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Possibilities to develop machinery for logging operations on sensitive forest sites

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Content

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Basic data for this project was collected through theme interviews conducted by the authors Rieppo and Kariniemi. The persons being interviewed were six foresters responsible for logging in a wood procurement district, six representatives of forest machine manufacturers and five logging contractors. The foresters in charge of logging worked in different parts of Finland in the companies Metsäliitto Osuuskunta, Stora Enso Oyj and UPM-Kymmene Oyj. The forest machine manufacturers involved were Oy Logset Ab, S & A Nisula Oy, Oy Partek Forest Ab, S. Pinomäki Ky, Ponsse Oyj and Timberjack Oy. The logging contractors operated in different parts of Southern and Central Finland and they had contracts with Metsäliitto, Forest and Park Service and Stora Enso.

There is an international EU –research project ECOWOOD going on in 2000 - 2002. The main aim in that project is to develop a protocol for ecoefficient wood harvesting on sensitive sites. The results gained in this project of Metsäteho Oy will be of great help in drafting the guidelines/rules.

On behalf of the ECOWOOD project I want to express our sincere thanks to Metsäteho Oy and to its shareholders for allowing us to utilise these results. We also want to thank the persons interviewed as the basic data were collected. However, no doubt the most important persons behind this publication are the two authors of the first report written in Finnish, Mr. Kaarlo Rieppo (M.Sc.(Eng.), M.Sc.(For.)) and Mr. Arto Kariniemi (M.Sc. (For.), M.Sc. (Soc.Sc.)).

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Many thanks to all of you!

Rihko Haarlaa

ABSTRACT

This paper includes some basic knowledge to be considered when discussing about the quality of work in harvesting wood and how to monitor it. This knowledge may aid to form an appropriate view on mechanised logging, environmental issues and trade of forest products. Many forest owners feel today, that leaving a good quality of work behind is the most important requirement set for logging machinery in the future. It is possible to present to the forest machine and equipment manufacturers some ideas on how to promote and influence the development of logging machines and equipment.

This paper is partly based on a literature study, partly on theme interviews. Recent literature on productivity, machine and method studies on logging was examined from the quality of work point of view. Observations supporting an improvement in the quality of work were recorded. The idea was not to find out the level of the quality of work in practice as such, but to assess the relationships between the methods, machines and equipment used in respect to the quality of work.

The interviews were conducted from May 22, 2000 to October 2, 2000 in Finland. The data consisted of six persons responsible for logging in a wood procurement district, six representatives of forest machine manufacturers and five logging contractors.

A good quality of work in logging is characterised by doing it in an agreed way. Indicators for reaching the goals are evaluated by assessing the damages caused to the remaining trees, the rut formation, the strip road spacing and width, the way the thinning regimes are followed and the choice of trees to be cut. The target level is formed as a joint effect e.g. of efficiency in wood production, of credibility of mechanised operations, of considering the environment and of fluency in trade of forest products.

Contributing factors to reach a good quality of work are the organisation of the logging, the forest machine operator as well as the machine and equipment technique. These factors may get a weighting value. However, the final result is a product of these factors, and all of them have to be considered.

When looking at the situation today the human influence in logging, especially the role of the operator, is getting more emphasis. On the other hand, in the long run the possibilities to develop appropriate technologies are dominating, especially the use of new technologies.

From the point of view of logging machinery the main factors affecting the work results, are the mobility of the vehicle, how to operate it and the work environment. In this paper, based on the development needs and possibilities, those aspects are looked at. An assessment of the present state is given and presents a basis for a more precise prediction of realistic targets.

Based on a literature review and interviews conducted, it is possible to conclude, that there still is great potential to improve the quality of work in logging. Some direct technical improvements could promote the quality of work, but there are even some other actions, which indirectly through the operator would have a positive effect. An improved quality of work is often also improving the productivity in work. Furthermore it makes the organising of the logging operations easier and makes it possible to operate in a more demanding work environment even year around and 24 hours a day.

The following is a list of research and development (R&D) needs concerning forest machinery, where inputs would be justified:

- Better visibility (illumination, no dazzling, visibility)
- Analysis of the CTI-system and eventual construction and testing of a test machine
- The properties of tyres (width, diameter, tread, pressure) and their development
- Control of the crane and its development (e.g. the automatic functions)
- The role of a rotating cab on the operator, his productivity and the work result
- Research into the role of levelling (seat, cabin, whole machine)
- Steering of the machine (turning radius, “cutting” of corners) and possibilities to develop a vehicle with frame-steering and turning wheels
- Research into the possibilities to utilise on-board weighing scales
- Lighter machine construction
- The role of tracks and comparison of different tracks
- The role of a balanced boggie and its comparison with a single wheel
- The role of the size of the harvester head on the operation control, work result and productivity
- Possibilities to increase automation
- Possibilities of work rotation and its effect on a normal logging system
- The effect of a harwarder (harvester-forwarder) on the operator’s work

1. Introduction

This report is based on a study of Metsäteho Oy, which was made within a project “Actions to promote a good quality of work in logging”. It includes a state-of-the-art review on the meaning of the quality of work in logging and a description of the development needs and possibilities of logging machinery from a good work quality point of view. Possibilities to use a statistical control method for monitoring the work quality and a measuring routine for this purpose will be presented in another paper.

In developing logging methods and machinery one has to pay attention not only to the productivity but also to the quality of work. Logging does not only deal with harvesting of wood efficiently but it also is a silvicultural treatment of a stand and considers the environment protection. In demanding operational conditions, e.g. in thinning and especially on soft soils and peat land, the role of work results will be emphasised.

This paper includes some basic knowledge to be considered when discussing the quality of work in logging and how to monitor it. In addition, this knowledge may aid in the formation of an appropriate view on mechanised logging, environmental issues and trade of forest products. Many forest owners feel today, that leaving of a good quality of work behind is the most important requirement set to logging machinery in the future. It is possible to present to the forest machine and equipment manufacturers some ideas on how to promote and influence the development of logging machines and equipment.

This paper is partly based on a literature study, partly on theme interviews. The recent literature on productivity, machine and method studies on logging was examined from the quality of work point of view. Observations supporting the development of the quality of work were recorded. The idea was not to find out the level of the quality of work as such, but to assess the relationships between the used methods, machines and equipment in relation to the quality of work.

The theme interviews were based on an in advance prepared list. The interviews were conducted from May 22, 2000 to October 2, 2000. The data consisted of six persons responsible for logging in a wood procurement district, of six representatives of forest machine manufacturers and of five logging contractors. The foresters in charge of logging worked in different parts of Finland in the companies Metsäliitto Osuuskunta, Stora Enso Oyj and UPM-Kymmene Oyj. The forest machine manufacturers involved were Oy Logset Ab, S&A Nisula Oy, Oy Partek Forest Ab, S. Pinomäki Ky, Ponsse Oyj and Timberjack Oy. The logging contractors operated in different parts of Southern and Central Finland and they had contracts with Metsäliitto, Finnish Forest and Park Service and Stora Enso.

The interviewed persons we encouraged to give answers by own words and based on their own experience and local features of their operation areas. The authors Rieppo and Kariniemi conducted the interviews.

However, it is good to remember that the topic of this paper has been dealt with even earlier in Finland /1/. In that publication as an ideal situation the goal not to leave any ruts to the site nor any damage to the remaining stand after harvesting, was mentioned. Also the role of some machine components affecting the work result was discussed in it. Likewise based on an interview of persons with various background and profession brought up views on how the forest machinery should be developed to meet the set environmental requirements. A popular topic at that time was the use of biodegradable oils in addition to the demand to use lighter machines in logging.

2. Concepts and terms

The quality of work in wood harvesting and logging refers to the state of the forest stand and ground (viz. forest floor) after logging operations have been carried out. Factors affecting the state of the forest stand include/2, 3,4/

- damage on trees (stand damages)
- rut formation (on forwarding tracks)
- spacing between the strip roads (forwarding tracks)
- width of forwarding tracks
- stand density before and after thinning
- choice of trees removed in the thinning process
- type of machines used

Damage on trees is commonly classified according to the size, location and depth of induced scars. Rut formation is measured either as the length of tracks per hectare having a rut depth deeper than 100 mm or as a percentage of the total length of the tracks. The stand density after thinning indicates, if the density per ha of the remaining trees is in accordance with the harvest plan. The choice of trees indicates if the trees have been selected and removed according to the silvicultural regimes /2, 3,4/.

The quality of work encompasses such aspects as the quality of timber assortments produced, environmental issues, landing operations and planning of the logging. Poor quality of work in logging may cause both direct losses in tree growth and wood quality and indirect losses. Excessive track ruts and stand damage cause reduced tree growth; while stand damage causes loss in wood quality. The indirect losses from damage in a stand include increased susceptibility to insect, wind and snow damage /2, 3,4/.

3. A proper work quality on sensitive sites

3.1 The goal is determined by the entire system

A good quality of work in logging is characterised by doing the work in an agreed way. Indicators for reaching the goals are related to the damage caused to the remaining trees, the rut formation, the strip road spacing and width, the degree of conforming with the preselected thinning regime and the choice of trees to be cut. The target quality level is formed as a joint effect e.g. of the efficiency in wood production, of the credibility of mechanised operation, of the consideration of the environment and of the fluency in trade of forest products.

Contributing factors to reaching a good quality of work are the organisation of the logging, the forest machine operator as well as the machine and equipment technique available (cf. Fig. 1). Each factors presented in figure 1 is given a weighting value, and the final result is a product of these factors; and all of them have to be considered. If any variable gets a value of zero, so the final result will be zero.

A framework for producing good quality of work is set by the requirements for efficient logging and timber production. Factors influencing a credible operation are affected by the level to which the environmental issues have been considered, appreciation of mechanised logging, and by the timber trade.

The indicators of good logging work may be divided into direct and indirect ones. By indirect quality of work is meant for the quality of timber produced and the “hygiene” on the operation.

Timing of logging operation is very demanding when there is a need to have year around mechanised operations. The logging method has to combine the useable technology, the prevailing environmental conditions and the set production and work result requirements together. The role of the logging method gets increasingly emphasis as the technology advances.

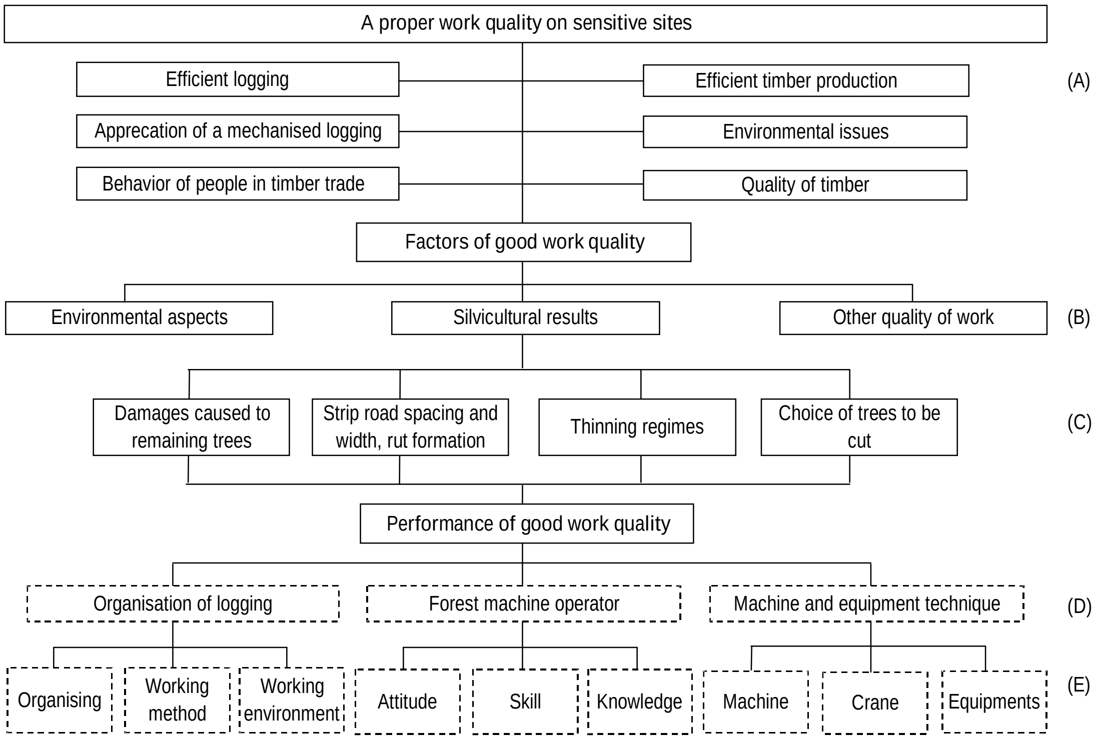

Figure 1. A 'forum' for a good quality of work in logging. The various levels to be dealt with are: Setting of the goals for the quality of work in logging (A), components for a good quality of work (B), components for a good quality of work in logging (C), components for producing a good quality of work (D) and a more close division of the components for producing a good quality of work in logging (E).

The forest machine operator is the most important factor affecting the quality of work in logging. The attitude of the operator is important and is formed by the organisational culture of the logging organisation. His/her skill in handling the crane and the machine itself must be at a level which makes the operation in demanding thinning conditions possible. In addition to his technical know-how, basic knowledge on biology, environment protection and properties of ground, are connected with good quality of work.

The third factor affecting the quality of work in logging is the machine and equipment technique. The basic technical properties of the crane and the undercarriage set limits to which the target quality of work can be set. It is very likely that all technical possibilities to good quality of work from a logging point of view have not been fully utilised in recent years.

3.2 Producing of a good quality of work in logging

The greatest change in organising wood procurement has been the movement towards a sub-contractor-based activity. A good work result in logging is now the responsibility of a sub-contractor. This together with a centralised and computerised steering system is stressing the responsibility of the performing person (viz. the contractor/machine operator) in reaching a good work result in logging.

In addition to the production itself, logging entrepreneurs are also taking care of the planning of the operation and environmental issues. The planning of the operation is playing a key role as regards to the quality of work in logging. There is a great need to educate the logging contractors and their operators in this respect.

The management of the wood procurement operations is based on quality assurance. It is possible to set clearly the goal on the quality of work and the production may be followed up systematically. This follow-up gives feedback in respect to the quality of work in logging. By knowing the follow-up and the proper functioning of it, they increase the appreciation of the meaning of a good quality of work in logging.

Wood procurement in the Finnish forest industry today is mainly based on the use of general purpose logging machinery. It is easier to organise and employ the contractors, if the same machinery can be used both in thinning and clear-cutting operations. The high unit costs of small-sized harvesters also influences the choice of the machinery. The same one-grip harvester has to be able to manage all environmental conditions from first thinning to final harvest, both on mineral soils and on peat land.

Highly mechanised and year round logging together with a high quality demand for the timber produced, make the logging very challenging from quality of work point of view. The share of wood harvesting from peat land is increasing. The damage caused by timber cutting vary greatly and depend not only on the environmental conditions. In contrary, the variation in the amount of damage due to forwarding is minor, and is mainly explained by the environmental factors.

The environmental factors affecting the quality of work in logging are the wood volume before and after cutting, the tree size, the tree species, the gradient and the bearing capacity of the ground as well as the season and the time of day. The amount of timber removed affects the amount of work to be done and the space the machine has for working. For example, it is more laborious to fell directionally and to handle a big than a small tree.

The season is important to note here, because it affects the sensitivity of a stand to stem and root damages. During the summer period the probability of damage when touching a tree is 1.5 fold compared to other seasons /3/.

Operating of the harvester from the middle of a strip and handling of several trees at a time increases the risk for damage. Almost 70 % of all contacts are caused at felling a tree. However, even during the other work phases some contact occur, e.g. when delimbing or moving the stem. Commonly the stems to be felled or handled cause the contacts, but contacts do not cause damage /3/.

The problems related to the bearing capacity of the ground can be taken care of by use of special machines, timing of the operation, planning of the routes for forwarding and by collecting debris on to the tracks. The significant effect of the season on stand damage is related to the variation in the loosening of the bark on the tree trunk during the growing season. The season also affects the amount of light available during the work. If operator’s visibility is limited, the environment as a whole cannot easily be taken account of by the operator /3/.

The effect of the operator to the amount of stand damages is essential. His attitude and realisation of the harm caused by the damages play a decisive role. It is possible to affect those for instance by basic training of the operators, by extension, by guidelines and by work instruction. There are great differences among the operators in relation to the experience, outlining of the work and in their dexterity and skills' levels. Thinning is an operation where all these skills are required.

3.3 The role of the logging machinery

The role of the machine and equipment technique and the development potential in relation to the quality of work in logging will be discussed in detail in chapter 4. In this sub-chapter the machine and equipment development is considered with respect to the question of the quality of work in logging as a whole.

In figure 2 the meaning of various factors in developing a good quality of work in logging is looked at as a function of time. When looking at the present situation the role of the human input, especially the meaning of the operator is emphasised. In the long run however, the potential connected with the technology development is in a ruling position. Especially the utilisation of new technology is supporting this view.

The development of the human input means a long-term activity advancing in short steps. Long steps are only available by machine and equipment design, however. Organising of the activities is always an important co-ordinating factor.

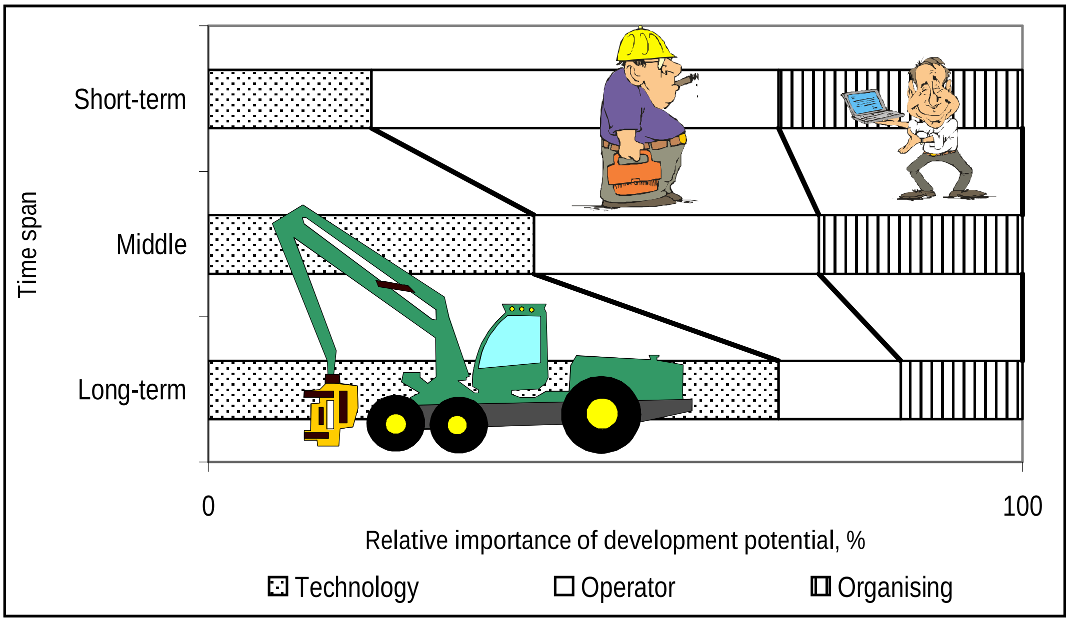

Figure 2. The view of the authors on the meaning of different factors affecting the quality of work in logging along the time span

4. The influence of a machine and its components on the work result

In this chapter the statements based on the theme interview are typed in *Italic*. The other part of the presentation is based on the literature review and judgements. Depending on the topic in question, the source has been utilised, where the subject matter has been presented in a most convincing way or by giving good reasons for the view. The aim has been to give a general view on the reported knowledge based on research or experience without any controversial targets.

From the machine point of view the main factors affecting the work results in logging are the mobility of the vehicle, its operation and the work environment (Fig. 3). In the following those factors will be looked at according to the development needs and possibilities. The drafting of the present situation is giving a basis for a more precise prediction of realistic targets in machine and equipment development.

4.1 The present situation

It has been said in the literature, that no actual improvement in the productivity forwarding timber has taken place in spite of a long-term development of techniques and methods. The machine availability and ergonomics are now better, however. The speeds of driving and loading are about the same as 20 years ago. The size of load in relation to the vehicle mass is not bigger, more likely less. The machine manufacturers are taking a precaution against over-loading situations and so the load space is kept reasonable in size. One could avoid over-loads by use of scales. This would even give an opportunity for a close follow-up of the production. In case of any disagreement on the amount of production, which might exist, this would provide quantitative data /5, 6,7/.

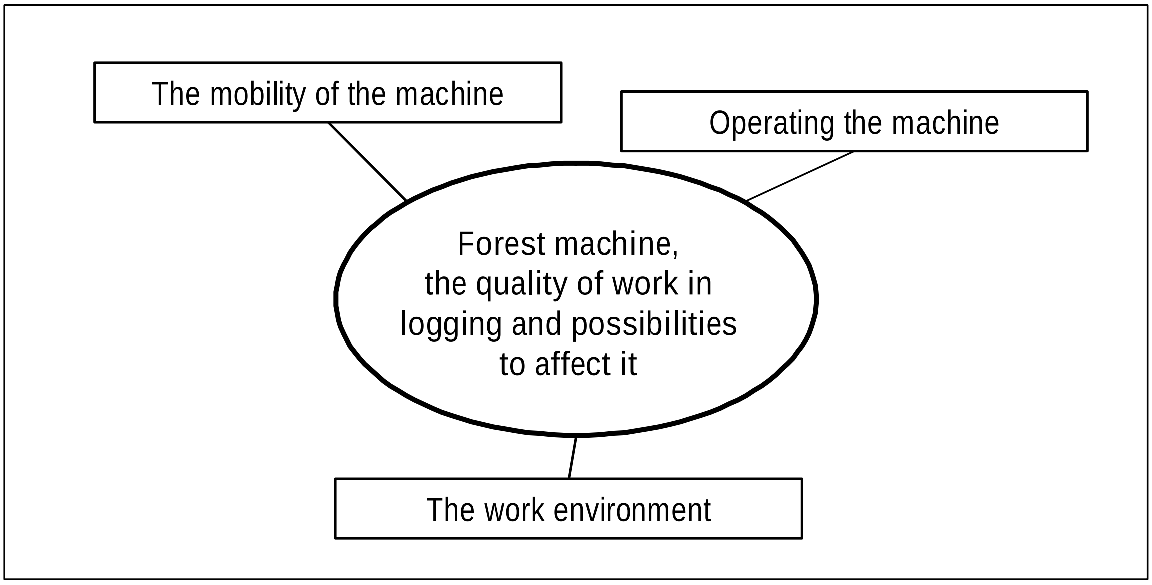

Figure 3. The main components affecting the quality of work in logging from the machine point of view

Quite often the problem is opposite; it is difficult to get a load heavy enough. Examples on those situations are e.g. the transport of tree parts and logging waste or short timber assortments /5, 6,7/.

Several studies have shown that rut formation is connected with the number of passes. In most cases the first pass explains more than 50 % of all ruts. On soft soils, as on farmland and peat land, the rut depth is increasing with the number of passes, until the vehicle is stuck /8/.

Harvester commonly cause shallow ruts and do not break the humus layer or root mat. On the other hand, a forwarder may cause deep ruts, may even break some roots and mix the humus with mineral soils. The driving by a forest machine may cause some physical changes down to a depth of 400 to 500 mm /8/.

Both the drawbar pull and floating affect the mobility of a vehicle. The drawbar pull indicates the ability of the vehicle to produce enough force to overcome the forces preventing the movement of the vehicle. The concept of floating on the other hand tells if the vehicle is able to move without sinking, i.e. the vehicle can stay on the surface of the ground /9/.

Most forest machines are fitted with tyres having a width of 700 mm at the factory; broad 800 mm tyres are not commonly used. Some thinning machines also get 600 mm wide tyres. In northern part of Finland 600 mm tyres are more common, because 700 mm tyres are worse in snow. Use of wheel tracks (bands) has decreased to some extent. They are in use, however, where there is much snow or the conditions are otherwise poor. When bands are used, the mobility is ensured, because enough traction is always secured.

Current forestry vehicles are agile, and no problems exist if the forwarding routes have been properly planned. The articulated steering as a structure is simple. From a ground damage point of view there must be enough thrust, so that the vehicle is not getting stuck in difficult places. It is very seldom that the mobility of a forest machine is not good enough. A high pulling force on the other hand gives the possibility to over-load the machine.

A rotating cabin means good visibility. This is important especially in thinning. The visibility affects both the productivity and the quality of work. Pointing of the lights in the dark functions better in the case of a rotating cabin. In a fixed-cabin model the capacity of the generator is not enough, because lights are needed around the whole machine. In case of a rotating cabin, no triangle between the cabin, the crane and the harvester head exist, into which some from the operation point of view harmful trees may remain.

There are three types of cranes in use: traditional knuckle-boom loader, parallel loader and telescopic loader. The type of crane might play an essential role when choosing a new machine, although it often is a matter of getting used to it. For a harvester the knuckle-boom loader is the worst alternative. It is easier to operate a parallel or telescopic loader. Attention has to be paid on the upper joint in a parallel crane and to the boom movement behind the machine in case of a telescopic boom *operation. A telescopic boom is also long even when the boom is contracted. A parallel crane shakes the machine most, because its long constructional parts are flexible.*

The mass of the harvester head sets the limits to the reach of the crane. Those heads have become heavier, which is not a good thing. The reason to it is that new properties and components have been added into them meaning a longer life for them, too. However, there also are some benefits from a heavier harvester head in delimbing and felling of cleared away small-sized trees. The harvester head of a harwarder (harvester-forwarder) has the benefit that one can fell trees, process them and load the timber with it. While loading one can hold the timber in a vertical position, which decreases the amount of damage caused to the remaining trees in dense thinning stands.

4.2 The aspects related to the off-road mobility

4.2.1 Development needs

Rut formation

Forming of ruts in forest soils is problematic both from the forest machine and forest ground point of views. The bearing capacity of ground (or actually lacking of it) makes the planning of logging in advance necessary and causes extra work both for the supervising staff and the logging contractors. One has to agree on the harvest season already when signing the sales contract, so that there are suitable operation areas spread evenly for all seasons. Extra time consumption might even be required for planning the forwarding tracks and spreading of logging waste (brash) onto the tracks /8/.

The plant cover gets more damage due to the slipping tyres than due to the excessive ground pressure. After the plant cover is broken the wheel sinks deeper and deeper causing ruts /10/.

The most important effect from rut formation is the loss in growth of trees caused by broken roots and soil compaction. Shallow ruts cause little damage and enable roots to survive /8/.

Load capacity

A good measure for the load capacity is a load index (KI), which is a ratio between the load mass and the machine mass. For a logging truck this index may be as high as 2.25, but for a forwarder it is typically less than 1.0, which means that the machine cannot carry its own weight /7/.

$$KI = \frac{\text{Load mass}}{\text{Machine mass}}$$

The mass of forest machines has increased. There are several reasons for this (Fig. 4). The size of the machines is now the biggest possible as the machinery being used in thinning cannot be bigger than they are today. Considering the weight of these machines a good planning of the logging operation is essential. Due to the rut formation, the load size is often limited; and during the spring thaw the operations are stopped entirely. Thinning during the summer still forms a problem. From the quality of the work point of view specialised machines would be a better alternative.

Nowadays the contractors do not like to change their old machines to smaller ones and start to work in "bushes". The contractors prefer to buy still bigger machines.

Some big-sized trees which exist in thinning stands cause problems for the small machines. In their use so-called cutting tracks (routes) or one-way tracks (routes) have to be used. Driving outside the actual forwarding tracks increases the risk of logging damage.

The forwarding distances have become longer than earlier. A bigger machine is required to keep time with the harvester. The productivity in forwarding should be higher. The rigid structure of the forwarder is binding the hands of the planner. For example, a significantly higher driving speed would require a vehicle body built on springs.

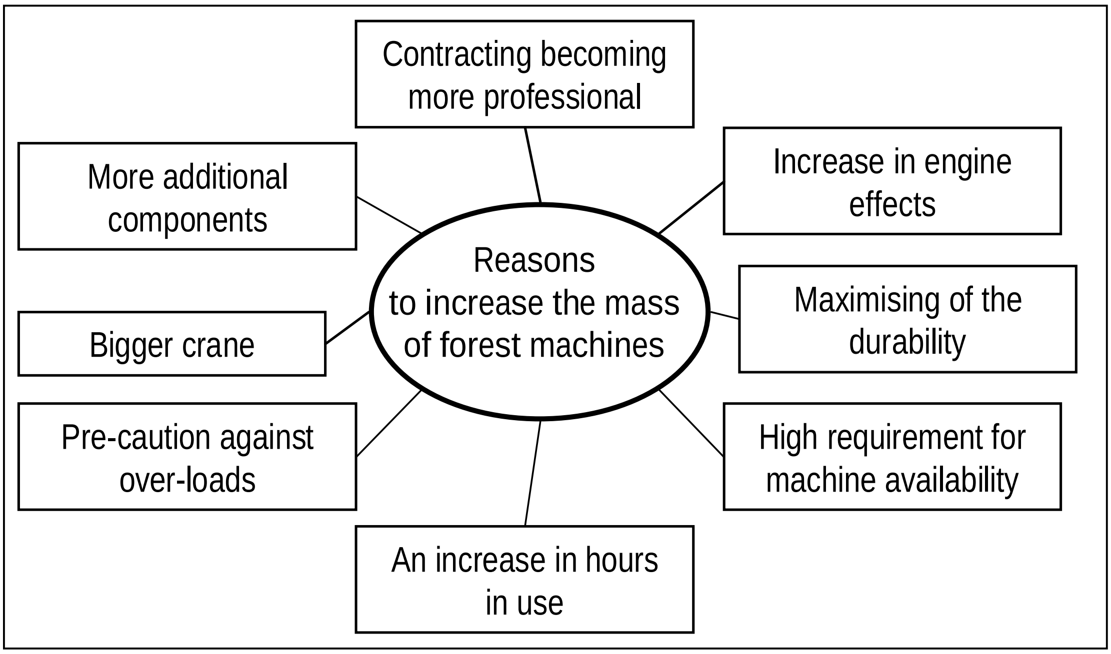

Figure 4. Reasons to increase the mass of forest machines

Ground pressure

In forestry, a formula for calculating the ground pressure is commonly used, where only wheel parameters are considered (Vehicle mass divided by a product of the number of wheels, the width and the radius of the tyre). In addition, the assumption is that the wheel sinks by 15 % of its diameter. The real ground pressure is 2 to 2.5 times the ground pressure calculated by that formula, however. The biggest mistake in the formula is, that it assumes unrealistic deep sinkage. By assuming so almost the whole side of the wheel is in the rut and the risk of getting stuck is high /9, 11/.

In a Swedish publication the highest allowable contact pressure 30-50 kPa was given /13/. The calculated ground pressure for present forwarder is 50-100 kPa. However, the ground pressure also depends on the weight distribution during the operation (Fig. 5). As a forest machine having a different machine configuration (4, 6 or 8 wheels) moves on a site sensitive for rut formation, a part of the motor effect is used to overcome the slope resistance caused by the sinkage. In principle, the wheel has to climb continuously a “slope” caused by the sinkage. This has its influence on the driving speed of the vehicle and so on the productivity of logging. If the driving speed of a forwarder is kept as at present, the power of the engine must be increased, which again increases the fuel consumption. To prevent damage to the ground, to avoid a need for additional drawbar pull and to decrease the fuel consumption there are good reasons to aim at avoiding deep ruts /13/.

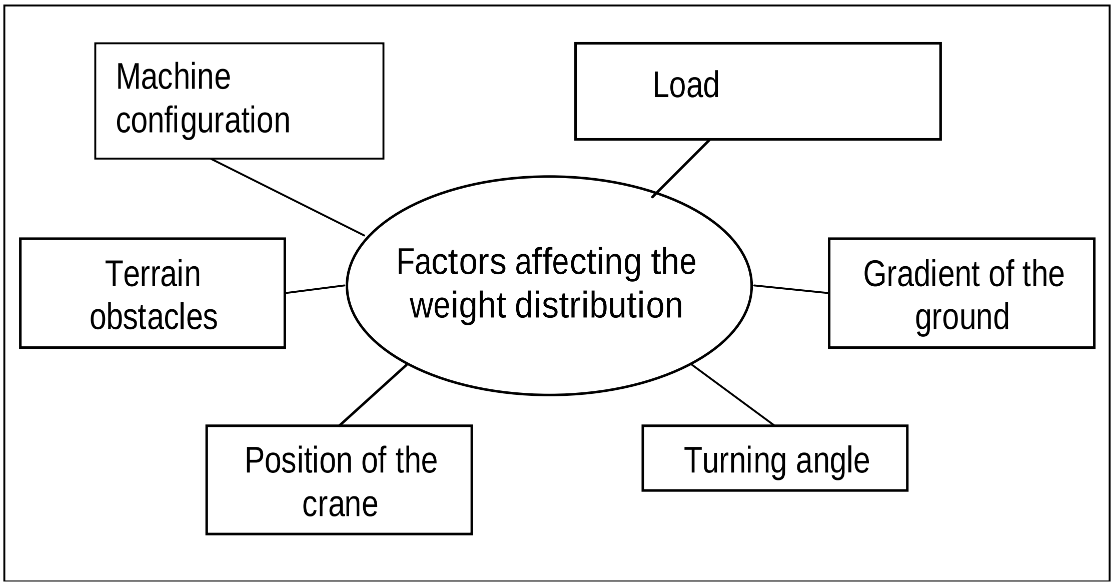

Figure 5. Factors affecting the weight distribution of a vehicle /8/

Tyres

Recently the outer measures of tyres have been increased, especially their width. The reason to this has been the better performance of a bigger wheel in off-road locomotion. Bigger wheels also cause less ground damage. It is not possible to increase the outer width of a vehicle, because a broader forwarder would require a broader strip road in thinning /9/.

A lower ground pressure would require broader tyres and a broader vehicle causes harm in thinnings. A broader tyre would also mean worse mobility in snow conditions.

A broader tyre increases the width of the contact area and usually also the elasticity of the tyre. An elastic tyre divides the load evenly over the whole contact area, which depending on the conditions might improve the traction. A broader tyre might also cause an increase in the rolling resistance and cause a so-called push effect, which increases the rolling resistance. The push effect means that a broad tyre collects along its front some soil, whereby increasing the rolling resistance of the vehicle wheel /9/.

When the other properties of a tyre are kept constant, an increased wheel diameter increases the thrust coefficient. The reason for this is primarily an increased length of the contact area /9/.

Even the tyre tread has its effect to the mobility of the vehicle. The main purpose of the tread is to form traction between the tyre and the ground and to develop a tractive effort with a purpose of propelling a vehicle under given conditions. The “self-cleaning” of the treads is an important property of the tyres /9/.

The properties of tyres have got worse when the so-called ball tyres have been introduced. Because the air space in those tyres is low, it is necessary to keep them hard; otherwise they do not last. On the other hand hard tyres are not flexible, which from the ground damage point of view is bad. If as an alternative the air pressure of tyres is lowered, the machine starts to behave in an “inert” way, which again may increase stand damage.

Wheel tracks (bands)

Tracks lower the ground pressure, but cause damage during steering and turning /5/. If the track plates have a bent shape and are fixed from the ends to a radius shorter than the wheel radius, then their speed during the locomotion is slower than that of the wheel. One can see this on a hard surface as a longitudinal movement of the track during driving. With usual metal tracks this movement is about 10 % from the distance driven. While the track is dragged forward it is breaking the ground surface and clearly increasing the drive resistance. It is possible to avoid this movement of the track by designing the track plates rather straight and hinging them near to the level of the outer surface of the wheel /10/.

Tracks increase the width of the vehicle by 50 to 100 mm. Track plates with a bent form scuff the terrain. New tracks (so-called eco-tracks) with straight plates are much better, but also for the time being even more expensive to purchase.

4.2.2 Potential for development

It is possible to decrease damages to the ground by spreading the tractive effort between all wheels. Slip of a wheel may be avoided by limiting the torque or by use of hydraulic power transmission or by other technical means. One may design and construct a hinged and turning boggie for the forwarder. It would make it possible to drive with the front axle wheels and the rear axle wheels along a different route. Damages caused during turning by a stiff boggie construction could be avoided by use of a steering boggie both in the front and in the rear /10/.

A harwarder is big enough machine to harvest seed trees, hold-overs, small-sized clear-cuts or wind-blown trees. In the case where it is used for thinning, two sizes of them are required. A harwarder could also serve well in a traditional harvester and forwarder logging system as an additional unit.

There is still much room for development concerning the construction of a forwarder. No stiff structures should be kept in mind to provide more freedom for new designs. For instance, based on single wheels one could design a three-axle vehicle.

The hydrostatic-mechanical power transmission has promoted the operation of the machine and will become more common. The machines have still to be developed so that it would be possible to control the speed and torque of an individual wheel to decrease the slip. Machines with eight wheels will become more common.

If it would be possible to increase the load capacity of a forwarder, it would be important to distribute the load more evenly. At present the load is resting almost entirely on the rear part of the vehicle. A better distribution of the load is a prerequisite for increasing the load capacity. This would lower the average ground pressure, too /6, 10/.

There is still considerable development to be done in respect to the forwarder mass. The weight distribution and the ground pressure during the operation are more important than the total mass. The weight distribution of a forwarder should be more even. This would require great constructional changes, however. The present machines with a rotating cabin and the crane in front of the cabin have a better weight distribution than those with a fixed cabin.

Over-loading of the machine should be avoided to increase the life of the machine. This would require a weighing scale in every machine. There are no technical reasons preventing their use, but it might be necessary to have a scale both in the crane and in the bunks. By use of a scale one could fully utilise the load capacity. The scale would also give the weight distribution. The scaled results would provide information for monitoring of the logging. The scale would mean extra work for the operator and cause additional costs, however.

The springs and a system to hold the vehicle continuously vertically straight would allow a higher travel speed. For clear-cutting operations the width of the forwarder could be 200 to 300 mm wider. By these means the driving speed of a forwarder could be increased to some extent.

The load space of a forwarder should be divided into sections, because there usually are so many timber assortments.

It is likely that the forest owners and the public will pay more attention to the damages caused by logging in the future /10/. Logging on sensitive sites must be limited to the winter period in Finland. During autumn, when the temperatures remain high, logging from peat land is more difficult and might not be possible from unfrozen ground at all. One solution to this problem would be to use a CTI (Central Tyre Inflation) system /14/. Some benefits from its use are presented in the Fig. 6 /5, 9, 13, 14/.

The use of a CTI –system helps also to organise the logging smoothly and to decrease the need to move the machines frequently between the sites, because those machines could operate on each site during the whole year around. If the use of CTI would cut the need for machine movement between sites to a half, it would mean savings according to a report from Southern Sweden of about 0.3 €/m^3 and about 0.1 €/m^3 in Northern Sweden /14/.

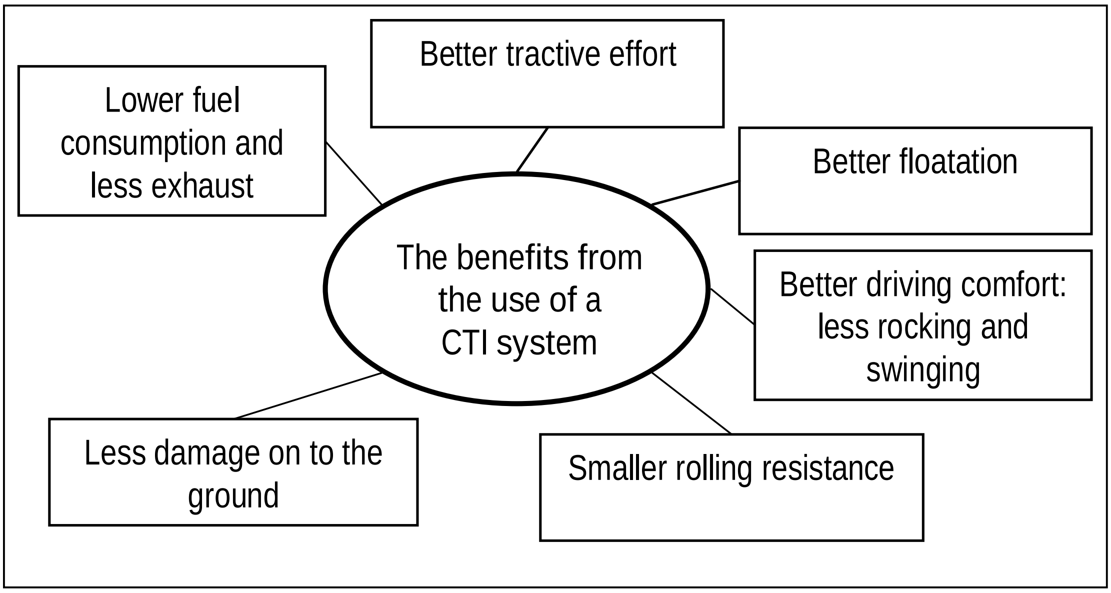

Figure 6. The benefits from the use of a CTI (Central Tyre Inflation) system /5,9,13,14/

A flatter tyre due to a lower air pressure increases the rolling resistance, warms up the tyre and causes more wear to the tyre, however. It is also possible to get mechanical damages or loosening of the tyre from the rim /5, 9, 13, 14/.

Tyre inflation and deflation is slow with CTI systems – it can take up to 15 minutes. This harm may be avoided by setting inside the tyre a solid part, which would require less air for control. In addition, a solid component would allow temporary driving on a punctured tyre /5,9,13,14/.

In a Swedish study the construction cost of a CTI –system was € 15 000. The equipment cost was estimated to be € 5000, if the system starts to become a common use item and then the mounting could take place during machine manufacture. Another study says that the system will cost € 13 000. In both reports the conclusion is that the system would pay back the investment with its benefits /5, 14/.

A low-pressure 600 mm tyre with a CTI system give a nominal ground pressure equal to a 800 mm tyre with normal air pressure. So it is possible to invest in CTI instead of broader tyres. In addition, such forest machine would be narrower and more suitable for thinning /14/.

Lower tyre air pressures would have a great meaning from the ground damage point of view. A lower air pressure would also increase the tractive effort. Tyres have to be developed in this direction.

It is technically possible to develop a CTI system to forwarders. The system would be especially good for operations in thinning, but it is expensive. It is rather complicated and so it requires more maintenance. If the filling of the tyres is a slow process, as it was in some tests, the control would be limited to certain locations and environments. In principle, the air pressure of tyres could even today be regulated according to environmental factors.

The present tyres are not suitable for a CTI system due to their hardness. The development work could start from the design of suitable tyres for the system.

Based on the literature study and theme interview some findings on the role of different terrain factors on the work result in logging according to the development inputs have been illustrated in Fig. 7.

4.3 Operating the vehicle

4.3.1 Development needs

Steering

The heavy front part of a forest machine is harmful for steering. The link axle only can operate at an angle of 45 degrees in a hydrostatic-mechanical solution. This is enough, although even a greater turning angle would be beneficial, but with current machine configuration, a greater turning angle would increase the risk of vehicle over-turning.

Current vehicles "cut in" while driving around the corners, more than earlier machines. Together with the use of 700 mm tyres, this may require one metre additional width to the strip road compared to a machine with 600 mm tyres, which commonly does not "cut in" while corning. The rear part of the vehicle should follow the tracks of the front part so that no follow-up by the operator would be needed.

As a vehicle, an eight-wheeled is not as agile as a six-wheeled one. Nor is it as good during the winter, because it tends to climb to the top of the snow layer. A thick snow layer also limits the movement of small machines. A balanced boggie is good in difficult driving conditions. A minor unbalanced behaviour of the boggie is beneficial when driving on snow cover, however.

Crane

The forest machine industry has started to construct cranes with a shorter reach, so that they can be made lighter. The reach must make operations up to 10 m possible, however. There is some slack in the links between the crane and the machine, which increases with the age of the machine, which makes the operation of the crane and the machine difficult.

Increasing the speed of movement of the crane in thinning means a higher risk. If the crane is mounted onto the front of the body, the visibility is worse, because the crane is near to the cabin. The best location for the crane would be behind the cabin. Problems in operating a parallel crane are caused by the different speed in the movement of the head depending on the position of the crane.

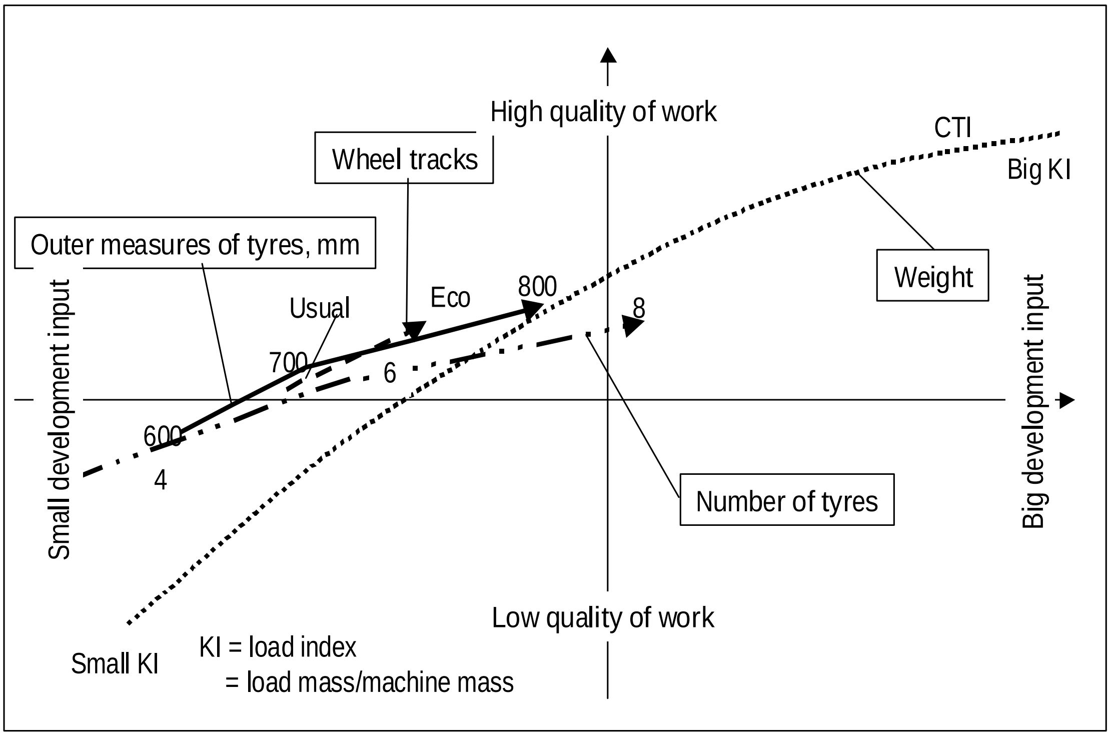

Figure 7. The role of different terrain factors on the work result in logging according to the development inputs

If a rotating cabin is used and the crane is mounted on it, then there is a space about two metres between the operator's seat and the turning point of the crane. Thus a machine has to be moved frequently so that the operator is able to see a suitable route to move the crane. This lowers the productivity in the work.

Harvester head

When making the harvester head lighter the durability becomes a problem, but a smaller head is needed. From the operating point of view the visibility is more important than the size of the harvester head. It is also very difficult to service a small harvester head. A bush clearing tool should be developed as a new component to the harvester head.

4.3.2 Potential for development

Slipping of a tyre either laterally or in the driving direction causes an increase in rut formation. To prevent the slip to the direction of driving different anti-slip solutions have been developed. Slip to the side direction exists especially in link-steered boggie vehicles. A traditional double-boggie machine makes ruts twice as deep as conventional machine, when turning. It would be possible to prevent the side slips by the use of an active steering system based on turning single wheels /8, 13/.

One should always use hydro-mechanical power transmission, because it is accurate and soft. One should use a system to steer all wheels in addition to the articulated steering to promote agile turns. This would mean an entirely new level of agility which would make the planning of strip roads easy. The construction would be complicated, however.

Separate wheels would be preferable to boggies, hence one could monitor and control each individual wheel.

It would be fine, if the crane would have a reach at least one metre longer. The reach should not be below 10 m. The location of the crane should be close to the operator and have a levelling system to keep the forces equal in all working positions. A crane pillar allowing wide movements would provide additional reach and good possibilities to operate near-by. Such a construction would be more complicated than the traditional ones.

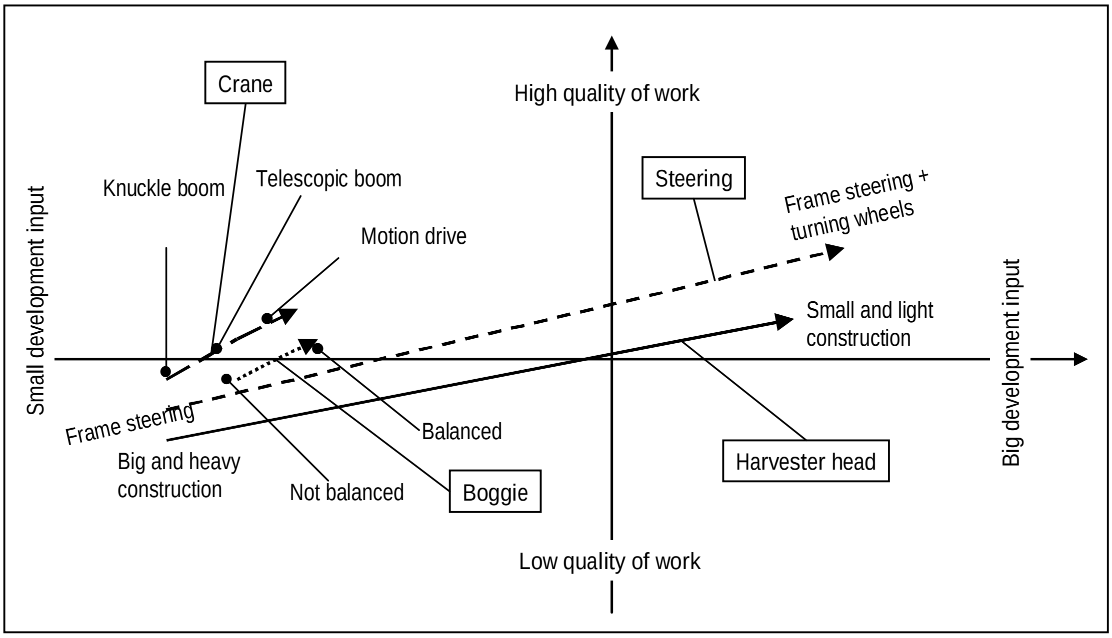

Figure 8. The role of different machine operating factors affecting the work result in logging according to the development inputs

When operating a forwarder the biggest part of the time comprises the work with the crane. To make it more efficient some of the movements of the crane should be automated and the need for the operator to learn decreased. This would improve the operating of the crane and the work productivity. The productivity could also be improved by a faster unloading. In unloading for instance some bundle arrangements or tipping of the load should be used.

By having stakes movable to vertical direction one could decrease the time consumption during the loader operations, because it would not be necessary to lift the loads between the stakes or over them. This would also decrease the fuel consumption. There already exists a bunk system on the market, which can be lifted and lowered with the help of a grapple without separate hydraulics /6/.

Based on the literature study and theme interview in Fig. 8 some findings on the role of different machine operating factors affecting the work result in logging according to the development inputs have been illustrated.

4.4 The work environment

4.4.1 Development needs

Visibility

Good visibility from a forest machine is an essential prerequisite for the operator to reach a high productivity in the work, to 'spare' his health, his machine, equipment and environment. Bad visibility increases the risk of having an accident; it lowers the performance of the operator and forces him to adopt strenuous work postures. As an example, long-term holding of the head turned backwards is unhealthy. If it is necessary to follow up the movements of the crane from a fixed cabin, the problems caused by bad visibility are emphasised. In a revolving cabin the operator has to turn his head much less compared to a fixed cabin /13, 15/.

During operation in the dark, the quality of work of most operators is lowered. One reason for this is that the lights of the machine are not powerful enough to illuminate the worst zones. Secondly, work in the dark is more exhausting than in daylight operations. It also increases the risk of making mistakes /15/.

In a two-shift operation the need for better lights is greater than in a one-shift operation. In thinning it is difficult to arrange enough illumination, because the stand causes considerable shading of operating areas /13/.

The illumination is very important. It is advisable not to work in thinning during the dark. However, in practice, such work must be done, although night shift work often is unpleasant and does not pay particularly well.

If the illumination level is low, the operator cannot see all the details very well. Even the distinguishing of colours is difficult and the making of observations is slow. An acceptable speed in making observations is reached at 50 lx, but it is still faster when the illumination is better. In mechanised forest operations the minimum acceptable illumination by white light is 50 lx, where the natural colours can be seen /15/.

New gas bulbs illuminate the surroundings better than the traditional incandescent or halogen lamps with yellow light at the same illumination intensity. These bulbs may produce even four times the illumination per Watt compared to the traditional halogen bulbs /15/.

The choice of a tree to be felled requires illumination. The problem is how to get enough illumination 10 metres away from the machine. Today the batteries do not last more than half a year. A dim evening is the worst. Sometimes the poor quality trees to *be felled need to be marked by axe during the day in advance. If that is not done, one has to return to the spot again to improve the quality of work, which lowers the productivity in work.*

There must be lights in the boom of the crane to point up to the top of a tree. The gas bulbs could clearly improve the illumination. However, it is not known how long they last and that needs to be tested. One of the reasons preventing their use today is their purchase price, many times more expensive compared to the usual ones. The capacity of the generators should be increased. That would make it possible to improve the illumination even by traditional bulbs. In any case one should use twin-lamps, where a lamp contains two bulbs.

Dirty windows, and their tendency to act as mirrors also causes a problem. It takes time to clean the windows, and when the sun is setting, it can cause considerable dazzling. In that case one has to operate so that the sun is shining from the rear. It is not possible to identify decay in a cut surface of spruce through an obscured window.

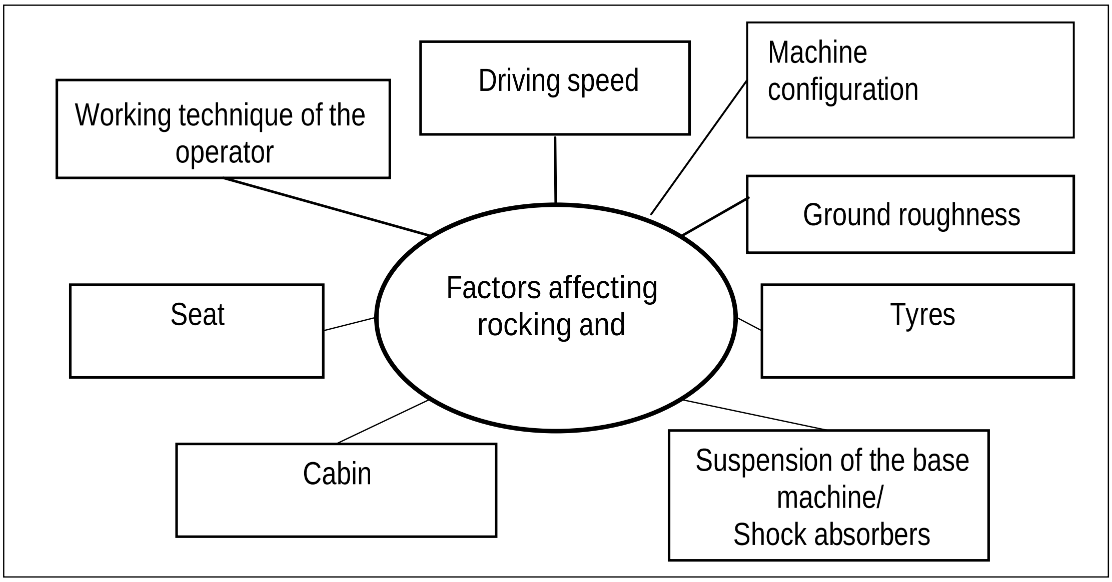

Figure 9. Factors affecting rocking and swinging of a forest machine /15/

Rocking and swinging

The problems concerning the operator's health are greater in thinning than in clear-cuttings. During cutting the operator has to concentrate on the work, because the stem is moving very fast. The operator's exposure to rocking and swinging increases with increasing speeds of processing and driving. Operating a harvester is regarded as being more strenuous than operating a forwarder /15/.

The rocking and swinging of forest machines cause both exhaustion and reduced comfort at work. There are several factors affecting the rocking and swinging (Fig. 9). The location of the cabin affects the level of rocking to which the operator is exposed. This is an unfavourable aspect relating to cabins which have been mounted high; for instance the hanging cabins. In those cabins, however, the level of high frequency vibration is low, and a freely hanging cabin damps the rocking and swinging to some extent /15/.

Some of the latest forest machines have a system which keeps the machine or the cabin horizontal. If the whole machine is in a horizontal position, the work environment of the operator is convenient, the operation of the crane on slopes is easier and the risk of turning the machine over is decreased. A cabin always kept horizontal provides an opportunity to have relaxed operation. It also reduces the strain on the back, because skewed postures are very exhausting. It primarily would be preferred to get the machine horizontal, secondly the cabin and thirdly the seat. If one could level only one direction, the lateral direction should be preferred /5, 15/.

From the convenience of work point of view a rotating and self-levelling cabin is good. A crane at the side of the cabin prevents the visibility to that side, however. Even a forwarder could have a rotating cabin. If no technical possibility to level the machine exists, the machine has to be stopped at a suitable place in terrain and operated there. A rotating and self-levelling cabin increases the purchase price of the machine, which has meant that they have not become common. In contrast, levelling of the seat is technically easy and cost effective, but only a compromise.

A freely hanging cabin moves the centre of gravity of the machine in a wrong direction and increases the risk of turning the machine over. More space is also required for it; and a direct touch to the machine (viz. "operator feel") is also lost. Levelling done under the cabin is a better solution.

Therefore, it is important to pay special attention to the chocks induced by a felled tree on the base machine of a harvester with a rotating cabin.

Noise

Noise does not cause any major problems in the present machines, but the continuous sound from the engine and the computer with a fixed speed are disturbing. When the machine gets older, the bearings get looser meaning more rocking and swinging as well. A harvester with a fixed cabin is stiller and better than that with a rotating cabin when cutting big trees.

Shift work

It is common that at the end of a long work shift the work tempo gets slower, especially when operating in the dark. One has to plan and organise the operation so that the operators can utilise the machine effectively during the whole shift. The operator of a forest machine is limited in the degree to which he can change his posture and alternate the work load; and thus might lead to health problems due to the work /15/.

Work with a high intensity and tempo (e.g. thinning) should actually only seldom last longer than six hours a day. It is a recommendation that an operator should have a five minutes break every hour. Introduction of more automatic functions to the work might bring along some mini-breaks. Those would allow the blood to penetrate into the tissues and transport away the products from the muscles. In the present harvester operation these mini-breaks are missing /15/.

A break connected to the functioning of the machine should be such that it would not be necessary for the operator to do anything for a period of at least three seconds. Such a break should occur once during each work cycle (e.g. once during processing a tree or loader's operation cycle during loading and unloading). During the course of these breaks the operator could plan his future work phases or observe the trunk for a improved measuring, i.e. better decisions on the cross-cutting points /15/.

There are still pressures to increase the productivity, although the quality of work result could get lower due to faster operations. Most older operators find it difficult to match the intensive tempo of modern harvester operations. One should make the operation easier by reducing the routine work.

The control of the quality of product requires attention. Because of this more damage might occur. The measuring based on the product value has made the work easier, however. If no attention is paid to measuring, more time is available for quality control.

4.4.2 Potential for development

When working with a harwarder (viz. harvester-forwarder) the operation may be planned according to the environmental requirements. For instance, one may cut timber when it is light and forward in the dark. In harwarder operation, the forwarding phase gives a break to the very stressful cutting work.

Even the most advanced modern seats mounted to the harvesters can significantly reduce only the high frequency rocking. By active moderation of the cabin vibrations one has also been able to reduce the low frequency whole-body vibrations. Thus the workload of the operators can be lowered. Some development work with active damping of the cabin vibrations has been done in Sweden. Those new systems resulted in a 50-60 % lower rocking and swinging, despite the driving speed of the machine increasing during the same time by 10 % /5, 16/.

Getting the cabin vibration free is only a partial solution to the problem. Ideally the whole machine should be vibration free. In addition to a better work environment one could gain some other benefits (Fig. 10).

Ergonomics are important for recruiting new operators. Rocking, swinging and noise levels have still to be cut down. The convenience of the machine operation affects the operator's attention levels and therefore the result of work. A meaningful improvement is not possible unless there is a suspension in the cabin or in the entire

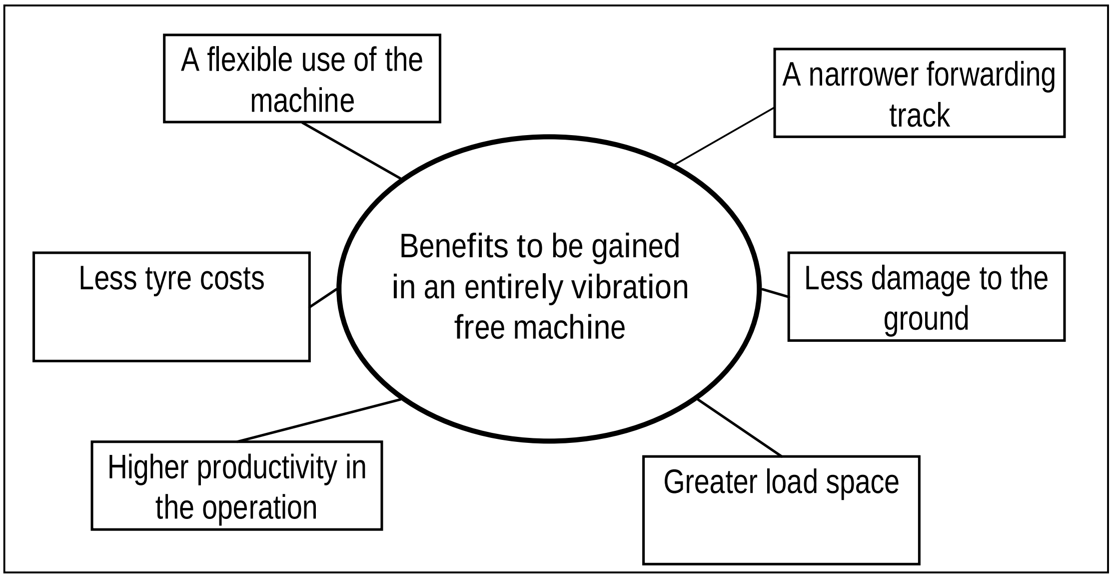

Figure 10. Benefits, in addition to the operator's better work environment, to be gained in an entirely vibration free machine /16/

machine. In the present machines some rubber cushions serve for shock absorbers. There should be at least air springs under the cabin. An active suspension under the cabin should be developed. If there was a system with active springs, some constructional components of the machine could be made lighter.

A levelling system for the cabin could lower the swinging. The levelling should act in all directions. In harvester work, a horizontal cabin affects the accuracy in the operational functions. When the cabin is standing straight during the driving damages to the remaining trees near to the strip road can be avoided. The driving as such is also more stable. The levelling of the crane (i.e. keeping of the pillar vertical) might be even more important than that of the cabin.

When introducing new automatic techniques into the machine, the functions to the operator and the machine should be divided so that the best sides of both of them are utilised. One should be careful in creating such automatic functions instead that the operator feels interesting and which are not exhausting. A negative side of the use of automatic functions is that the operator easily looses his interest in those functions and does not search for the knowledge needed for such operations /15/.

Some of the functions of the crane should be automated so that it would not be necessary to handle the levers continuously. By automation one could create important mini-breaks in the cutting operation, too. The automatic steering of the cross-cutting should be developed more. It should be possible to get from the stem not only the data on its length and diameter but also information on damages, crooks or bends. The scaling is still based on mechanical sensors. There should be scaling methods available not needing any touching of the stem. The automatic systems of the machine could also supply the operator with essential information, e.g. on diagnosis of faulty functions.

The construction of a forest machine should be such that the operator could sit in the direction of the crane boom. The visibility on to the work object should be improved and thus would decrease the risk of damage to the remaining stand.

A tired operator makes mistakes easily from the work result point of view. A pressing work tempo could be partly avoided by work rotation. The length of a work shift should never be longer than eight hours, because it affects the work quality and the use of the machine. One should utilise the possibilities of automation even here. One could use techniques to adjust the machine functions to correspond to the needs and abilities of each new operator.

Based on the literature study and theme interview in Fig. 11, some findings on the role of different environmental factors in forest machine operation on the work result in logging have been illustrated, with respect to development work inputs.

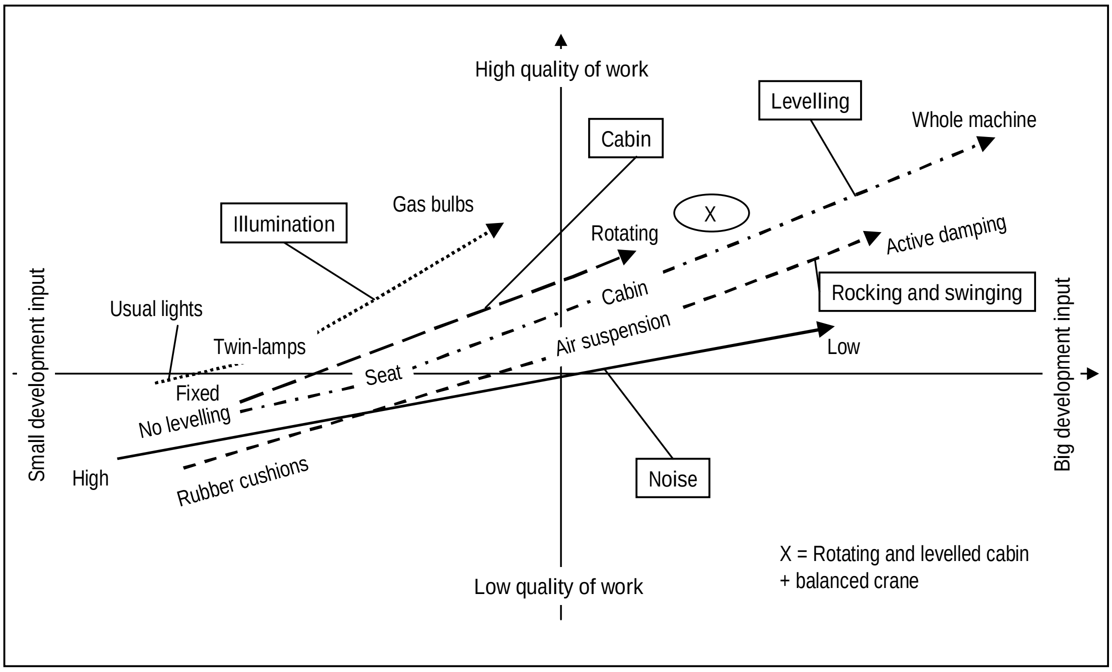

Figure 11. The role of different environmental factors in forest machine operation affecting the work result in logging according to the development inputs

5. Discussion and conclusions on the development potential

Based on the literature study and theme interview, it is clear that there still are great possibilities to develop the forest machines from the work result point of view. There are pure technical improvement possibilities (e.g. introduction of a spin control) and a full utilisation of the information technology (GIS & GPS), but also actions can be taken which through the operator indirectly can improve the work result in logging. An improved work result generally increases the productivity of the work. Organising of the operations is made easier as well, and operations in more demanding environmental conditions are often made possible year round or during the day and night.

Research and developments needs

The following is a list of R&D needs in order to improve work quality:

- Better visibility (illumination, no dazzling, visibility)
- Analysis of the CTI-system and eventual construction and testing of a test machine
- The properties of tyres (width, diameter, tread, pressure) and their development
- Control of the crane and its development (e.g. the automatic functions)
- The role of a rotating cab on the operator, his productivity and the work result
- Research into the role of levelling (seat, cabin, whole machine)
- Steering of the machine (turning radius, "cutting" of corners) and possibilities to develop a vehicle with frame-steering and turning wheels
- Research into the possibilities to utilise on-board weighing scales
- Lighter machine construction
- The role of tracks and comparison of different tracks
- The role of a balanced boggie and its comparison with a wheel
- The role of the size of the harvester head on the operation control, work result and productivity
- Possibilities to increase automation
- Possibilities of work rotation and its effect on a normal logging system
- The effect of a harwarder (harvester-forwarder) on the operator's work

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