on mechanised forest work seldom takes a holistic view and the research on cognitive ergonomics is almost absent. This research area is proposed for further research and the review provide some possible research questions to continue on with.

2010-10-22

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Contents

Introduction to Human Factors in forestry

The development in forest work has mainly focused on technical solutions to enhance productivity and safety. It has been noted by Högvall-Nordin (Högvall-Nordin, 2006) that the operator is almost described as a subordinate character when different media are describing forest machine work. But as Pürfurst & Erler (2006) acknowledge, the operator is a decisive factor for the system's performance. Especially the impact of operators' mental capacities on performance has been somewhat un-noted during development of these machines; hence we have a big potential in improving the harvesting system. Today, humans cannot reach machine capacity when it comes to work pace, productivity etc. This put a lot of stress on the operators and is thus connected to an unhealthy work environment.

Manual felling was dominating in the 70th, but when the single grip harvester was introduced to the market it rapidly gained interest and became the primary machine (together with the forwarder) in thinnings in the 90th (Andersson, 2004). This was also a period when many changes to improve the physical ergonomics in the machines was made and new logging systems introduced (Andersson, 2004; M. Thor, pers. commun., 16 Jan 2010). During this period both productivity and safety increased rapidly and the technological development was, according to Andersson (2004), necessary to keep the business acceptably profitable though declining raw material prices. Another example of the success with technological improvements is Axelssons (1998) comparison of logging operators health in 1970 with 1990 which showed a 70% reduction of accidents/million man-hours.

But, according to Backström & Åberg (1998) the accidents in machine work per 1 000 employee did not decrease during 1985–1990, as did the motor manual work. This shows that mechanization is no longer enough to provide a safer work environment for the individual. There are both issues regarding safety and health that are not dealt with when only focusing on technical problems and solutions, as well as productivity potential that remains unutilized. A problem that arises with technological development is that the nature of work is changing (Hollnagel & Woods, 2005); by now the physical properties of the worker are no longer the main limiting factor of productivity, but the cognitive abilities (Gellerstedt, 1993a) .

What is still to work with is the human factor and to adapt the work environment to the worker, and not the other way around as quite colourful argued by Sundberg:

"Adapt ourselves, you said? No. It would be at time someone adapted to us. And by the way: if you adapt yourselves you will see the prize there will be to pay." (Sundberg, 1985, p. 8 , own translation)

Fortunately there is a lot to win by looking at the human factors. Big differences in productivity between operators (Gellerstedt, 1993a; Ovaskainen, Uusitalo & Vaatainen, 2004) as well as high rates of health problems (Axelsson & Pontén, 1990) indicate problem, and thus opportunities, in this area of research.

During the late 90:s and 00:s, there has been a growing interest in developing the interaction and ergonomics of the human-machine system. Reasons for that are 1) productivity, or 2) which is more frequently mentioned in literature: physical well-being and safety (Attebrant, Mathiassen, & Winkel, 1998; Eklund & Cederqvist, 1998). Often only one of the reasons functions as the actuating force, but both are important for a successful outcome. What furthermore has attracted a lot more attention recently is how to cost justify investments in Human Factors (Bohlin & Hultåker, 2008).

When aiming at improving ergonomics in forest work one could stress either physiological-, organisational- or psychological improvement potentials, where the latter two has received much less attention. As previously stated almost all work has changed from doing to thinking and this put more emphasis on cognitive properties than needed before. It has although to be acknowledged that physiological, organisational and cognitive factors are depending upon each other, and influence the work situation interdependently.

AIM OF THE PAPER

In this paper a state of the art description of Human Factors, with emphasis on cognitive and physical ergonomics research in mechanised forestry work, will be done. The Nordic countries and Sweden primarily will be at focus. The research and development (or lack of) will then be discussed in relation to theories mainly from applied human factors research in aviation or other domains considered complex.

Research could be divided into two areas of interest, namely how the demands (workload) affect 1) the human and 2) the performance. You must understand the former to be able to correct the outcome of the latter and thus this paper will more or less address both of these questions.

TERMINOLOGY IN HUMAN FACTORS

In Human Factors studies the terminology is often unclear, and the research and definition of many of the underlying domains, or research fields, overlap. Beith (1999) mention *Ergonomics*, *Human Engineering*, *Human Factors Engineering*, *Usability Engineering*, and *User-centered Design* as synonymous terms to *Human Factors,* but more could be added. Because of all this confusion there is a need of defining your research field, and to start with I will introduce a definition of Human Factors Engineering by Beith (1999):

Human factors engineering is an applied science that takes research about human abilities, limitations, behaviors, and processes and uses this knowledge as a basis for the design of tools, products, and systems. Applying human factors principles leads to designs that are safer, more acceptable, more comfortable, and more effective for accomplishing their given tasks.

The above quote represents the findings from Licht, Polzella & Boff (1989) who's definitions of human factors engineering put emphasis on design as the medium to influence changes in the human-machine system whereas the field of Human Factors often uses a broader definition:

Human factors involves understanding of all aspects of the way humans relate to the world around them, with the aim of enhancing operational performance, safety, through life costs and/or adoption through improvement in the experience of the end user, i.e. all issues related to the operator and the environment in which they operate. (Rodrigues & Coogan, 2008, p. 1)

In *Ergonomics* the emphasis is stronger on humans at work than is in definitions of *Human Factors* or *Human Factors Engineering*, but as you saw in the quote by Rodrigues & Coogan, 2008. *Human Factors* often emphasize work as well.

Another closely related term worth mentioning is Human-Machine Interaction[1]. In the view of this paper Human Factors (Ergonomics or Human Factors Engineering) is a systematic approach to study problems arising in Human-Machine Interaction. The Human-Machine System is furthermore the target system serving as a candidate for change/redesign. Further on in this paper the terminology of Human Factors will be used to include all ergonomics (and hence Human Factors Engineering), and following the International Ergonomics Association (IEA) I will sometimes specify different research areas within this field as physical ergonomics or cognitive ergonomics. The field of organisational ergonomics will be touch upon in the terms of organisational factors which could contribute in solving a problem.

Physical Ergonomics

The main problem regarding physical ergonomics in mechanised forestry work, as seen today, are neck and shoulder pains. A quote from Gellerstedt (2002, p. 35): *"Work features found to limit an operator's efficiency were: few breaks in the work; very intensive handling of controls (4000 control inputs per hour in our study) (…); restricted view from the cab; lack of information about the stand and log; and skewed and twisted work postures."* indicate that many different aspects of work contribute to this problem; vibration, lighting, working posture as well as organisational aspects and aspects of cognitive ergonomics (which will be presented in next section). The solution to the problem is therefore multifaceted and needs work on all these levels.

HEALTH PROBLEMS IN FOREST MACHINE OPERATION

According to Eklund & Cederqvist (1998) forest machine operators exhibit high frequencies of physical strains. Most common complaints are musculoskeletal disorders, psychosomatic complaints and hearing impairments, although the latter two might be a minor problem according to Vik & Veiersted (2005). The major problems are more specific associated with repetitive stress injuries (RSI) in the; lower back, neck and shoulder and/or forearm and wrist (Eklund & Cederqvist, 1998). During the late 80-th about 50% of the machine operators experienced RSI, mainly characterized by neck and shoulder complaints (Axelsson & Pontén, 1990). Those in this study who had more than ten years of experience in mechanised forestry had the highest prevalence (50–60%) of RSI. The lowest value of reported RSI complaints (27%) in the same study was amongst operators in the age of 35–44 years and had 1–4 years of experience. Vik (2005) found that 16,2% resp. 15,5% of the operators have had symptoms in neck respectively shoulder often or very often.

[1] Although widely used I have not found any definition of Human-Machine Interaction (HMI) in my research on this topic, but T. Alm (2007) has a view of HMI similar of mine.

Important when evaluating risk factors regarding ergonomics are the pattern of strain (intensity), duration and frequency. The higher the intensity of the strain, the longer the duration and the higher the frequency the higher the risks are (Attebrant, et al., 1998; Conway, Szalma, Saxton, Ross, & Hancock, 2006). This is true regarding physical work as well as vibration, noise and chemical exposure, although Attebrant, et al. (1998) reports low intensity as a high risk factor too. In other publications (Conway, et al., 2006; Westgaard, 1988) low intensity is not considered a risk per se, but in combination with the extremes of the other factors (duration and variability).

Characteristics of risk factors in forestry machine work are, according to Attebrant, et al. (1998): 1) low intensity of (physical) strains and stresses, 2) long duration of work and 3) small possibilities to vary the work. This is consistent with the research of others (Attebrant, et al., 1998; Gellerstedt, 1993a; Nåbo, 1990), although Eklund & Cederqvist (1998) consider the physical strain to be high. This was also the fact during 1970th, but research in physical ergonomics during 1970-1980 mainly focused on reducing the (intensity of the) strain in the trapezius muscle (neck and shoulder musculature) and successfully reduced the strain from about 16% of maximal activity till about 4% (Attebrant, et al., 1998). According to Attebrant et al. (1998) the (probably) lowest possible limit of the strain would be about 2–4% of maximal activity.

Later research also focus on the trapezius muscle, but not so much in reducing the maximal activity as on the possibilities of pauses and micro pauses, i.e. reduce the duration and/or enhance variability of work (etc. Eklund & Cederqvist, 1998). Gellerstedt (1993a) has shown that operators with problem in the trapezius muscle had fewer and shorter (micro) pauses during work. This is seen as the major cause to problems in neck and shoulders. The research on trapezius muscle activity and pains indicate that long periods of work with sustained low-level muscle activity, i.e. without pauses, is correlated with pains (Østensvik, Veiersted, & Nilsen, 2009). But the research is inconclusive, sometimes contradictive, and there is yet no way to determine limits in muscle activity in order to prevent future muscle pain symptoms (Delisle, Lariviere, Plamondon, & Salazar, 2009; Jensen, Nilsen, Hansen, & Westgaard, 1993; Veiersted, Westgaard, & Andersen, 1990; Voerman, Vollenbroek-Hutten, & Hermens, 2007; Østensvik, et al., 2009). High demand on precision and concentration along with psychosocial factors are also contributors who must be considered regarding trapezius pains (Eklund & Cederqvist, 1998).

Organisational ergonomics, i.e., changes in work practice and work management do also play a large part in today's research on reducing the duration of exposure to stress in the trapezius muscle. Many consider organisational changes to be the most promising way to move forward and decrease the injuries and strains (etc. Axelsson, 1998; Axelsson & Pontén, 1990; Bohlin & Hultåker, 2007; Lewark, 2005b). This is also the view of Lewark & Kastenholz (2007) who believes that the main problem of today isn´t lack of knowledge about the problems, but putting existing knowledge into practice.

Knowledge about interplay between contributing factors to pains in the lower back were lacking in 1998, but according to Eklund & Cederqvist (1998) work in a sitting posture, repetitive tasks, vibration, psychosocial factors, smoking, age, muscle strength, physical fitness and former problems in the back are risk factors. Additional causes of the problem are awkward working postures (mainly due to bad visibility towards the ground, tree tops and the sides) and control design. Problems with forearm and wrist are associated with high grip strength, high frequency of movements, fixed working postures, work method, grip size, type of grip and the use of gloves (Eklund & Cederqvist, 1998).

PROPOSED IMPROVEMENTS

Attebrant et al. (1998) propose two ways to increase productivity and a more efficient use of time; technical development and a change of work organisation. While also the changes associated with ergonomic problems in forest machine work (Attebrant, et al., 1998; Eklund & Cederqvist, 1998) are identified to be of those two categories (technical and organisational) consideration has to be made not to influence productivity negatively when improving the ergonomics of work.

Attebrant et al. (1998) proposed three organisational changes; different and varying tasks, more pauses during work, and fewer work hours. Past experience has shown that it is difficult to find additional tasks to vary machine operation (Persson, Olsson, Ekengren, Andersson, & Lindbäck, 2003). Persson et al. (2003) did also find that the rotation between harvester and forwarder work increased a bit between the years 1994–1998, but not from 1998–2002. It has also been tried using different schedules of work shift to include more variation and pauses, but many contractors are now back to working eight hours straight (Persson, et al., 2003). The changes Eklund and Cederqvist (1998) proposed to improve working postures and variability; rotating cabins, more settings in the chair to vary work posture and controls designed to avoid pronation of the forearm, have been implemented in some way or other (etc. Asikainen & Harstela, 1993; K. A. Ericsson, pers. commun., 9 Feb., 2010), but there is still more to do.

NOISE AND SOUND

The noise and sound level in forest machines are not considered a health problem in today's machines. However, the noise in forest machines were (barely) below the maximum allowed level (85dB(A) given by the National Board of Occupational Safety and Health in 1998 (Staal Wästerlund & Lestander, 1998). Recommended was though a level of 80 dB (A) (Landström, 1998). Today the maximum allowed level is 75 dB(A) and this would have put some machines in the former investigation above what's allowed in legislation. With a noise level at 85dB(A) of middle frequency sound it start to become difficult hearing normal talk at a one meters distance (Landström, 1998).
The legislated maximum noise level is furthermore not set according to comfort-, or performance- criteria, but health criteria. Noise affects perception, response time and mental performance (if the task is cognitively demanding) (H. Alm & Ohlsson, 2003), for these reasons the sound level should be taken seriously. Rieppo, Kariniemi, & Haarlaa (2002) believes that the noise level is restricting the recruitment new operators, and recruitment is a problem today. If sound signals are to be used in the machines consideration has to be taken so that there is a disparity of at least 10dB, preferably 20dB, between the sound signal and the background noise (if sounds are about the same frequency) for new and difficult information to be perceived (Grandjean, 1988).

The use of radio is another problem when investigating and designing forest machine operations. In a study by Gellerstedt (1993a) the noise level was 78dB(A) when using the radio. Almost every machine operator uses the radio, and this must be taken under consideration when evaluating the sound environment. The recommendations are also set for eight hours of work, and statistics show that (especially) contractors often work more than that per day (Staal Wästerlund & Lestander, 1998; Vik & Veiersted, 2005).

Proposed improvements

There were no changes proposed to enhance sound environment by Landström (1998), but work organisation was seen as a possible way to improve the situation.

Vibration

If the machines could be entirely vibration free Rieppo, et al. (2002) suggest the following benefits related to harvester operation:

- A more flexible use of the machine
- Less tyre costs
- Less damage to the ground
- Higher productivity in the operation

Vibrations also affect human health, comfort and performance (Wikström, 1998). According to Conway et al. (2006) performance degrades as duration and intensity increase, also high levels of frequency was found to influence performance negatively in whole-body vibration. Conway et al. (2006) also found performance accuracy-based tasks to be degraded more than those emphasising the speed of the response. Because of findings supporting the hypothesises that vibration degrades performance and increase driver fatigue a lot of recent research in forestry has focused on vibration and vibration control (Tobisch, Walker, & Weise, 2005).

Vibration in forest machine work has been measured to fall below the ISO-recommendations of 0,5m/s^2 for 8 hours of work, but in a study by Granlund & Thor (2005) the forwarder exceeded the recommended limit when driving more than 35 m/min, and otherwise it is in level or right below the limit. According to Oh et al. (2004) several studies indicate that the average speed of skidders and forwarders lay somewhere around 60–93m/min, where skidders are the fastest with a reported speed up to 233m/min. The consequence is that employers have to take measures to provide a better work environment for the operators. Never in the study by Granlund & Thor (2004) did the machines exaggerate the highest level of acceleration allowed (1.1 m/s^2 (”Vibrationer-Arbetsmiljöverkets föreskrifter om vibrationer samt allmänna råd om tillämpningen av föreskrifterna” 2005)). But several studies have identified problems with applying the ISO recommendations regarding vibration in forest operation. The major criticisms are that:

1. Little research has been done to confirm that vibration degrades performance. At the same time the relationship between level of exposure

(m/s^{2,} Hz and duration) and pains are not fully known (Wikström, 1998). "Since the general expectation is that vibration degrades performance, few are motivated to support extensive research to confirm this." (Conway, et al., 2006, p. 1744).

2. Forest machine contractors often work more than eight hours a day (Staal Wästerlund & Lestander, 1998).

3. There are some difficulties, like how to quantify ride quality, in the use and application of the recommendations for off road vehicles. For a further discussion on this see Oh et al. (2004). Addressing this question Tabell (2003) have made an attempt to standardize measurements in single-grip harvesters and Skogforsk have according to Jonsson, Löfroth, & Thor (2006) developed a standardized test field for forest machines together with Hultdins AB.

The main part of vibration measures in forestry machines has been made on forwarders or skidders, and not so much on harvesters. The main sources of vibrations in harvesters are, according to Gellerstedt (1993a), transportations on an uneven ground and the felling situation when the tree hits the ground. When talking to the operators they also mention a worst case scenario during transportation, when the machine slips off a stone or a stump (etc. Gellerstedt, 1993b). This will introduce a heavy chock to the body by which the effect could last up to 5–10 minutes before being able to work again.

Vibrations are in literature divided into whole body vibration (WBV) and hand-arm vibration (HAV). WBV and HAV both effects health, comfort and performance, but WBV could also contribute to motion sickness, sight impairments and fatigue (Wikström, 1998).

Problems related to HAV are rare in forest machines. "White fingers" is the most common among injuries caused by HAV and while they are so rare, individual measurements are to be taken when and if problems arise (Wikström, 1998).

The combination of WBV and bad working postures, fixed working postures, cold climate and heavy work with controls could together contribute to enhanced strain and stress on the body. What has been seen is that WBV, especially shocks, could contribute in gaining pains in the lower back. It may also contribute to neck- and shoulder pains common with forest machine operators (Wikström, 1998).

PROPOSED IMPROVEMENTS

Wikström (1998) presented a number of improvements to be made in prevention of WBV in forest machine operation:

- Enhance ground conditions.
- Reduce driver speed.
- Repair or change into a better damping in the chair.
- A chair that facilitate better and variable working posture.
- Improved cabin suspension.
- Optimize tires.
- Optimize tyre pressure.

Small changes have been made to improve the working posture; the chair has for example been improved to support easier adjustments and is also equipped with better foaming both in quality and design. The damping in the chairs has not improved that much the last ten years but a new chair suspension is being developed by SITTAB Stol AB and it has shown to last at least about three times the suspension of today's chairs in preliminary tests . This will help reducing the time driving with worn out suspension and thus being exposed to unnecessary high levels of vibration. (K. A. Ericsson, pers. Commun., 9 Feb., 2010)

Lighting and sight

The lighting conditions in forest machines were not satisfactory in 1998 according to Augdal (1998) as well as Staal Wästerlund & Lestander (1998), Gellerstedt (1993a) reported etc. problems in seeing the treetops in the dark and especially in snowy conditions. The use of xenon lights instead of halogen lights was tested in 2000, and the operator feedback was positive (Nordén & Thor, 2000). In study by Poom, Löfroth, Nordén & Thor (2007) xenon lights improved visual detection of green objects compared to halogen lights. Today most of the manufacturers have xenon lights as optional. Although the affirmative feedback on Xenon lights, a study by Walker, Tobisch & Weise (2005) still indicate problems in lighting the work area. Research on LED technology is now ongoing according to (Magnus Thor at Skogforsk pers. commun., 16 Jan. 2010).

Working under non satisfying lighting conditions might lead to vision impairment and headaches as well as an disrupted circadian rhythm (Augdal, 1998). Satisfactory lighting conduce to a better visual performance and a positive general health, but to strive for same lighting conditions in forestry work as in indoor work would not be realistic due to weather and seasonal conditions as well as night work.

While the operator receives the main part of needed information through sight, bad lighting conditions could impair performance severely. The time needed for visual object detection and the number of human errors[2] decreases almost logarithmic along with increased lighting (Augdal, 1998). Mental tasks are therefore solved more efficient with sufficient lighting in the sphere of activity.

Another aspect of the problem with sight is the positioning of different information sources which, according to Burman & Löfgren (2007), could contribute to strains in the neck and shoulder musculature. Scattered positioning of information implies changes in focus, repositioning of the head and accommodation of gaze.

PROPOSED IMPROVEMENTS

Staal Wästerlund & Lestander (1998) and Rieppo, et al. (2002) reported a lack of research in this area regarding forest machine work. Staal Wästerlund Lestander (1998) would like to see some research in and about the lighting conditions during working hours, as well as during season to see how the conditions for lighting are changing. They would also like to see some research regarding the readability of instruments in the cabin with attention to reflections, contrast and lighting. Rieppo, et al. (2002) are more general in their suggestion that research is needed on the subjects of better illumination, less dazzling and better visibility. A small study by Nordén & Thor (2000) indentified a couple of problem areas regarding reflections and lighting and showed the potential for improved settings, they also gave some guidelines in how to improve the settings in the machines. Some of the improvements in this study was proposed as early as 1974 (Teljstedt, 1974), but evidently not yet implemented.

Climate, gases and particles

In a study by Jansson (2002, cited in Tobisch, et al., 2005) it was indicated that forest machine operators were exposed to an unhealthy level of particles and exhaust fumes.

Climate is another part of the environment that has an effect on the human body. Effects of climate could be put into three categories; 1) health hazards, 2) impairments of functioning and 3) reduction in comfort. In creating a safe, productive and attractive work environment, all of these are to be considered.

In 1998, most of the cabins were equipped with a satisfactory climate control systems and the climate would be fairly well after a couple of minutes during both cold and hot days according to Bohm, Holmér & Norén (1998). Cabin temperature was therefore not considered a health hazard in modern forestry machines. But this is only the case when the machine is up and running, operators can be exposed to extreme weather conditions during repair and stoppage, (Bohm, et al., 1998).

Bohm et al. (1998) recorded that only a few studies in realistic environments had been made of the relationship between performance and heat, and no

[2] A definition of human error made by Reason (1990, p. 9): "*a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome*". If the outcome is intended is always normatively defined (Dekker, 2010).

study had been made according cold and complex mental, as well as physical, functioning in cabin work. The studies of heat and performance showed that human performance decreased, especially with slower reaction time and impaired information detection. Some of these studies showed impairment already at 27°C. When body temperature are lowered with 1.0 – 1.5 degrees, severe degradation of cognitive functioning –especially memory – will arise according to H. Alm & Ohlsson (2003). During work inside the cabin this might not be a problem, but during repairs in wintertime there is a need to dress properly.

"The conclusion is that suboptimal climate conditions affects performance. The exact nature of the effects as well as the relationships with climate conditions are however still to determine in detail." (Bohm, et al., 1998, p. 27, own translation)

As for the third aspect of climate impact; machine operators have reported dissatisfaction with the climate control in the harvesters in a study by Walker, et al. (2005).

Proposed improvements

No improvements have been suggested in the reviewed literature, but there have been improvements in the work environment in the last ten years. The level of exhaust fumes from the machines has steadily decreased since 1999 following the emission requirements in the EU for diesel-powered machinery (Wetterberg, Magnusson, Lindgren, & Åström, 2006) and a climate system has been inserted in the driver seat to enhance operator comfort (K. A. Ericsson, pers. Commun., 9 Feb., 2010). The air inside the cabin can now be more efficiently cleansed from particles with more efficient filters (level 1 in the European ergonomic and safety guidelines for forest machines 2006) provided by retailers (C. Löfroth, pers. Commun., 25 oct., 2010).

CONCLUDING REMARKS ON PHYSICAL ERGONOMICS

Guidelines have been developed to attend some of the problems previously described. One checklist mainly for forest machine manufacturers is the "European ergonomic and safety guidelines for forest machines 2006" (Gellerstedt, 2006), another is an ergonomic tool package for contractors from the COMFOR project (Lidén). But the guidelines are not static and address only a limited amount of questions, thus research must be done to revise and improve the recommendations.

A lot could be gained by studying the effect of vibration on human performance, and especially the low frequency levels of vibration measured in forestry machines. By better knowledge about this the work environment could be improved in gain for, hopefully, both productivity and operator health. But there has to be a simultaneous research in how to best reduce vibrations in the machines. The levels of today are considered to be a problem during work and one should thus not wait trying to reduce them until new findings explain the specific nature and impact of these vibrations.

When new possibilities of lighting occur there should be studies investigating the impact of changed lighting conditions and forest machine work. Aspects to investigate could be performance measures, quality aspects of the produced work, work satisfaction and/or fatigue.

Cognitive Ergonomics

In a literature review Tobisch, et al. (2005) made the conclusion that machine operators suffer more from psychological stress than physical stress, both of which might manifest themselves in physical impairments. Neck and shoulder pains are certainly one of the greatest health problems amongst harvester operators. Apart from health problems high psychological demands may result in accidents and reduction in productivity. Gellerstedt (1993a) did find mental demands on the operator to be the main limiting factor regarding productivity of the human-machine system. Since his study demands in operator attention and cognitive functioning has increased as a function of increased work hours, increased capacity of the machine, new environmental and logging directives as well as an enlarged work task[3] (Gellerstedt, 2002). Efficient work is thus not only more productive, but also more considerate towards the human body (as well as brain if someone feels a need of separating those).

"Workload is a hypothetical construct; it represents the cost incurred by human operators to achieve a specific level of performance and is not, therefore, uniquely defined by the objective task demands; and it reflects multiple attributes that may have different relevance for different individuals; it is an implicit combination of factors." (Hart & Staveland, 1988, p. 144).

Burman & Löfgren (2007) (as well as H. Alm & Ohlsson, 2003) points out that there has been little research on the cognitive, and psychological, aspects of forest machine work. As Hart & *Staveland said as early as 1988 (p. 164)* "ME [mental effort] has become an important contributor to the workload of an increasing number of operational tasks because operators' responsibilities are moving away from direct physical control to supervision".

Although the relationship isn't fully known, mental workload together with measurement of actual performance, could, according to Alm (1998) be used to examine the mental strain caused by different types of tasks. According to him the extremes (high or low) of mental workload have been proven to affect performance negatively. Karasek's (1979, p. 287) job strain model states that "psychological strain results not from a single aspect of the work environment, but of the joint effects of the demands of a work situation and the range of decision-making freedom (discretion) available to the worker facing those demands." When demands of the task(s) are too high, or there is too much uncertainty this could lead to mental stress and human error.

When measuring and defining performance one must take into consideration more than m^3/h, this hasn't been done in previous research according to Staal Wästerlund & Lestander (1998). They propose quality of work (output quality) as a parameter to measure performance. In combining these two parameters (quality of work and m^3/h) the measure of performance will be more precise

[3] Several sources have argued that an enlarged work task is lightening the burden of the operator (Attebrant, et al., 1998; Eklund & Cederqvist, 1998; Synwoldt & Gellerstedt, 2003, etc.)

and reliable than by using just one of them, and the inference drawn from performance to workload (or vice versa) will hold much more validity.

When thinning with a harvester, which has the highest mental workload in the cut-to length (CTL) system (Gellerstedt, 1993a; Zylberstein, 1992), Gellerstedt (2002) points out that the amount of control inputs might distract the operator from cognitive activities such as choosing the tree to be removed. Additionally, mental stress can cause physical strains as: neck- and shoulder pains, heart attack, gastric ulcer, migraine and asthma (H. Alm, 1998). In a study on Austrian harvester operators Bergers (2003) first results indicated that the average operator (Table 1) did not recover during night from the high loads of stress during day. Although it is somewhat a "well known truth" that mechanised forestry work is associated with high mental workload and stress, it important to know that several studies did not confirm these statements (Berger, 2003).

Table 1.
The average Austrian harvester operator, adopted from Berger (2003).

Work hours	>50 h a week
Food habits	Eat cold food
Living conditions	Cannot live at home during work
Education/training	4.2 days

The harvester operators are according to Gellerstedt (2002) not mentally overloaded as they are able to answer questions and recall radio news. This might be true for some situations, but as he point out in the same article there could be situations where the machine control inputs are too high and thus cause troubles in other cognitive activities. This state is what Miller (1960) refers to as Information Input Overload (IIO). IIO refer to situations where more information is available than could be handled within the time limit of the task. When these situations occur, humans have to make a trade-off between the demands of the task and available resources. Different coping strategies (Table 2) allow the human to degrade gracefully unlikely machines who tend abruptly to botch up (Hollnagel & Woods, 2005).

Table 2.
Coping strategies for Information Input Overload. Strategies mentioned in Miller (1960) as well as Hollnagel & Woods (2005), but *Error* and *multiple channels* only mentioned in Miller and *reduced precision* only mentioned in Hollnagel.

Strategy	Definition
Omission	Temporary and arbitrary non processing of information, thus some input is lost.
Queuing	Delay response during high load on the assumption that it will be possible to catch up later.
Filtering	Neglect to process certain categories. The information not processed is lost.
Cutting categories of discrimination	Reduce the level of discrimination and thus use less precision to describe input.
Multiple channels	Process information through two or more parallel channels at the same time.
Decentralisation (a case of multiple channels)	To distribute processing if possible, call in assistance for example.
Escape	To abandon the task and give up
Error	Processing of incorrect information, which may enable the system to return to normal processing afterwards.
Reduced precision	To trade precision for speed and time. All input is considered but only superficially and reasoning is shallower.

Although forest machine operators aren't in a constant IIO-mode over the work hours it might cause trouble depending on duration, frequency as well as the situation in which IIO appears.

Studies by Gellerstedt (1993a, 2002) and Zylberstein (1992) also show that the operator lacks information in many situations, bucking for example. Examples of information lacking are data on tree quality, the environment in which they are operating, machine status and feedback from their past work (especially important in thinning). The information flow is furthermore limited by the fast processing of the trees, bad work postures, control handling, vibrations and noise etc. The state of lacking needed information is what Hollnagel & Woods (2005) refer to as Information Input Underload (IIU). Humans use coping strategies[4] (Table 3) to handle these situations as well as the IIO-mode (Hollnagel & Woods, 2005).

Table 3.
Coping stragegies for Information Input Underload (Hollnagel & Woods, 2005)

Strategy	Definition
Extrapolation	To "stretch" existing evidence to ft a new situation. It is often based on fallacious casual reasoning.
Frequency gambling	To use the frequency of occurrence of past items/events as a basis for recognition or selection.
Similarity matching	To use the subjective similarity of past event/items as a basis for recognition or selection.
Trial-and-Error	Not follow any systematic principle in interpretations and/or selections. Also called "random selection".
Laissez-faire	To give up an independent strategy in lieu of just doing what others do.

Working with an almost constant state of IIO or IIU is not optimal with regards to efficiency and safety. The IIO- or IIU strategies will sometimes save the situation and allow the operator to continue work without interruption. But sometimes they won't, or maybe the "wrong" strategy for a situation is chosen, and it is those situations which must be avoided or at least put to a minimum.

[4] Some of which are referred to as error forms (or automatic retrieval mechanisms) by Reason (1990).

Hollnagel & Woods (2005) points out that coping strategies often will be used although no "objective" state of IIO or IIU could be detected. The strategies may sometimes serve the purpose to assist the operator in conserving effort and keep spare capacities for more demanding situations, etc. emergencies. One way, and probably the best way, to avoid problem in the interaction between human, machine and environment is by informed design of work and work environment to support the processes and the understanding of the human operator.

AUTOMATION AND COGNITIVE DEMANDS

Automation is often seen as the solution (etc. Burman & Löfgren, 2007; Gellerstedt, 2002), both on the "human bottleneck" regarding productivity issues and on ergonomic problems.

"Relieving the operator of many fast and simple work elements will enable better and faster planning and judgements on the forest and the logs. It will also free up time for new tasks such as supervisory control of partly autonomous machines, which now are under testing in Sweden." (Gellerstedt, 2002, p. 46).

Automation might be beneficial in terms of economy and precision of work (Sarter, Woods, & Billings, 1997), but may also be disadvantageous especially on behalves of mental workload and the numbers of serious failures. A consequence of introducing a new system, might be an automated one, is that the task and the demands on the human is not simply reduced, but changed (Sarter, et al., 1997). Vigilance tasks, like monitoring automation, may often increase the mental workload instead of reducing it according to Hart & Staveland (1988) and Rehmann (1995). Automation will thus affect information detection and processing positive or negative depending on whether it supports human processes or not.

In hindsight it is quite easy to address problems in previous strategies, and one of the earlier traditions in automation philosophies, *the left over principle* (Hollnagel & Woods, 2005), has the focus of mechanizing as much as possible and leave the human to cope with whatever is left to do. The obvious problem with this view is that humans are treated as flexible creatures with the ability to handle all the problems machines couldn´t, without addressing the question of human capabilities or limitations (Hollnagel & Woods, 2005). The belief that automation can replace the human operator (*the substitution myth*) has furthermore been shoved not to hold, and Bainbridge (1983) is of the opinion that the humans become more crucial for system performance the more advanced automation. If automation isn't carefully designed for collaboration with the human many of the assumed benefits with automation will therefore fail to appear (Sarter, et al., 1997). There is little known about how to best distribute cognitive tasks between human and machine, and this is, according to Alm (1998), a requisite in optimal usage of automation. As of the understanding of the picture of mental workload in harvesters today, time has to be saved by automation to be able to handle the demands of supervision introduced by the new automation.

Other problems that could occur with automation presented by Alm (1998) are: overconfidence in the system when the operator fails to intervene when appropriate; distrust in the system when the operator refuse to use the system even though appropriate. Amalberti & Deblon, (1992) also point out the fact that the operator will lack in training of manual procedures due to increased automation and this will impoverish the operator's knowledge and specifically the skilled expertise. If the operator doesn't possess required knowledge to override the automation when necessary, this might be a major issue both regarding safety and productivity.

PROPOSED IMPROVEMENTS

Previous research stresses the fact that operators work under heavy mental load at the same time as they have a need for more information. What are lacking are basic studies about what information a forest machine operator needs and how the information is received, this has been noted by e.g. Burman & Löfgren (2007). The information flow during the felling process has been in focus of research, and is quite well presented in Gellerstedt (2002). Additionally, knowledge of machine status is for example an important aspect to take under consideration when deciding the information need (and load) in forest machine operation. This is an aspect Staal Wästerlund & Lestander (1998) feel lacking in previous studies.

Some of the work on better information presentation demanded by Staal Wästerlund & Lestander (1998) has already been addressed (e.g (Forsberg, 2002; Lundin, Malmberg, & Näslund, 2005; Norén, Rosca, & Rosengren, 2008) in their design of interfaces for bucking instructions respectively head up display. But without the proper knowledge of the information need of the entire human-machine system, the design of a safe and productive work will not be informed and thus not optimized. To be able to handle the tasks at hand, the operator has to seek and process information from the environment inside and outside the cabin, thus the research of the needs cannot stop within the cabin. An investigation of the information (and value of information) received by sound, noise and vibrations was accordingly recommended by Staal Wästerlund & Lestander (1998). A problem they saw with the reduction of noise or vibration is that it might lead to a reduction in information about etc. processes and machine status. This information must then of course be compensated in some way.

Another issue concerning information need and retrieval from both inside and outside the cabin was raised by Alm (1998). He stressed the part physical and social environments play in being able to direct attention to important aspects. As for the more general question of mental workload and its effect on forestry work Staal Wästerlund & Lestander (1998) raised a couple of questions that still are valid (and thus nor fully answered) today:

1. What are the correlations between duration of work and impact of mental workload?
2. What will high mental workload do to productivity, quality and performance of forestry work?
3. What qualities of the stand and the work environment will have an effect on the mental workload of the operator?

There are thus quite a few aspects of mental workload and information need in conjunction with performance and productivity in harvester operation not addressed in previous research.

Discussion and further research

This review has pointed out the importance of human factors research in forest operations, with the most important arguments being:

- Machine operators suffer more from psychological stress than physical stress. (Tobisch, et al., 2005).
- Mental demands on the operator are the main limiting factor regarding productivity of the human-machine system. (Gellerstedt, 1993a).
- Physical strains are a major problem which has both physical and mental causes.

Many other complex domains (cf. nuclear power, aviation etc.) are large safety critical systems. Accidents in forestry have been heavily reduced the past 30 years and there is no risk of producing a new Chernobyl accident within the forest harvesting system.When system safety is not a critical issue in forestry one dimension of the problem space is reduced , and the complexity problem in forestry is instead related to productivity, quality, health and problems in finding labour.

The complexity further emerges from productivity- as well as environmental demands and the skills and knowledge needed to fulfil them. Conflicts between productivity- and environmental- as well as quality related goals add to this complexity. The continuous need for higher productivity and efficiency will put even higher demands on the operators if the problem isn´t addressed already by researcher, manufacturers and the clients (mainly large forest companies).

By looking at the reference list in this review (which by no means should be considered complete) not very much has been done the last ten years. Considering the last five years (since 2005) there are five reviews or guidelines and less than ten publications considering new studies of Human Factors related to harvester operation. The topics addressed in these publications are: standardised vibration measurements (mainly forwarder), lighting, design of bucking instructions, working technique and questions related to illness and economy in forest work[5]. One can truly see that human factors research hasn´t been prioritised and this could become be a major drawback for the industry.

But let's be optimistic and believe in further research and implementation. No matter what change you introduce into an existing workplace (organisational, technical etc.); these will have both physical and mental impact on the worker. With this conclusion that no change could be said to be purely physical or mental, the entire influence on the operator must be considered during design and evaluation.

[5] There are additional publications relevant for discussion, but they do not really cover the area of human factors.

As seen by previous research the effect of single improvements in the working settings has minor implications on the neck-shoulder problem. Some researchers suggest that organisational changes are the major way to reduce injuries (Attebrant, et al., 1998; Axelsson & Pontén, 1990; Lewark, 2005b) but specific organisational changes did not contribute to health improvements regarding these issues (Axelsson & Pontén, 1990) and some of the changes are difficult to introduce because of economical matters (Persson, et al., 2003).Technological changes of ergonomic conditions have in many ways provided in a better work environment (etc. Axelsson, 1998), but to the changes has also contributed to the rise of repetitive stress injuries (RSI, neck-shoulder pain). It is probably because of these documented problems Synwoldt & Gellerstedt (2003) made a warning about the possibility that an ergonomically well-designed machine could be an "ergonomic trap". But as a contrast to the latter statement has some studies (etc. Asikainen & Harstela, 1993) indicated that the use of mini levers do contribute to less pain in the trapezius muscle. And by reducing the physical workload it is quite probable[6] that it takes longer to develop such injuries (RSI) –even though I have no evidence for this statement as for now. I am furthermore prone to believe that this criticism arise from considering ergonomics as something purely physical and thus reducing the possibility of ergonomics (Human Factors) as a field to improve work related stress. In doing so they are neglecting the contributions that could have been made by a redesign of the cognitively demanding aspects of the work, as well as neglecting the contributions could been made by a more holistic view.

It is, as many have stated (Axelsson & Pontén, 1990; Gellerstedt, Lidén, & Bohlin, 2005; Lewark, 2005a), important to induce a holistic view of work and problems that are connected to work. Seen from a holistic view, the reduction of work related stress will probably gain from more work on the organisational level where many shortages have been identified. But there is also a need to use the knowledge within research of cognitive ergonomics and mental workload, as well as vibration and sitting postures to put the pieces together and hopefully solve the overall problem. The work environment does not consist of one single piece and so does seldom the solution either. What cognitive ergonomics furthermore can contribute to, except a better work environment, is higher productivity. Mental demands on the operator was seen as the main limiting factor regarding productivity many years ago (Gellerstedt, 1993b) and if not well designed, the introduction of new information technology (decision support, automation, quality measurements etc.) potential benefits of these systems will probably be unutilized. There might even be so that what's introduced to help instead becomes a burden and hence lower the productivity if not well thought out and engineered.

One risk with relieving the operator from one task (or burden), like seen in the development from manual to mechanised harvesting, is that it might lead to higher strain on another part of the body. One could never be certain of the implications of introducing something new into a system (compare to automation surprices, Sarter, et al., 1997), and these changes must be followed up in an iterative manner. On the other hand, doing nothing will certainly not solve

[6] see the chapter Health problems in forest machine operation for research on intensity, duration and frequency

the problem that truly exists today! By redesigning (redesign of work, not purely machine) with an informed and holistic, or systemic, view the risks and flaws with a new design are much more likely to be foreseen and avoided.

FURTHER RESEARCH

Complexity in the harvesting system seems to be a matter of the quality in the information in combination with the modes of interaction but there has not been very much research on the information need at all. It is therefore important to investigate both the operators subjective belief of what information is needed, as well as somewhat more objective criterions of what is needed. When complementing the questions of what is needed by the task with what the operator believes they need, this could provide a better basis for solutions to the IIU and IIO problem. A quote from Amalberti & Deblon (1992, pp. 652–653) describes the problem:

"Thus, although it is true that workload varies as a function of the number of pieces of information to be processed, it is not the flux in the actual number of pieces of information in the cockpit which is decisive (external or objective criterion) but clearly the number of pieces of information the pilot believes are necessary to guarantee overall understanding of the situation, efficient anticipation and sufficient trust in the system (internal or subjective criterion)."

Some important questions concerning mental workload still to be answered contain:

- What is the operator's subjective belief of what information is needed and what are the somewhat more objective criterions of what is needed?
- How is the information received?
- What is the mental workload of the harvester operator today?
- How does the mental workload affect the performance of the harvesting system?
- How should we design harvesting work according to these findings?

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