Improvements of ergonomic assessment procedures for forest machines

– A comparative evaluation of three established test methods

Rolf Tobisch, Oscar Hultåker,
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The Swedish University of Agricultural Sciences
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– En jämförande utvärdering av tre etablerade testmetoder

Verbesserungen von ergonomischen Beurteilungsverfahren für Forstmaschinen
– Eine vergleichende Bewertung von drei eingeführten Prüfmethoden

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Abstract

Three established procedures – one Nordic, one recently developed Swedish based on the Nordic one, and one German procedure – for assessing the ergonomics of forest machines were evaluated by senior test engineers experienced mostly in the German procedure. Mostly, the three assessment procedures cover the same aspects. The largest dissimilarities exist in the rating schemes. The German procedure assesses most of the different aspects on a pass or fail basis while the other two result in ergonomic profiles considering severity and exposition. A working measurement method was developed based mainly on the Nordic procedure and complemented with items and sub-elements from the other two. The working method was used for measurements on five forest machines and the ergonomics of the machines were assessed according to the three procedures thus enhancing the test engineers' knowledge of the different assessment procedures. Their experiences were documented. Problems calling for improvements as well as advantages of the different assessment procedures are discussed. Recommendations for the development of European ergonomic guidelines for forest machines are given. A combination of the three procedures together with some methods improvements is expected to support the European ergonomic guidelines for forest machines to be developed.

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Abstract

Three established procedures – one Nordic, one recently developed Swedish based on the Nordic one, and one German procedure – for assessing the ergonomics of forest machines were evaluated by senior test engineers experienced mostly in the German procedure. Mostly, the three assessment procedures cover the same aspects. The largest dissimilarities exist in the rating schemes. The German procedure assesses most of the different aspects on a pass or fail basis while the other two result in ergonomic profiles considering severity and exposition.

A working measurement method was developed based mainly on the Nordic procedure and complemented with items and sub-elements from the other two. The working method was used for measurements on five forest machines and the ergonomics of the machines were assessed according to the three procedures thus enhancing the test engineers' knowledge of the different assessment procedures. Their experiences were documented. Problems calling for improvements as well as advantages of the different assessment procedures are discussed.

Recommendations for the development of European ergonomic guidelines for forest machines are given. A combination of the three procedures together with some methods improvements is expected to support the European ergonomic guidelines for forest machines to be developed.

It is advisable that the reader of this report is familiar with at least one of the evaluated assessment procedures.

Keywords: assessment procedures, cases, checklists, ergonomics, forest machines, guidelines, measurement methods

Preface

ErgoWood – Ergo-efficient mechanised logging operations – is a three-year project supported by the European Commission (contract number: QLK5-CT-2002-01190) aiming at developing guidelines on ergonomic matters for European users, buyers, and manufacturers of forest machines. The work will promote the development of safe and efficient forest machines, which are easy to use and maintain, as well as improving the sustainability in human resources. The project also involves developing and sharing of good examples of work crew building, work-shift scheduling, job rotation, and work enlargement in logging operation. Partners from Germany, Sweden, France, Norway, Poland, and the United Kingdom have participated in the ErgoWood work.

This report is a revised version of a deliverable of the ErgoWood project – deliverable 5 of work package 3. The report is a co-operation between the German Centre for Forest Work and Technology (KWF) and the Department of Forest Products and Markets at the Swedish University of Agricultural Sciences (SLU).

It is advisable that the reader of this report is familiar with at least one of the evaluated assessment procedures. Ergonomic Guidelines for Forest Machines in any of the Swedish, English, or Finnish editions (Gellerstedt et al., 1998; 1999a; b) is thus probably the one, which is most easily available through book retailers.

KWF – Kuratorium für Waldarbeit und Forsttechnik

KWF is the German Centre for Forest Work and Technology giving technical and scientific support to German forestry by:

- Improving technology and working conditions in forestry considering profitability, environmental compatibility, ergonomics, safety, and health.
- Giving decision support for users through assessment of forest technology.
- Mediation between science, forestry, and industry.
- Processing and translating into action of scientific test results as well as field experience in forest technology.
- Giving solutions for forest technological issues of topical relevance.

Department of Forest Products and Markets, Swedish University of Agricultural Sciences

The activities of the Department of Forest Products and Markets at the Swedish University of Agricultural Sciences include research, education, and information dissemination on wood sciences, industrial production processes, and business economics of the wood production chain in a national as well as an international perspective.

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We also thank Mr Karl-Heinz Litzke for his help in making it possible for us to assess two additional machines at the Kunsterspring Forest Worker Training Centre. We were actively supported by the staff there.

Summary

Three established procedures for assessing the ergonomics of forest machines have been evaluated: (i) the Ergonomic Guidelines for Forest Machines that is developed jointly by the Swedish University of Agricultural Sciences (SLU), the Forestry Research Institute of Sweden (SkogForsk), and the Swedish National Institute for Working Life (ALI), (ii) the Ergonomic Checklist for Forest Machinery that recently has been developed by SkogForsk and is used at the Swedish testing facility Svensk maskinprovning AB (SMP), and (iii) the German procedure for testing of safety and performance in forest machines that is used by the German Centre for Forest Work and Technology (KWF), and has been developed by the joint German testing facility Deutsche Prüfstelle für Land- und Forsttechnik (DPLF) in co-operation with KWF. Our aim is to provide a basis for discussions preceding the development of European technical ergonomic guidelines for forest machines within the EU supported project ErgoWood – Ergo-efficient mechanised logging operations.

The evaluation was made by senior test engineers experienced mostly in the German procedure. An initial comparison of the three assessment procedures revealed that the characteristics of the assessments do not differ much. The recommended tolerance values are also nearly always identical. However, there are some characteristics that are assessed in one procedure but not in the others. That regards skidders, winches, and remote controls. The largest difference between the assessment procedures is found in the rating schemes and classification of the machines. The guidelines developed by SLU, SkogForsk, and ALI use an assessment divided into items, which are sub-divided into a number of sub-elements. Each element is assessed separately thus considering severity and exposition. The final assessment of an item is based on the worst assessment attained by a single element. The end result is an ergonomic profile of the assessed machine. The procedure that is used at SMP has adopted most of the items and sub-elements from these guidelines. However, they are assessed differently. Each element is allotted a number of penalty points in which severity and exposition are considered. Within an item the points are added and compared with threshold values. The finally resulting ergonomic profile of this procedure is usually slightly better than that obtained by the procedure in the guidelines developed jointly by SLU, SkogForsk, and ALI. The DPLF checklists used by KWF for safety testing only differentiate between a machine fulfilling or not fulfilling minimum requirements. They do not classify the machines. However, in the framework of the tests of KWF data on machine performance are investigated. This documents important technical data serving as a ground for assessing the machines.

Based on the comparison of the three test methods a working measurement method was developed. It finds its basis in the guidelines developed by SLU, SkogForsk, and ALI. As some items and sub-elements are not fully covered by this procedure the working measurement method was complemented with items and elements

from the method used at SMP and from the German method of KWF. The working measurement method was used when assessing the ergonomics of five forest machines, thus making assessment cases. These assessment cases enhanced the experiences of the test engineers and their knowledge of the three different assessment procedures. The machines assessed were three harvesters, one forwarder, and one skidder. Apart from one of the harvesters, all machines were new and represented the state of the art of forestry technology. The test engineers' experiences were documented.

The assessment of the ergonomics of the five forest machines revealed that several items and sub-elements can only be usefully assessed with yes or no. It is not advisable to have ranking systems for all sub-elements classifying them into ergonomically better or worse. In the European ergonomic guidelines for forest machines to be developed an all black and white assessment should be applied for these characteristics. However, for many other items an ergonomic ranking seems to be useful. For these items, a ranking should be integrated into the European ergonomic guidelines for forest machines. Both the ranking systems used in the guidelines developed by SLU, SkogForsk, and ALI and the procedure used by SMP have advantages and disadvantages. A combination might be feasible.

In the assessment cases some noticeable problems were documented calling for further improvements in the European guidelines. The investigation reveals that the ergonomics of a forest machine cannot be fully assessed by two test engineers working together on a machine using a checklist. The measurements would probably produce much more useful results and the time required would be shortened if an expert of the particular machine were consulted during the work. The manufacturer should also provide additional information. Concerning some aspects alternative measurement solutions need to be developed. Alternative solutions would be advantageous for not having to carry out light and visibility measurements at night and for having cheaper methods for measuring the cab climate. These items will probably not be included in European ergonomic guidelines for forest machines with the current methods. For this purpose e.g. questionnaires, interviews, and diaries might also be used for the assessments.

In summary, a combination of the different procedures evaluated together with some over all methods improvements could be expected to benefit the development of the European technical ergonomic guidelines for forest machines.

Sammanfattning

Tre etablerade system för att bedöma ergonomin hos skogsmaskiner har utvärderats: (i) Nordiska ergonomiska riktlinjer för skogsmaskiner som är utvecklade gemensamt av Sveriges lantbruksuniversitet (SLU), Stiftelsen Skogsbrukets forskningsinstitut (SkogForsk) och Arbetslivsinstitutet (ALI), (ii) Ergonomisk checklista för skogsmaskiner som nyligen utvecklats av SkogForsk och används vid Svensk maskinprovning AB (SMP) samt (iii) det tyska system för att testa säkerhet och prestanda hos skogsmaskiner, som används av det tyska skogsarbets- och skogsteknikcentret Kuratorium für Waldarbeit und Forsttechnik (KWF) och som utvecklats av det gemensamma tyska testinstitutet Deutsche Prüfstelle für Land- und Forsttechnik (DPLF) i samarbete med KWF. Vår avsikt är att skapa en utgångspunkt för diskussioner inför utvecklandet av Europeiska tekniska ergonomiska riktlinjer för skogsmaskiner inom det EU-finansierade projektet ErgoWood – Ergo-efficient mechanised logging operations.

Utvärderingen utfördes av erfarna testingenjörer med vana främst från det tyska systemet. En inledande jämförelse av de tre bedömningssystemen visade att egenskaperna i bedömningarna inte skiljer sig mycket åt. De rekommenderade toleransnivåerna är också nästan genomgående desamma. Emellertid finns vissa egenskaper som bedöms i ett system men inte i de andra. Det rör lunnare, vinschar och fjärrkontroller. Den största skillnaden mellan bedömningssystemen är rangordningsshemata och klassificeringen av maskinerna. Riktlinjerna utvecklade av SLU, SkogForsk och ALI använder en bedömning indelad i avsnitt som i sin tur är indelade i olika granskningspunkter. Varje punkt bedöms separat med beaktande av risk och utsatthet. Den slutliga bedömningen av ett avsnitt bygger på den sämsta bedömningen av någon enskild punkt. Slutresultatet är en ergonomisk profil av den bedömda maskinen. Systemet som används vid SMP använder de flesta avsnitten och granskningspunkterna från dessa riktlinjer. De bedöms emellertid annorlunda. Varje punkt tilldelas ett antal straffpoäng där risk och utsatthet beaktas. Inom avsnitten läggs poängen samman och jämförs med gränsvärden. Den ur detta system resulterande ergonomiska profilen är vanligen något bättre än den som erhålls med systemet i riktlinjerna från SLU, SkogForsk och ALI. DPLF-checklistorna, som används av KWF för säkerhetstester, skiljer bara mellan en maskin som uppfyller eller inte uppfyller minimikrav och klassificerar dem inte. Däremot utreder man inom ramen för KWFs tester data avseende maskinprestanda. Då dokumenteras viktiga tekniska data som utgör en grund för att bedöma maskinerna.

Grundat på jämförelsen av de tre testmetoderna utvecklades en arbetsmätmetod. Den finner sin grund i riktlinjerna utvecklade av SLU, SkogForsk och ALI. Eftersom vissa avsnitt och granskningspunkter inte helt täcks in av detta system kompletterades arbetsmätmetoden med avsnitt och punkter från metoden som används av SMP och från den tyska metoden från KWF. Arbetsmätmetoden användes när ergonomin hos fem skogsmaskiner bedömdes. Därigenom skapades

bedömningsfall som utökade testingenjörernas erfarenhet och deras kännedom om de tre olika bedömningssystemen. Tre skördare, en skotare och en lunnare bedömdes. Förutom en av skördarna var alla maskinerna nya och representerade den aktuella tekniska nivån inom skogsteknologin. Testingenjörernas erfarenheter dokumenterades.

Bedömningen av de fem skogsmaskinernas ergonomi avslöjade att åtskilliga avsnitt och punkter bara kan bedömas tillfredsställande med ja eller nej. Det är inte lämpligt att ha rankningssystem för alla punkter och klassificera dem som ergonomiskt bättre eller sämre. För dessa egenskaper måste även i de europeiska ergonomiska riktlinjerna för skogsmaskiner en helt svart-vit bedömning tillämpas. För många andra avsnitt verkar emellertid rankning vara användbart och borde infogas i de europeiska ergonomiska riktlinjerna som skall utvecklas. Både rankningssystemen använda i riktlinjerna utvecklade av SLU, SkogForsk och ALI och systemet som används av SMP har fördelar och nackdelar. En kombination kunde vara lämplig.

I bedömningsfallen dokumenterades några tydliga problem med systemen som behöver lösas i de europeiska riktlinjerna. Undersökningen visar att ergonomin hos skogsmaskiner inte till fullo kan bedömas av två testingenjörer som arbetar tillsammans och använder en checklista. Mätningarna skulle sannolikt ge mycket användbarare resultat och den tid som krävdes skulle minska om en expert på den specifika maskinen rådfrågades under arbetet. Tillverkaren behöver också tillhandahålla tilläggsinformation. Avseende vissa aspekter behöver alternativa mätmetoder utvecklas. Alternativa lösningar vore fördelaktigt så att man inte behövde utföra belysnings- och siktmätningar under natten och för att ha billigare metoder för att mäta hyttklimatet. Dessa avsnitt kommer troligen inte med sin nuvarande utformning att ingå i de europeiska ergonomiska riktlinjerna för skogsmaskiner. För dessa avseenden kunde också exempelvis frågeformulär, intervjuer och dagböcker utnyttjas för bedömningarna.

Sammanfattningsvis kunde en kombination av de utvärderade systemen tillsammans med en övergripande metodförbättring förväntas vara till nytta för utvecklingen av de europeiska tekniska ergonomiska riktlinjerna för skogsmaskiner.

Zusammenfassung

Drei eingeführte Verfahren, mit denen die Ergonomie von Forstmaschinen beurteilt wird, sind bewertet worden: (i) die Nordische ergonomische Richtlinie für Forstmaschinen, die bei der Schwedischen Universität für Agrarwissenschaften (SLU), dem schwedischen Forstforschungsinstitut Stiftelsen Skogsbrukets forskningsinstitut (SkogForsk) und dem schwedischen Arbeitslebensforschungsinstitut Arbetslivsinstitutet (ALI) entwickelt ist, (ii) der Ergonomischen Checkliste für Forstmaschinen, die kürzlich von SkogForsk entwickelt worden ist und bei dem schwedischen Prüfungshaus Svensk maskinprovning AB (SMP) angewendet wird und (iii) die deutsche Prüfungsverfahren für Sicherheit und Leistung in Forstmaschinen, die im Kuratorium für Waldarbeit und Forsttechnik (KWF) angewandt wird und von der Deutschen Prüfstelle für Land- und Forsttechnik (DPLF) im Zusammenarbeit mit dem KWF entwickelt worden ist. Unser Ziel ist eine Diskussionsbasis für die Entwicklung einer europäischen technischen ergonomischen Richtlinie für Forstmaschinen innerhalb des EU-finanzierten ErgoWood Projekts – Ergo-efficient mechanised logging operations – zur Verfügung stellen.

Die Bewertung wurde von leitenden Prüfingenieuren durchgeführt, die sich vorwiegend mit dem Deutschen Beurteilungsverfahren befassen. Ein erster Vergleich der drei Beurteilungsverfahren zeigte, dass sich die Bestandteile den Beurteilungen kaum voneinander unterscheiden. Auch sind die geforderten Grenzwerte nahezu identisch. Es gibt jedoch auch Elemente, die in einer Methode beurteilt werden aber nicht in den anderen. Dies betrifft Skidder, Seilwinden und Funkfernsteuerungen. Die größten Unterschiede zwischen den drei Beurteilungsverfahren bestehen in der Auswertung und der Klassifizierung der Maschinen. Bei der von der SLU, SkogForsk und ALI entwickelten Richtlinie wird die Prüfung in einzelne Abschnitte unterteilt, die wiederum in mehrere Elemente zerfallen. Jedes Element wird getrennt beurteilt in der Beachtung von Risiko und Exponierung. Für die Beurteilung des Abschnitts wird die Beurteilung des am schlechtesten beurteilten Elements genommen. Dadurch erhält man ein Ergonomisches Profil von der zu beurteilenden Maschine. Die System die am SMP angewandet wird aufgreift zu der überwiegende Teil der Abschnitte und Elemente dieser Richtlinie. Lediglich die Beurteilung findet anders statt. Jedes Element erhält eine Anzahl von Strafpunkten wohin Risiko und Exponierung beachtet werden. Die Punkte innerhalb eines Abschnitts werden aufaddiert und mit einer Grenzwerttabelle verglichen. Dadurch kann man ebenfalls ein Ergonomieprofil erstellen, was in der Regel etwas günstiger ausfällt, als nach der von der SLU, SkogForsk und ALI entwickelten Verfahren. Die beim KWF bei der sicherheitstechnischen Überprüfung eingesetzten DPLF-Checklisten unterscheiden lediglich, ob die Mindestanforderungen erfüllt sind oder nicht. Eine Klassifizierung der Maschinen findet nicht statt. Jedoch werden im Rahmen der KWF-Prüfung auch Daten zur Maschinenleistung ermittelt. Diese dokumentieren wichtige technische Daten die eine Grundlage für eine Beurteilung der Maschine bilden.

Bei dem Vergleich der drei Prüfmethoden wurde eine praktikable Messmethode entwickelt. Die Grundlage der praktikablen Messmethode bildet die von der SLU, SkogForsk, und ALI entwickelte Richtlinie. Fehlende oder unzureichend geprüften Abschnitte und Elementen wurden aus den SMP- und KWF-Prüfmethoden übernommen. Die praktikable Messmethode wurde bei der Beurteilung von der Ergonomie der fünf Forstmaschinen benutzt, aus denen Beurteilungsfälle gemacht wurden. Die Beurteilungsfälle vergrößerten die Erfahrungen der Prüfingenieure und ihre Kenntnisse des verschiedenen Beurteilungsverfahrens. Es wurden drei Harvester, ein Forwarder und ein Skidder beurteilt. Außer einem Harvester waren alle Maschinen neu und auf dem heutigen Stand der Forsttechnik. Die Erfahrungen der Prüfingenieure wurden dokumentiert.

Bei der Durchführung der ergonomischen Beurteilung der fünf Forstmaschinen stellte sich heraus, dass es viele Abschnitte und Elementen gibt, die sinnvoller Weise nur mit ja oder nein beurteilt werden können. Eine Rangfolge für alle Elemente für ergonomisch besser oder schlechter ist nicht ratsam. Für diese Eigenschaften sollte auch in die europäische ergonomische Richtlinie für Forstmaschinen eine reine schwarz-weiße Beurteilung vorgenommen werden. Bei vielen Abschnitten ist es jedoch sinnvoll eine Bewertung der Ergonomie vorzunehmen. Diese sollte auch in die europäische ergonomische Richtlinie für Forstmaschinen, die entwickelt werden werden, einfließen. Ob die Auswertung der Abschnitte nach der SLU, SkogForsk und ALI entwickelten Verfahren oder der SMP Verfahren erfolgen soll, ist noch festzulegen. Gegebenenfalls wäre auch eine Kombination zwischen den beiden Auswertungen möglich.

Bei den Beurteilungsfällen wurden einige Probleme dokumentiert die in der Europäischen Richtlinie verbessert werden müssen. Es zeigt sich auch, dass die Ergonomie einer Forstmaschine nicht nur von zwei Prüfingenieuren alleine mit der Maschine anhand einer Checkliste zu beurteilen ist. Es wäre immer sinnvoll, um Zeit zu sparen und Besserer Resultat zu bekommen, bei der Prüfung auf eine Person zurückgriffen zu können, die die Maschine kennt. Weiterhin sind vom Hersteller zusätzliche Erklärungen abzugeben. Für einige Aspekte müssen alternative Messmethoden entwickelt werden. Alternative Lösungen wären vorteilhaft um nicht die Beleuchtung- und die Sichtmessungen nachts zu machen und um billigere Methoden für die Messung des Kabineklimas zu haben. Diese Abschnitte werden voraussichtlich mit seiner heutigen Gestaltung bei der europäischen ergonomischen Richtlinie für Forstmaschinen entfallen. Hier könnten auch zum Beispiel Fragebögen, Interviews und Tagebücher für die Beurteilung herangezogen werden.

Grundsätzlich wird erwartet, dass die Entwicklung der europäischen technischen ergonomischen Richtlinie durch eine Kombination der verschiedenen Beurteilungsverfahren und eine allgemeine Verbesserung der Prüfmethoden profitieren würde.

Table of content

Introduction

Large scale mechanisation of forestry in the Nordic countries with purpose built forest machines began in the 1960's (e.g. Bostrand, 1984; Drushka & Konttinen, 1997). The need for ergonomically efficient machines was early recognised. In Sweden an Ergonomic Checklist for Transport and Materials Handling Machinery were originally published in Swedish and English in 1969 (Hansson & Pettersson, 1969a; b). It was used for forest machines and has been revised several times. The last two revisions were carried out in 1998 and in 2003. The 1998 revision was done jointly by the Swedish University of Agricultural Sciences (SLU), the Forestry Research Institute of Sweden (SkogForsk), and the Swedish National Institute for Working Life (ALI) and was published in Swedish, English, and Finnish (Gellerstedt et al., 1998; 1999a; b). The 2003 revision was an effort by SkogForsk and the Swedish testing facility Svensk maskinprovning AB (SMP) (Löfroth et al., 2003).

In Germany the first official guidelines for assessing the ergonomics of forest machines were introduced in 1977 in West Germany (Rehschuh & Tzschöckel, 1977). This formed the basis for the ergonomic assessment procedures carried out by the German Centre for Forest Work and Technology (KWF). At that time only tractors were subject to official testing. Harvesters and forwarders were not used in German forestry. However, the assessments included several additional equipment to tractors that were used in forestry work, e.g. winches, hydraulic bundlers, butt plates, stabilisers, skid tongs, and cranes. The German assessment procedures have been continuously developed since then (DPLF, 2003; KWF, 2003).

In 1979 the Forest Engineering Research Institute of Canada (FERIC) published a preliminary work on assessing the ergonomics of Canadian forestry equipment (Zerbe, 1979). This report was updated in 1994 to account for the ongoing evolution in machinery and safety standards (Golsse, 1994a; b). Ergonomic checklists applied for forestry machinery also exist in other countries. However, these are often unpublished. The second last revision of the checklists from Sweden (Gellerstedt et al., 1998), published also in English and Finnish (Gellerstedt et al., 1999a; b), were also translated to e.g. Portuguese and Spanish.

ErgoWood

The work we report here is part of a project named ErgoWood – Ergo-efficient mechanised logging operations. It is a three-year project supported by the European Commission. Partners from Germany, Sweden, France, Norway, Poland, and the United Kingdom have participated in the work aiming at developing guidelines on ergonomic matters for European users, buyers, and manufacturers of forest machines. The work will promote the development of safe and efficient forest machines, which are easy to use and maintain, as well as improving the sustainability of the human resources. The project also involves developing and sharing good examples of work-crew building, work-shift scheduling, job rotation, and work enlargement in logging operation. Different ways of organising forest work will be investigated and assessed. Results on different matters are presented in this and other reports as well as in two handbooks. This report is a revised version of an internal deliverable of the ErgoWood project – deliverable 5 of work package 3. The report is a co-operation between KWF and SLU.

We present results from a comparative evaluation of three established European procedures for assessing the ergonomics of forest machines: (i) the Ergonomic Guidelines for Forest Machines developed in the Nordic countries by SLU, SkogForsk, and ALI (Gellerstedt et al., 1998), (ii) the Swedish Ergonomic Checklist for Forest Machinery recently developed by SkogForsk and used at SMP (Löfroth et al., 2003) derived from the previous one, and (iii) the procedure established in Germany composed by safety testing according to checklists of the joint German testing facility Deutsche Prüfstelle für Land- und Forsttechnik (DPLF) (DPLF, 2003) – developed and used by KWF – and testing of machine performance by KWF on their own (KWF, 2003).

Initially we compare which items and sub-elements that are included and tolerance values of the three procedures. We also compare the rating scheme and the subsequent classification of the machines. From the initial comparison we develop a working measurement method for the purpose of assessing forest machines according to the three evaluated procedures. Senior test engineers experienced mostly in the German procedure use the developed working measurement method for making assessments of five forest machines. Besides the experiences of the measurements we also discuss suitable assessment procedures for important ergonomic items not covered by the three evaluated assessment procedures. We present an appraisal of the assessment procedures including:

- Evaluating the time required for each item of the assessment procedures.
- Evaluating the competence and effort required for each item of the assessment procedures.
- An appraisal of the comprehensibility of the results.
- An evaluation of the suitability of the assessment items for ergonomic assessments.
- Evaluating if the assessments can be reproduced by various testing personnel in different locations.

We prioritise the different assessed items from an accidental and a health point of view. We discuss the most essential problems that appeared during the assessment work. Finally we give proposals for the new European technical ergonomic guidelines for forest machines to be developed regarding items to be included and methods to be used.

We advise the reader to be familiar with at least one of the evaluated assessment procedures. Ergonomic Guidelines for Forest Machines in either of the Swedish, English, or Finnish editions (Gellerstedt et al., 1998; 1999a; b) is thus probably the one most easily available. The procedures used by SMP (Löfroth et al., 2003) and by KWF (DPLF, 2003; KWF, 2003) are produced for internal use. This report thus mostly takes its point of departure from the Ergonomic Guidelines for Forest Machines. However, we present a more detailed analysis when any of the other assessment procedures is deviating.

Aim

The objective of this report is to provide a ground work for discussions preceding the development of European technical ergonomic guidelines for forest machines through a comparative evaluation of established ergonomic assessment methods for forest machines.

In order to ascertain the suitability of different procedures for assessing ergonomic aspects of forest machines the three established European procedures were to be compared – the Nordic assessment procedure recommended in the Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998), the Swedish procedure developed for use at SMP (Löfroth et al., 2003), and the procedure established in Germany composed by safety testing according to checklists of DPLF (DPLF, 2003) – developed and used by KWF – and testing of machine performance carried out by KWF on their own (KWF, 2003). Four forest machines – two harvesters, one forwarder, and one skidder – were to be assessed based on measurements with a working measurement method developed from the three available assessment procedures. The working measurement method had to be constructed in such a way that two test engineers should be able to make the required measurements of one forest machine within two working days. The assessments had to be carried out by senior test engineers experienced in the German procedure.

The purposes of the comparative evaluation were:

- To serve as a basis for discussions preceding the development of new ergonomic guidelines.
- To understand the ideas behind and evaluate the rating systems in the different guidelines.
- To identify essential, not so important, or discretionary assessment items for the manufacturers and the users of the machines with respect to ergonomics with the purpose of producing an easy to use checklist for the users.
- To identify the usefulness of the different assessment procedures.
- To investigate procedures for ergonomically important items not covered by current assessment procedures.
- To identify shortcomings in the current assessment procedures.

Method

The comparative evaluation of the three different assessment procedures under study was divided into four parts. Firstly, the different procedures were compared with the aim at identifying differences and developing a working measurement method. Secondly, the working measurement method developed was used for ergonomic measurements on five forest machines thus enhancing the test engineers' experiences. Thirdly, the test engineers' experiences were documented and discussed. Fourthly, the experiences of the test engineers formed the basis for suggestions regarding the development of European ergonomic guidelines for forest machines.

As the test engineers supposed to carry out the study were mainly experienced in the procedure used by KWF, a one week course was arranged by SMP in Umeå in July 2003, with the aim of increasing the knowledge of the guidelines set out by Gellerstedt et al. (1998) and the checklist derived from those by Löfroth et al. (2003). Two representatives of KWF attended the course together with other partners of ErgoWood.

Initial comparison of assessment procedures and development of a working measurement method

Originally it was planned to compare two different procedures for assessing the ergonomics of forest machines – (i) the Nordic procedure of the Ergonomic Guidelines for Forest Machines developed in Sweden jointly by SLU, SkogForsk, and ALI (Gellerstedt et al., 1998) and (ii) the procedure established in Germany composed by safety testing according to checklists of DPLF (DPLF, 2003) – developed and used by KWF – and testing of machine performance carried out by KWF on their own (KWF, 2003). However, the recently developed Swedish procedure used by SMP developed jointly with SkogForsk (Löfroth et al., 2003) were also included in the comparison as it provides a third alternative. Based on an initial comparison between the three different assessment procedures a working measurement method was developed by senior test engineers experienced mainly in the German procedure used by KWF.

Ergonomic measurements on five forest machines

The working measurement method was to be used by experienced test engineers for the measurements for the ergonomic assessments of four forest machines. One additional machine also came to be included in the study. The evaluation is thus based on the experiences from the assessment cases of five forest machines. One new harvester was assessed on the premises of KWF. This machine was scheduled for a regular assessment. One forwarder and one harvester were assessed on the premises of the German importer, with the kind assistance of the supplier. Both these machines were also new. In addition to this, assessments were also carried out on a harvester and a skidder at a forest worker school. The skidder had been used for about one year and the harvester was about ten years old. The latter relatively old machine was of particular interest for monitoring the ergonomic progress in the last ten years. Usually the machines assessed are factory new or at least less than one year old.

The assessments were carried through in 2004 by senior test engineers experienced in the procedure established in Germany. Two test engineers had the main responsibility for the assessments and took part in all the assessment work. On some occasions some more test engineers also experienced in the German procedure of KWF took part in the assessments.

Documentation and discussion of the assessments

The test engineers documented their experiences of the measurements and assessments in a self-reporting system. This gave the opportunity to later expand the discussion on advantages and disadvantages of the different assessment procedures, items, and sub-elements. A summary of the discussions were compiled.

In order to evaluate the working measurement method, the measuring and set-up times in hours were recorded for each assessment item. A grading system with three classes was devised for five additional criteria:

- The competence required: 1. Can be carried out by a suitably instructed person; 2. Have to be carried out by a test engineer with basic knowledge of forest machinery; 3. Can only be carried out by an expert with extensive knowledge of forest machinery.
- The effort required: 1. Simple aids and devices are required, e.g. a yard stick or a protractor; 2. Complex measuring devices are necessary; 3. Requires measurement on a test course or in a special laboratory.
- The comprehensibility of the measurement and its necessity: 1. Can be understood by an interested layman; 2. Is not clear at the first sight; 3. Can only be understood by an expert.
- The measurement definition: 1. Based on standards; 2. Based on internal test methods; 3. Largely based on estimates.
- The measurement reproducibility: 1. Exact measurement is possible; 2. Results depend on the testing personnel or the measurement conditions; 3. Results strongly depend on the testing personnel or the measurement conditions.

In order to decide upon the importance of the different assessed items the test engineers' experience of the relevance of the items from an accidental and health point of view were documented in three classes for each item:

- Accidental risk: 1. The risk of accident is very high; 2. There is a possible accident hazard; 3. The item is irrelevant for accidents.
- Health risk: 1. The health risk is high; 2. There is a possible health risk; 3. The item does not affect health.

Formulating suggestions for the development of European ergonomic guidelines for forest machines

Based on the discussions among the test engineers and from their experiences of the assessments with the working measurement method, summarising suggestions regarding the development of European ergonomic guidelines for forest machines were compiled.

Background data

The background of the test engineers

The measurements with the working measurement method and the following assessment were carried through by senior test engineers experienced in the German procedure for assessing the ergonomics of forest machines (DPLF, 2003; KWF, 2003). Before making the comparative evaluation forming this study two of the test engineers attended a one week course arranged by SMP in Umeå in July 2003, with the aim of increasing the understanding of the Nordic guidelines set out by Gellerstedt et al. (1998) and the Swedish checklist derived from those by Löfroth et al. (2003). Thus they had some experience of the Nordic and the Swedish assessment procedures.

The machines used for the assessment cases

Five heavy-duty forest machines were assessed in the assessment cases: two factory-new harvesters – a Valmet 911.1 and a Ponsse Beaver – a ten year old Timberjack 870 harvester, a factory-new Logset 5F forwarder, and a one year old HSM 805 skidder with a winch and skid tongs.

Valmet 911.1 (harvester) – factory new

The Valmet 911.1 is a harvester with a fully tiltable swivelling cab. The crane is located on the right side of the cab and turns with the cab. The reach of the crane is 9.75 m and the machine can fell trees up to 61 cm in diameter. The total weight of the machine without water filling is 17 100 kg. An engine of 140 kW powers the machine. The Valmet 911.1 is a 6-wheeler with an articulated frame steering. The main field of application is the felling of trees with a breast height diameter of 20 to 35 cm.

Ponsse Beaver (harvester) – factory new

The Ponsse Beaver is a 6-wheeled harvester with an articulated frame steering. The total weight of the machine with water filling is 16 600 kg. An engine of 125 kW powers the machine. The machine can fell trees up to 60 cm in diameter. The crane reach is 9.9 m. The main field of application is the felling of trees with a breast height diameter of 20 to 35 cm

Timberjack 870 (harvester) – ten years old

The oldest assessed machine was a Timberjack 870 built in 1994. It is safe to say that the technology of this harvester was not up to date. It had been running for 13 450 hours and showed visible signs of wear. The machine was well maintained and the ergonomically important parts were in their original state. Only the emergency exit was rendered unusable by the addition of a rear view mirror.

The Timberjack 870 is a 4-wheeler with an articulated frame steering. An engine of 112 kW powers the machine. The crane reach is 9.7 m. The cab can be tilted by

15° sideways. The total weight of the machine without water filling is 13 800 kg. The main field of application is the felling of trees with a breast height diameter of 14 to 25 cm. However, the machine can fell trees up to a diameter of 45 cm. Despite the age of the machine, the performance is comparable to modern machines.

Logset 5F (forwarder) – factory new
The Logset 5F is a medium sized forwarder with an unloaded weight of 14 820 kg and a maximum load capacity of 11 000 kg. An engine of 91 kW powers the machine. The maximum speed is 20 km/h. The machine has bogie axes in the front and rear making it an 8-wheeler. The machine was equipped with a Loglift F 72 crane with a reach of 7.2 m.

HSM 805 (skidder) – one year old
The HSM 805 is a skidder powered by an 85 kW engine. The machine is equipped with two winches with a towing force of 80 kN each and a 5.6 m long crane. The HSM 805 weighs 9 320 kg. This skidder is a four wheeled articulated frame steered machine.

Results

The comparative evaluation of the three assessment procedures under study was divided into four parts. Firstly, the three procedures were compared with the aim at identifying differences and developing a working measurement method. Secondly, the working measurement method developed was used for the ergonomic assessments of five forest machines with the three evaluated procedures. This formed assessment cases giving the test engineers enhanced experiences. Thirdly, the test engineers' experiences were documented. Fourthly, the experiences of the test engineers forms the basis for suggestions regarding the development of European ergonomic guidelines for forest machines.

Three procedures for assessing the ergonomics of forest machines

Three assessment procedures regarding the ergonomics of forest machines are compared: Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998), Ergonomisk checklista för skogsmaskiner (Löfroth et al., 2003), and Prüfliste Forstspezialmaschinen (Forstspezialschlepper, Rückezüge und selbstfahrende Vollernter) (DPLF, 2003) together with the machine performance tests by KWF (KWF, 2003). On the basis of this comparison a working measurement method is developed.

Nordic Ergonomic Guidelines for Forest Machines

The most comprehensive procedure for assessing the ergonomics of forest machines is the Nordic Ergonomic Guidelines for Forest Machines published in 1998 by Gellerstedt et al. in Sweden in collaboration between the Department of Operational Efficiency at the Swedish University of Agricultural Sciences (SLU), the Swedish National Institute for Working Life (ALI), and the Forestry Research Institute of Sweden (SkogForsk). In 1999 it was published in English as Ergonomic Guidelines for Forest Machines and also in Finnish. The aim of the Ergonomic Guidelines for Forest Machines is to provide guidance on ergonomic matters for manufacturers, buyers, and users of forest machines. It is a further development of checklists being used in Swedish forestry since the 1970's.

The guidelines consist of a general description of the importance of ergonomics followed by guidelines for ergonomic assessments. The different areas assessed are grouped into 16 items: (i) Cab access, (ii) working posture, (iii) cab, (iv) visibility, (v) operator's seat, (vi) controls, (vii) operating the machine, (viii) information, (ix) noise, (x) vibration, (xi) climate control in the cab, (xii) gases and particulates, (xiii) lighting, (xiv) instructions and training, (xv) maintenance, and (xvi) brakes and operator safety. The items are sub-divided into several elements. Regarding each sub-element the machine is assigned to one of five classes A to D or a class 0 for unacceptable ergonomics. Class A represents the best ergonomics. The assignment of classes considers the severity and exposition associated with the sub-elements. The final rating of an item is based on the worst assessment for a requirement regarding any sub-element. The end result of the assessment is an ergonomic profile of the machine, which can be compared to other machines. The rating finds its anthropometric background in ISO 3411 (1995).

The different measurements of the Nordic procedure by Gellerstedt et al. (1998) are of varying difficulty. Some might be carried through and be understood by a layman while others require highly skilled test personnel and expensive test equipment. Most measurements of the assessment procedure concern technical specifications of the machines. However, some measurements also concern the operator experiences of the machine being assessed. The procedure is developed for harvesters and forwarders, but the assessment procedures are general and should be applicable for all sorts of machinery used in forestry.

The basis of the assessment according to the Nordic procedure is found in standards applicable to the items being assessed and in the requirements of the EU machine directive 98/37/EC. However, the Ergonomic Guidelines for Forest Machines does not have any legal status. The agreement of buyers, sellers, and users of forest machines to follow the guidelines is voluntary.

Ergonomic Checklist for Forest Machinery

The Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998) has been revised by the Swedish testing facility SMP jointly with the SkogForsk (Löfroth et al., 2003). The aim of the Ergonomic Checklist for Forest Machinery is to supply forest machine manufacturers, users, and researchers with a suitable and easy-to-use tool for ergonomic assessments of forest machines.

Many questions and measurement methods in the procedure currently used by SMP are either left unchanged or only slightly modified compared to the Nordic procedure. The developed checklists assess 13 items: (i) Cab access, (ii) cab, (iii) visibility, (iv) operator's seat, (v) controls, (vi) working posture, (vii) information, (viii) noise, (ix) gases and particulates, (x) lighting, (xi) instructions and training, (xii) maintenance, and (xiii) brakes and operator safety. Some parts of the procedure are revised, which save assessment time and costs e.g. regarding visibility or the measurement of the cab climate. The checklists renounce inquiring for the experiences of operators of the machine, which makes the checklist to a higher degree relying on clearly defined standards and assessment procedures.

The largest modification in the procedure used by SMP compared to the Nordic procedure in the guidelines by Gellerstedt et al. (1998) is the introduction of penalty points for assessing the requirements within each item. Each measured sub-element receives points for the reached rating level: 0 points for level 1, 1 point for level 2, 2 points for level 3, 5 points for level 4, and 15 points for level 5. As a rule level 5 means that the ergonomics of an element is unacceptable. Each result is multiplied by a weighting factor of 2, 4, or 6, which depends on the ergonomic importance of the individual element. All penalty points for the elements of a particular item are added. The sum of penalty points is then compared to tabulated values to obtain an ergonomic profile for the particular item. The final rating of the machine into one of five classes A to E, where A is the ergonomically best class, is based on the total sum of points. Class E indicates that the machine is ergonomically unacceptable. The assignment of penalty points considers the severity and exposition associated with the sub-elements. This rating procedure usually results in a slightly better rating of the machine than in the previous guidelines. That is a direct result of the point system, which prevents that an unfavourable assessment of a single element, which might be difficult to fulfil, leads to a severe down grading of the rating of a whole item. However, some important elements are classified as very important points (VIP) meaning that the level 1 requirement for that specific element has to be full-filled in order for the item to be classified as class A. The end resulting classification is an ergonomic profile, which may be compared to other machines.

The assessment involves measurements of varying difficulty. The focus of the measurements concern technical specifications. The procedure is developed for harvesters and forwarders. However the assessment procedures are general and should be applicable for all sorts of machinery used in forestry regarding the aspects assessed.

In appendices a copious list of requirements that must be met is presented. The questions in this part can only be answered by yes or no and does not include a division into ergonomic assessment classes from better to worse.

The basis of the assessment according to the procedure used at SMP is found in several standards applicable to the items being assessed and in the requirements of the EU machine directive 98/37/EC. The Ergonomic Checklist for Forest Machinery does not have any legal status.

Prüfliste Forstspezialmaschinen (Forstspezialschlepper, Rückezüge und selbst-fahrende Vollernter) together with the machine performance test by KWF

The German procedure developed by the German Centre for Forest Work and Technology (KWF) are continuously being updated. It includes ergonomic and safety requirements. One part is the safety testing according to collaborative checklists of the joint German testing facility DPLF to be used for assessing agricultural, forestry, and gardening machines. Special checklists exist for each type of machinery e.g. harvesters, forwarders, and skidders and are also available for winches and remote control systems. The forestry checklists are developed and the tests carried out by KWF (DPLF, 2003). In addition to this, KWF carries out additional specific assessment procedures for each machine type for assessing machine performance including several key ergonomic characteristics such as noise and vibration (KWF, 2003). The target groups are test institutes, manufacturers, and machine dealers.

The ergonomic and safety assessment according to the DPLF checklists is divided in 26 items of which some are not applicable for purpose built forest machines. The assessments depend on the compliance with standards and technical regulations. The different measurements of the German procedure are of varying difficulty. Some might be carried through and be understood by a layman while others require highly skilled test personnel and purpose constructed test equipment. A machine can only pass or fail each item of the assessment. Either the ergonomics are acceptable or not. Machines that do not comply with the requirements need to be rectified. If the rectification of e.g. a sub-standard ladder requires the complete re-designing of several machine components the machine may be left in the current state if the operator is only subjected to minor risks.

In addition to the ergonomic assessment by test engineers according to the DPLF checklists, KWF also carries out performance assessments. Where applicable, the assessment includes certificates of environmental compatibility, e.g. an eco-audit according to the ISO 14000 system (see ISO 14001, 2004). The manufactures have to present declarations concerning legal requirements and technical standards. The KWF performance assessment requires that the machine manufacturer or dealer supply all documents related to the machine as well as specifications regarding special requirements. In addition to this, KWF asks for supplementary reports concerning specific properties of the machine, which can only be measured at great expense. The machine performance assessment also comprises a review of the results from an operator's diary, interviews, and questionnaires from a sample of operators. Part of the information contained in the performance assessment by KWF is also used for the assessments according to the DPLF checklists. The machine performance assessment of KWF is a documentation of relevant technical and performance data of the machine and includes a rating of the assessed machines in five classes from very good to insufficient.

Regarding anthropometric standard the German assessment procedure is based on several sub-standards derived from ISO 3411 (1995). The basis of the assessment according to the KWF procedure is found in standards applicable for the items being assessed. The testing procedure of the KWF has adopted the requirements of the EU machine directive 98/37/EC.

Comparison between the three assessment procedures
It seems as if the German procedure of KWF (DPLF, 2003; KWF, 2003) is the one of the three evaluated procedures that has the strongest legal status according to e.g. the EU machine directive 98/37/EC. The Nordic procedure of the Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998) and the one used at SMP (Löfroth et al., 2003) also to some extent rely on the EU machine directive. However, basically they rely on voluntary agreements within the industry.

The three assessment procedures all aim at manufacturers of forest machines. However, they all also aim at different other target groups. The Nordic procedure also aim at buyers and users of forest machines. The procedure used by SMP also aim at machine users and researchers besides manufacturers. The procedure used at KWF also aim at testing institutes and machine dealers besides manufacturers.

The principal items and sub-elements of the three assessment procedures are very similar. E.g. the minimum applicable tolerance values are usually the same. The different assessment procedures have their basis in the same anthropometric standard, i.e. ISO 3411 (1995). However, the procedures cover slightly different items. The German procedure developed and used by KWF has special checklists for winches and remote control systems, which are not included in the other procedures. The procedure used at SMP has adapted most of the items from the Nordic procedure apart from the items operating the machine, vibration, and climate control in the cab. The items in the SMP procedure are divided into individual elements that usually resemble those found in the Nordic procedure.

The most important difference between the three assessment procedures is the rating schemes. Partly the German procedure used by KWF within the framework of the DPLF checklist only differentiates between machines that fulfil the necessary requirements for performing specific tasks and those that do not fulfil them. However, the additional performance tests of KWF document the machine performance and makes a rating of the machine regarding a number of technical key characteristics including some ergonomic aspects. In the Nordic procedure the assessment is divided into 16 items, which are assessed and classified individually. The overall class of a particular item corresponds to that of the element with the lowest rating thus resulting in an ergonomic profile of the machine. In the procedure used by SMP the elements are assigned penalty points and weighted according to their importance from an ergonomic point of view. The final amount of penalty points result in an ergonomic profile with usually a slightly better classification of the machine than in the Nordic procedure. In the Nordic procedure all aspects are assessed on a rank ordered scale. In the SMP assessment and the German procedure there are questions which can only be answered with yes or no. A rating into ergonomically good or bad is not possible for those items.

The German procedure used by KWF is the simplest procedure for assessing machines of the three compared. No weighting of the answers is required after completing the DPLF checklists. For the separate testing of machine performance additional information is collected from manufacturers and users. The Nordic measurement methods and assessment procedure is the most comprehensive but takes much longer time to carry through and includes costly measurements on some items, e.g. on cab climate. The procedure used by SMP is more easy-to-use than the Nordic one by excluding some items difficult to measure by test engineers or items that are time consuming or expensive to carry through, i.e. operating the machine, vibrations, and climate control in the cab.

Data collection methods of the three assessment procedures

In the assessment procedures different data collecting methods are used. Checklists are usually based on EN or ISO standards. They are useful for measuring a wide variety of technical parameters and are used in all the three evaluated procedures. Processing the assessment procedures prescribed in checklists usually involves two test engineers working with the assessment procedure. Assessments of items such as vibration and noise require measurements in working conditions on the forest sites as they are very difficult to carry out on the test premises. Moreover, experts are better able to assess the operation of the machine under normal working conditions than under test premises. For safety aspects, which might be difficult to properly assess on either test premises or under working conditions, manufacturers' declarations may declare that the machine complies with relevant standards and regulations. Such declarations have to be supplied by the manufacturer or dealer declaring that the machine complies with the relevant standards and regulations and describe the measures taken to achieve this compliance. All the three procedures to some extent use manufacturers' declarations. The most comprehensive use is found in the German procedure.

Questionnaires might be used to study opinions by operators and others regarding the practical suitability of the machines being assessed. It is a form of field report about the machine. When using questionnaires efforts have to be made for getting the respondents completing them. Thus the questionnaires should be designed to motivate the respondents to participate. If possible, the respondent himself should obtain some advantage by filling out the questionnaire. Interviews at working sites or by phone are another mean of posing specific questions not feasible in questionnaires. When carrying out measurements on the forest sites there is an excellent opportunity for interviewing. Respondents are usually much more inclined to participate in an interview than to fill out a questionnaire. Interviews may also be carried out on telephone and could be of quantitative or qualitative nature. Thus interviews might be a mean to make sure the respondents answer questions otherwise also possible posing in distributed questionnaires. Furthermore operators may keep a diary for some period of time for obtaining data on their experiences. Diaries are useful for obtaining data concerning the performance of the machine, the maintenance requirements, and fuel consumption. In the KWF performance test of the German procedure questions, interviews, and diaries are used for collecting data.

Development of a working measurement method

From the comparison of the three established assessment procedures being evaluated it was obvious that the methods cover mainly the same aspects. Thus we developed a working measurement method to make the measurement work more effective. It finds its basis in the items and sub-elements of the Nordic procedure by Gellerstedt et al. (1998). This is complemented with items and elements from the Swedish procedure by Löfroth et al. (2003) and the German one by KWF (DPLF, 2003; KWF, 2003). The working measurement method includes all measurements required for assessments according to any of the three procedures.

The working measurement method thus covers:

- Machine data
- Cab access
- Working posture
- Cab
- Visibility
- Visibility diagram
- Operator's seat
- Controls
- Operating the machine
- Information
- Noise inside the cab
- Noise outside the cab
- Vibrations
- Climate control in the cab
- Gases and particulates
- Lighting
- Illumination diagram
- Warning signals
- Operator's manual
- Training
- Maintenance
- Brakes
- Operator safety
- Mental stress
- Winch
- Remote control

Experiences of the assessment cases

We applied the working measurement method in five assessment cases thus assessing the ergonomics of five purpose built heavy duty forest machines according to the three assessment procedures. Experienced test engineers assessed the ergonomics of two factory-new harvesters – a Valmet 911.1 and a Ponsse Beaver – a ten year old Timberjack 870 harvester, a factory-new Logset 5F forwarder, and a one year old HSM 805 Skidder with a winch and skid tongs.

The experiences of the test engineers from the assessment cases were collected in their own documentation and in discussions among them. The experiences are presented below for each assessed item separately. We thus make clear disparities between the three assessment procedures, noticeable problems experienced in the measurements and proposals for solutions, and other experiences from the measurements. Thereafter, giving an overview of the experiences, we present some key values regarding the measurements.

In practice the measurements and the assessment process according to all three procedures evaluated is an integrated inseparable process. Our overall impact from the assessment cases is that there is a need for more than two test engineers in order to carry out all the measurements required for a comprehensive assessment. The time restrictions of our study of not using more than two working days of two test engineers for assessing one machine restrict the comprehensiveness of the measurements

Machine data
The item of machine data comprises specifications of the manufacturer, type, serial number, weight of the machine, and much more in all three procedures. They are required for identifying the assessed machine and the production series. Some data may be found in the manuals. In other cases the finding of the data could require great effort.

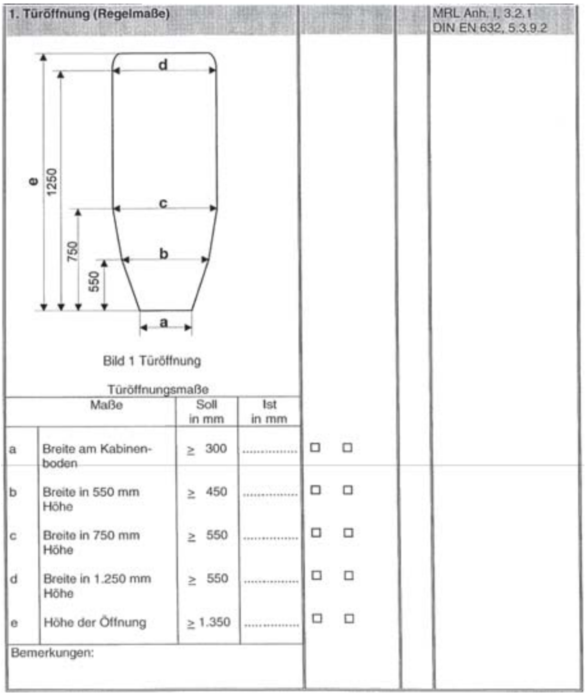
The presence of an expert of the particular machine, e.g. an operator or a service mechanic, could facilitate the finding of data. The following data should be specified: (i) Machine, (ii) motor, (iii) wheels, (iv) crane, (v) articulation joint, (vi) grapple, (vii) harvester head, (viii) winch, (ix) remote control, (x) control, and (xi) software. The assessment item of machine data are of no importance for the ergonomics.

Cab access
The minimum requirements for the cab access item are comparable in all three assessment procedures. The German procedure includes acceptable diameter ranges for the handrails and handles and recommends a minimum distance of 50 mm between handrails and the mounting surface. This ensures that the handrails and handles can be used safely with gloves. Also demanded is a three-point contact for mounting, i.e. two feet and one hand or two hands and one foot in contact with the machine. The three-point contact may be abandoned under defined circumstances. Working platforms are also assessed. According to the KWF measurements, a distinction is made between steps with a pitch <70° and ladders with a pitch of >70°. Steps are checked to see if the step size is observed (2 * step width + rise ≤700 mm). In the procedure used by SMP and in the Nordic procedure the minimum clearance (≥150 mm) between the step and the machine is used. In the assessment according to the German procedure the measurement is made from the front edge of the step (≥150 mm). The procedure used by SMP and the Nordic procedure prescribe just one mean of access. The German procedure open for assessing more than one mean of access. The Nordic and the German procedures look for emergency exits, which the procedure used by SMP does not.

Additional means of access must also be assessed and should be included in the assessment of the maintenance item including also access to maintenance points. The requirements for the access to maintenance points can be less stringent than for the cab access. It could be difficult to integrate additional means of access in a rating system with penalty points as in the assessment procedure used at SMP.

The number of points would vary with the number of accesses. This is not a problem with the Nordic and the German procedures. The maintenance points sometimes may be accessed by moveable ladders, which should lead to a reduced rating. It would be better to measure the minimum clearance between the step and the machine from the front edge of the step according to the KWF procedure than according to the procedure used by SMP and the Nordic procedure. The measurements should be taken on the step with the least clearance.

A clear definition of the measurement points is required for determining the width and height of the cab door. The matter is illustrated by the opening of the operator's door. The definition for the size of the door is comparable in all three assessment procedures. Figure 1 depicts the definition according to the German procedure.



	Maße	Soll in mm	Ist in mm		
a	Breite am Kabinen-boden	≥ 300	....	□	□
b	Breite in 550 mm Höhe	≥ 450	....	□	□
c	Breite in 750 mm Höhe	≥ 550	....	□	□
d	Breite in 1.250 mm Höhe	≥ 550	....	□	□
e	Höhe der Öffnung	≥ 1.350	....	□	□

Bemerkungen:

Figure 1. Minimum sizes for the operators' door from the DPLF checklists used at KWF (DPLF, 2003).

Figure 2 illustrates the practical problems of measuring cab access. The door restricts the lower width of the entrance. Furthermore, the mounting of the seat means that the full width cannot be used. Which width should we assess? In which way is the angle to the other components taken into account? In many cases the width and the height of the upper part of the entrance are obstructed by gas operated springs. How to measure this width must be clearly defined in the new European ergonomic guidelines.

Figure 2. Measuring the door width in the assessed Valmet 911.1.

The emergency exit, as well, should have a minimum length and width as is prescribed in the KWF procedure. Failure to comply with this should lead to downgrading. The emergency exit of one of the machines was blocked by an additionally mounted rear view mirror. In order to avoid this, the emergency exit should be opened in the test.

The anti-slip features of the steps and platforms are of great importance. Perforated panels are best suited for this purpose. If mounted above a closed surface, it should be possible to remove the steps and platforms for cleaning purposes. A roughened surface with sand paper is insufficient and a smooth panel surface should be rejected.

Working posture

Working posture is not assessed to the same extent in the German procedure as in the procedure used by SMP or in the Nordic procedure.

From practical reasons the cab, seat, visibility and controls should be assessed before assessing the working posture as is done in the procedure used by SMP.

Cab

The seat reference point (SRP) is not clearly defined on the sketches in the measurement instructions of any of the three assessment procedures as the seat surface and backrest are presumed to be a flat surfaces. Furthermore, the seat surface and backrest are placed in a horizontal and vertical position respectively. In reality, the surface of the backrest facing the operator is convex in the vertical direction and concave in the horizontal direction. The seat surface is adapted to the form of the buttocks. The seat has a ridge in the centre and troughs on the sides. The surface is uneven in all directions.

The new European ergonomic guidelines must include a clear definition of the seat reference point (SRP). Alternatively the seat index point (SIP) (see ISO 5353, 1995) may be used. Another possibility is to clearly refer the SRP to the SIP.

In order to prevent crushing, the German procedure prescribes a clearance between the seat and the adjacent components of at least 25 mm. This clearance is difficult to maintain with a swivelling seat. The proposal for European guidelines for forest machines should take into account that a swivelling seat is not necessary in a swivelling cab.

Visibility
Visibility to the front, left, and right is covered as one single item in the SMP and the Nordic procedures. The procedure in use at SMP and the Nordic procedure prescribe that the front wheels must be visible. Moreover, the front wheels need to be defined.

Visibility to the right may differ from the left side as the crane may be mounted on the side of the cab. In some machines the operating direction is not the same as the driving direction. In most cases, the operator should always be able to see the first wheels in the travelling direction during work.

It would be better to deal with each direction separately. Presumed that the height of the cabs are approximately the same it would be simpler to measure the angle of upward view rather than the height above ground at a distance of 10 m. The required upward field of view needs to be defined for skidders.
The use of a camera system should be added into the item.

Visibility diagram
Since 1999 a visibility diagram is no longer required according to the German procedure. Up to then, this diagram was created for each assessed machine. However, the persons responsible for the assessment declared that the time required for this procedure was disproportional to the actual benefits of the diagram. This is an item where the layman or operator would be unable to carry out the assessment and specialist equipment is needed.

The significance of the visibility diagram is very low compared to the effort required to produce it. If the brief description of the visibility described in the previous sub-section is insufficient, then a simpler method than the current visibility diagram must be devised.

Operator's seat
The sideways pitch is added in the procedure used by SMP compared to the other procedures. The seat reference point (SRP) is not clearly defined in any of the three procedures. In the Nordic procedure and in the procedure used at SMP the armrest pitch is defined as the angle between fore arm and upper arm. This angle is useful for ergonomic considerations but it is impossible to measure. The seat height, length of armrests, and the height of the armrests often deviate from the

recommendations in the Nordic procedure and in the procedure used by SMP. The values from the working measurement method used on the five machines are recorded in Table 1. The seat damping may be limited in the upper and lower position.

The rear panel of the cab often restricts the fore and aft adjustment of the seat. Usually the seat cannot be swivelled in the rear position. The restriction depends on the position of the backrest.

Table 1. Recordings from measurements on operator's seat

	Seat height	Armrest length	Armrest height
Valmet 911.1	44 - 58	20 - 28	18 - 29
Ponsse Beaver	41 - 54.5	29.5 - 33	19 - 30
Timbejack 870	40 - 53	33 - 37	24.5 - 32
Logset 5F	37 - 48	33 - 40.5	18 - 35
HSM 805	41 - 54	14.5 - 23.5	fixed 19
Recommended	40 - 65	20 - 30	15 - 27

The sideways pitch added in the procedure used by SMP should be adopted in the new European guidelines for forest machines. The height adjustment of the joysticks in relation to the armrests should also be part of the ergonomic assessment. A better definition of the lower seat position is required. The armrest pitch should better be measured as a deviation from the horizontal. The achievable parallel distance between the armrests often depends on the length settings. We suggest that the distance between armrests should be measured in the middle length position.

A defined backrest angle is required for measuring these adjustments. The backrest is usually convex in design. This requires a clear definition of where to position the protractor in order to measure the backrest adjustability.

In some seats the height of the lumbar support can be adjusted along two fixed points. This is better than one fixed point but even better would be the possibility for adjusting the point. The horizontal adjustability of the lumbar support must be formulated more precisely. The structure of the seats varies considerably. The armrests may be attached to the backrest, the seat surface, or the sub-structure. If the armrests are fixed to the backrest they will move as the backrest is adjusted. The same applies to the seat surface. This might have positive effects and may be part of the design. However, the adjustments for each sub-element must be clearly defined for the assessment.

Seats with an active damping system are now available on the market. The assessment must take this into account.

Controls

In the German procedure a special dummy for measuring the position of the controls is used. The dummy is placed on the operator seat and a mass of 75 kg is applied. Then each button and pedal is touched with a special pointer. Special assessment software is used to determine and graphically depict the position of the control from the length of the pointer, the angle of elevation, and the lateral angle.

The seat adjustments must be clearly defined for the measurement of controls. In the case of swivelling seats it is necessary to note whether the measurements are taken in the driving or working direction. This requires two different measurements. The set-up of the dummy of the German procedure is time consuming. However, the results are somewhat more exact than those obtained by measuring tape and spirit level. It is questionable whether it is worth the extra effort. The actuating forces are not part of the scope of the German procedure.

A steering wheel is no longer mandatory in forest machines. Some machines are steered using levers or a small wheel mounted on the armrest. Questions on steering wheels do not apply in these cases, in particular questions regarding the free space around the steering wheel. Some newly developed joy-stick type controls are neither finger tip nor hand operated in the way defined in previous measurement methods. Thus, new more suitable measurement methods and assessment criteria has to be developed for this type of joy-stick controls (Figure 3).

Figure 3. Ergonomic joy-stick.

Operating the machine

The operation of the machine could not be determined reliably with two test engineers using a checklist. For some instances the questions of the current procedures could be modified to enable the test engineers to answer them precisely. This part of the assessment would better benefit from the presence of a machine operator with experience of the machine being assessed. However, it will not be possible to adequately assess the ergonomically important topic of operating the machine within two assessment days.

Information
The measurement time for the item on information from the machine varies from machine to machine.

The assessment of the information item requires the presence of an additional person who is familiar with the machine. This could be an operator who has used the machine for a longer period of time or was trained by the manufacturer or dealer.

A skidder operator working outside the cab using a remote control has difficulties receiving information from the machine. Bundling the error readings and triggering the horn could remedy this. The operator could then goes into the cab and investigate the error readings. Another alternative would be to transmit the error readings to the remote control. A bundled error message would probably suffice this as well and the operator would have to enter the cab to locate the problem.

Noise inside the cab
According to the German procedure noise is measured inside the closed as well as the opened cab. According to the Nordic procedure and the procedure used by SMP the engine should be running at the rated speed and the air conditioner level should be set to midway.

The German procedure is useful especially for skidders, since skidder operators often work with an open door. It is useful to measure the engine noise and the air conditioner separately at different levels in order to determine the main source of noise, as in the Nordic procedure and the procedure used by SMP. The objective should be to minimize the ventilator noise. In many machines the ventilator is louder than the engine noise. In order to obtain a measurement of the total exposure, the engine and the air conditioner should be measured simultaneously. It is important to make sure the on-board radio is switched off during the noise measurements.

A precise assessment of noise inside the cab requires measurements in working conditions. For an overview, a measurement in the cab at rated speed and with the air conditioner running will be sufficient. The assessment can be carried out for the left and the right ear in succession. One measurement of the dB(A) value is sufficient. If this is too high, then the dB(C) value will be too high and vice versa.

Noise outside the cab
The cable skidder operator regularly works outside the cab to skid logs. This job means that the engine sometimes needs to run at high speed. The operator is then

exposed to the noise of his own machine. In harvester and forwarder work the operator rarely needs to leave the cab. However, on certain occasions, e.g. after a windfall, other persons may be working in the vicinity of the machine. These persons have to be protected from noise.

The measurement of noise outside the cab requires that the machine is positioned in a free space. This may involve moving the machine to a field test location.

Vibrations
Vibration measurements are carried out in normal working conditions. The Nordic assessment procedure describes a technique for measuring vibrations in normal working conditions with both standardised and subjective measures. The German performance assessment by KWF requires that the periods spent on different tasks should be recorded during the vibration measurement. E.g. in the case of a forwarder the periods are recorded when the machine is being driven, loaded, and unloaded. These times and the relevant vibration values are converted to standardised norm values.

The results of vibration measurements might be difficult to interpret as they depend on the operator, the ground conditions, the type of wood, traction aids, etc. However, measuring in working conditions is preferable to measuring on a test circuit. A test circuit will always be a compromise and is only an inadequate representation of reality. It is important to remember that vibration measurements have an inherent error of about 10%.

Climate control in the cab
A functional air-conditioner is an important contribution to the comfort of the operator. Very exact techniques can be devised for this item as are described in the Nordic assessment procedure requiring that the machine or relevant parts of it such as the cab, the engine, and the radiator is placed in a climate chamber.

Unfortunately the exact techniques of the Nordic procedure require that the climate chamber must be sufficiently large. It is doubtful if these measurements can be completed in one day, since the chamber must be cooled to -20°C and then heated to +27°C. The technique requires that the whole machine must equilibrate with the external temperature.

Previous experience gathered has shown that even after equilibrating the machine for 13 hours, the hydraulic fluid was still 15K warmer than the surrounding temperature. The effort and the expenses of transporting a machine to a climate chamber exceed the value of the measurements. A relatively simpler measurement technique has been developed but did not meet the requirements posed (Tobisch et al, 2002).

In order to make a statement about the quality of the air-conditioner it would be possible to ask the operator. However, this means that the machine must have been used for at least one summer and one winter season. Such an assessment will not be transferable to other climatic conditions. The temperature distribution in the cab during heating and cooling is relatively easy to measure. An interesting aspect in this context would be the temperature distribution in the cab after a door has been opened.

Gases and particulates

The assessment item of gases and particulates is not included in the German procedure and in the procedure used at SMP. Moreover, the purification class of the filters in the cab air intakes, which is an item in the procedure in use at SMP, could not be ascertained for any of the machines assessed. This information could be obtained in a manufacturer's declaration.

Gases and particulates were not assessed in the assessment cases with the working measurement method.

Lighting

Skidders are not required to be equipped with lights according to the German procedure.

Lights are not very useful in a cable skidder because it is not possible to sufficiently illuminate the end of a 100 m long cable without an excessive effort.

A basic overview of the performance of the lighting unit can be obtained by determining the type, number, power, direction, and location of the lamps. These values, however, are insufficient for assessing the quality of the illumination. Matters could improve with a method determining the location and direction of the lamps. The light distribution of the lamps could then be calculated using the known radiation patterns. The lighting assessment has to include comparisons between halogen and xenon lamps.

Illumination diagram

The method with illumination diagrams is used to make statements about the quality of the lighting. The measurements depend on the angle of incidence of the radiated light at a sensor. According to the currently used techniques the sensor must be held horizontally. The Nordic procedure and the procedure used by SMP prescribe measurement points 2 m around the harvester head or grapple. Since 1999 the regular presentation of an illumination diagram or lighting curve has been excluded from the assessments carried out in Germany. Since then, these measurements are only carried out when there are outspoken complaints about the lighting or when weak illumination is suspected.

The method with illumination diagrams is associated with a large error. Furthermore, this type of measurement does not correspond to the real light conditions as experienced by the operators. The position of the measurement points prescribed in the Nordic procedure and in the procedure used by SMP must be more clearly defined.

Warning signals
The assessment techniques of the warning signals are comparable in all three procedures.

A skidder operator working outside the cab using a remote control has difficulties getting warning signals from the machine. Bundling the error readings and triggering the horn may remedy this. The operator could then goes into the cab to investigate the error readings. Another alternative would be to transmit the error readings to the remote control. A bundled error message would probably suffice this as well and the operator would have to enter the cab to locate the problem.

Operator's manual
The operator's manuals are increasingly stored in the on-board computer. If the on-board computer can be operated independently from the machine it is sufficient for a printed excerpt of the manual to be available in the machine containing the instructions for restarting the on-board computer. Such a printed excerpt must also include the circuit plan and the relevant fuses.

The query "Ergonomic instructions, e.g. legroom, controls…" of the procedure in use at SMP does not make any sense. If it is to be used, it needs to be reworked.

Training
Two test engineers dealing with a machine on test premises cannot answer questions on training. The manufacturer's declaration, questionnaires, and operator interviews are better techniques for obtaining the relevant information about training on a specific machine.

Maintenance
The machine maintenance manuals are used for an assessment based on the maintenance index SAE J817/2 (1991) in the Nordic and the SMP procedures. The procedure used in Germany prescribes that the feed openings for fluids must be located less than 1.5 m from ground level or near a safe foothold. The German procedure also demands safe filling, draining, and collection of fluids.

The maintenance instructions contained in the manuals of the assessed machines varied considerably. E.g. the manual of one machine recommends that the air intake filters should be cleaned daily. However, the recommendations of another machine state that the same filters should be cleaned when necessary. In a third manual, cleaning of the air filters is not mentioned at all. The same inconsistencies could be found in relation to checking the tyre pressure. Before a maintenance index is introduced as a standard method, standardized values must be determined for standard tasks. It is also very unclear how to assess some of the maintenance tasks. The instructions for completing the tables of the maintenance index should be illustrated with examples.

A vacuum pump should be stored in the machine to reduce the loss of oil in the case of a leakage in the hydraulic system. This should be included in the assessment system.

Brakes
The brakes are not tested at KWF in their procedure. The German procedure relies on the fact that the machines are generally licensed for road traffic. This license is issued by a different test authority where brakes are sufficiently assessed.

No operator of the assessed machines wanted to carry out a full braking test. For this reason, the assessment of brakes were not carried out. Stop brake measurements revealed that the brakes failed at an incline of 20% in one of the machines. Any brakes that are good enough for road traffic will probably be sufficient in the forest. The failure of the stop brake assessment of one of the machines mark the importance of break measurements.

Operator safety
The German procedure contains a number of sub-elements in relation to operator safety:

- The rims must not be separable as long as they are on the machine. They must not be joined by spot-welding or countersunk bolts.
- Locking pins or similar objects must have captive securing components or must be connected to the device.
- Provisions must be made to guarantee safe filling and draining of operational fluids.
- Wheel blocks must be present
- The maximum traction force and bearing pressure must be indicated on the towing hook.
- A tyre pressure placard must be attached to the machine.

The stand safety of the machine requires a better definition. Maybe the assessment item on operator safety would benefit from a division of the item on operator safety in two e.g.:

- Operator safety in relation to working position, roll over protective structure (ROPS), fall over protective structure (FOPS), seat belt, etc.
- Operator safety during maintenance.

There is little sense in forcing the safety of the machine into an ergonomic rating. E.g. any sharp edges found on the machine must be rectified. The item on operator safety calls for a pass and fail type of assessment, which will not flow into the ergonomic profile.

Mental stress
Although mental stress plays an important role in the ergonomics of a machine, the lack of basic assessment principles make any assessment difficult.

The only basic principle available for assessing the mental stress is found in a brochure from KWF (Rehschuh & Tzschöckel, 1977). A typical question addressing mental stress issues posed in this brochure is: ”Are frequent peak loads of work avoided?” Unfortunately, these questions are not formulated in a way that make comparable assessment results achievable, especially not when two different test engineers carry out the measurements. A possible solution would be to ask the operators about their experiences of the machines as discussed in the section on operating the machine. Another possibility would be to focus on strain instead of stress measuring physiological parameters such as heart rate or the electrical skin resistance on test persons during normal work. This would require that the tested operators are suitably trained for the particular machine. The required effort of this would, however, not be proportionally to the results.

Winch
Basic assessment principles for assessing the safety of winches have been worked out in the German procedure but are not included in the Nordic procedure or in the procedure in use at SMP.

For most of the assessment it is not feasible to introduce different ergonomic classes. E.g. an 80 kN winch may not pull with a force exceeding 80 kN in the lowest position to prevent the cable from breaking. However, the traction of the winch should be maintained near 80 kN in order to prevent a loss of performance. Thus there is little scope for an ergonomic rating. A spool out device (Capstan) is an ergonomically important feature for winches above 80 kN. This is also either present or not.

The diameter of the cable is particularly interesting from the ergonomic point of view. As a rule, the operator has to unravel the cable by hand, which means that the weight of the cable should be kept as low as possible. However, the traction power of the winch means that the cable must have a prescribed minimum diameter. The ergonomics of the machine could be improved by installing two winches with different power. Then the skidder can use the lighter rope for normal work. The stronger winch or both winches are used for heavy stems. Another ergonomically relevant dimension is the winching speed. If too slow, the skidder could not work effectively. If too fast, the operator could not follow the skidded wood.

The moving cable creates an extra hazard, which is not found on other machines.

The cable entry is a particularly exposed part of the winch, which must be constructed in a way that prevents hands from being seized. The biggest hazard that can occur when working with a winch is that the cable may break under tension. A cable unleashed in this way may strike a person dead or cause severe injuries. A damaged cable cannot withstand the full traction and will break as soon as the load becomes jammed and the winch starts pulling with full power.

The following assessments can be derived:

- The traction power of the winch must be limited and must not be exceeded under any circumstances.
- The cable must be capable of withstanding this traction plus a safety margin.
- All components exposed to the traction must be constructed to withstand the same traction.
- A placard of the type of cable used must be fixed visibly on the machine.
- The wear and tear on the cable should be kept to a minimum.

Because of the construction of the machine, the cable will deteriorate more rapidly if the drum or the pulley diameters are too small. A small bending radius will cause substantial movement of the steel wires inside the cable. The minimum diameter is based on the cable diameter and is assessed in the procedure used by KWF. The bending radius should adapt to the cable diameter on the drum. If the cable lies too flatly, it would be strongly deformed when being pulled, which also will lead to increased wear. The durability of the cable also depends on how the cable is spooled on to the drum. Poor spooling quality may cause the cable to become snagged under spooled layers when winching a big load. This causes a buckling load at the contact points. It also makes it very difficult to spool out the cable at a later stage. Thus a poor spooling quality not only leads to increased wear and tear but also has an effect on the ergonomics of pulling out the winch cable. A good spooling quality is usually achieved when the fleet angle does not exceed 4° measured from the vertical line between the pulley and the drum. This can be further improved if the cable is spooled through a guide.

If an operational procedure is interrupted, the winch brake must engage within 500 ms to prevent the winched load from slipping. The overlap time between the release of the clutch and the engaging of the brake must also be checked. In addition to this, the brake must produce a braking force that exceeds the maximum traction force of the winch by a factor of 1.25. The cable must not be fixed to the drum too strongly. The cable must be pulled free from the attachment when the traction exceeds the rated traction force by a maximum factor of 0.5. It should be possible to release the brake of the winch using the normal control mechanisms even if there is a complete loss of operational power, which is an important safety feature in the case a person is trapped and needs to be freed.

Remote control
It is only in the German assessment procedure that the assessment of remote controls is included in the ergonomic assessment.

Within the EU the use of radio equipment is regulated through the EU radio and telecommunications terminal directive 1999/5/EC. The remote control has to be constructed in accordance with this directive and national legislation regarding radio frequencies and transmitting power.

The control unit must be protected against showers at least according to the requirements of IP 54 but rather IP 55 according to EN 60529 (1991) and must be easy to carry. The remote control must also survive a drop from 1 m onto a concrete floor without damage. The carrying harness must be sturdy and functional.

The foremost issue when considering the remote control is the safety of the operator. The switches and buttons must be protected from accidental actuation by a projecting sleeve. Despite these features, the radio control must be operable with protective gloves and all controls must be permanently and clearly coded. The antenna of the radio control must not obstruct the user and the reach must exceed the maximum distance between the operator and the machine, which normally corresponds to the cable length in a forest with trees. The radio control should dispose of an emergency stop and an emergency call system.

The requirements for the safety of the remote control are either fulfilled or not. An ergonomic ranking is therefore not feasible for remote controls. The machine must remain immobile when the buttons and switches are in their default position. Similarly, the machine must not make any inadvertent moves especially when switching the control unit on or when battery power is low, the on-board net diminishes, or when the transmission range is disrupted. In cases where the transmission is disrupted, the machine must remain fully operational or must switch to safe mode. The safe mode for a winch is accomplished when the winch stops and the brake is engaged. If any of the aforementioned disruptions happen while the operator is operating the machine with the remote control, then the machine must initiate a full stop.

Some key values of the measurements
In order to obtain an overview of the quality of the working measurement method the measurement time, set-up time, personnel required, effort required, comprehensibility of the result, definition of the method, and reproducibility of the measures are evaluated for each assessment item. Apart from the time measures of the measurement and set-up times a three grade scale is used, thus meaning:

- The competence required: 1. Can be carried out by a suitably instructed person; 2. Have to be carried out by a test engineer with basic knowledge of forest machinery; 3. Can only be carried out by an expert with extensive knowledge of forest machinery.
- The effort required: 1. Simple aids and devices are required, e.g. a yardstick or a protractor; 2. Complex measuring devices are necessary; 3. Requires measurement on a test course or in a special laboratory.
- The comprehensibility of the measurement and its necessity: 1. Can be understood by an interested layman; 2. Is not clear at the first sight; 3. Can only be understood by an expert.
- The assessment definition: 1. Based on standards; 2. Based on internal test methods; 3. Largely based on estimates.
- The measurement reproducibility: 1. Exact measurement is possible; 2. Results depend on the testing personnel or the measurement conditions; 3. Results strongly depend on the testing personnel or the measurement conditions.

These evaluations are summarised in Table 2.

Table 2. Evaluation of some aspects of the different assessment items of the working measurement method

	Measurement time	Set-up time	Competence	Effort	Comprehensibility	Definition	Reproducibility
Machine data	1 h	0 h	1	1	1	1	1
Cab access	1 h	0.1 h	1	1	1	1 Unclear definitions	1
Working posture	0.5 h	0.1 h	3	1	2	3	3
Cab	0.7 h	0.1 h	1	1	2	2 Unclear definitions	1
Visibility	0.3 h	0.1 h	2	2	3	2	3
Visibility diagram	2 h	0.5 h The field of view has to be outlined	2	3 Darkness required	3	2	3
Operator's seat	1.2 h	0.1 h	2	1	1	2 Measurement points not exactly defined	2
Controls	1.5 h	0.2 h	2	1	3	2 Measurement points not exactly defined	2

Table 2. (cont.)

	Measurement time	Set-up time	Competence	Effort	Comprehensibility	Definition	Reproducibility
Operating the machine	0.5 h Only in the Nordic procedure	0.1 h	3	2 Operator required	3	3 Exact definitions not possible	3
Information	1 h	0.1 h	3	1 Machine must be running	3	3 Inaccurate description	3 Assessment varies individually
Noise inside	0.2 h	0.1 h	2	3 Machine must be running at operational speed	1	1 Measurement method LdB(A)eq	2
Noise outside	0.2 h	0.5 h Machine must be running at operational speed in working conditions on forest sites	2	1	1	2	2
Vibrations	1.5 h	1.5 h	2	3 Requires special equipment	2 Knowledge of norms required	1	2 Depends on the environment
Climate control	No measurement carried out		2	3	1 Climate chamber	2	2
Gases and particulates	0.2 h Without measuring concentration	0.1 h	2	3	2	1	2
Lighting	0.5 h Only number and power	0.1 h	2	1	2	2	2
Illumination diagram	2.5 h	2 h If the measurement points are to be labelled	2 Measurement in darkness	3	2	2	2 Depends on the weather

Table 2. (cont.)

	Measurement time	Set-up time	Competence	Effort	Comprehensibility	Definition	Reproducibility
Warning signals	0.5 h	0.1 h	1	1	2 Meaning seldom understood	2 Symbols not clear	2
Operator's manual	2 h Highly variable	0 h	3	1	2	3 No exact instructions	3
Training	Not measured		3	1	2	3	3
Maintenance	2.5 h	1 h With assessment	3	1	2	1 SAE-standard not exact enough	3 Instructions inadequate
Brakes	0.2 h Without full application of the brakes	1.5 h	2	3	2	1 Documented in norms and standards	2
Operator safety	1 h	0 h	2	1	2	3 Rules unclear	2
Mental stress	No measurement carried out				2 No guidelines available	3 No exact guidelines	3 Only estimates possible
Winch	2 h Complex assembly Only in the German procedure	3 h	3	3 Special measuring devices	2	2	1
Remote control	1.5 h Only in the German procedure	0.5 h	2	1	2	2	1
Total time required	24.5 h	11.8 h					

According to the assessments in Table 2, the most difficult assessment items are the operating of the machine, visibility diagram, information, working posture, visibility, operator's manual, training, climate control, and mental stress. When considering the total time required it is necessary to take into account that not all assessment items have to be carried out on all machines. The most time consuming measurements of the items assessed are the winch, illumination diagram, maintenance, vibrations, visibility diagram, operator's manual, and remote control.

The relevance from an accidental and a health point of view of the different assessment items are evaluated through the use of a three grade scale such that:

- Accidental risk: 1. The risk of accident is very high; 2. There is a possible accident hazard; 3. The item is irrelevant for accidents.
- Health risk: 1. The health risk is high; 2. There is a possible health risk; 3. The item does not affect health.

The results are summarised in Table 3 showing that the most important assessment items from an accidental and a health point of view are the working posture, visibility, training, and mental stress.

Table 3. Accidental and health risks included in the different assessment items of the working measurement method

	Accident risk	Health risk
Machine data	3	3
Cab access	1	2
Working posture	1	1
Cab	2	1
Visibility	1	1
Visibility diagram	-	-
	The significance is low	
Operator's seat	3	1
Controls	2	1
Operating the machine	2	1
Information	2	3
Noise inside	2	1
	Measurement points not precise	
Noise outside	2	2
		Only for persons outside the cab
Vibrations	3	1
Climate control	3	1
Gases and particulates	2	2
Lighting	1	2
Illumination diagram	3	3
Warning signals	2	3
Operator's manual	2	2
Training	1	1
Maintenance	1	2
Brakes	1	2
Operator safety	1	3
Mental stress	1	1
Winch	1	2
Remote control	1	2

Through the summaries of Table 2 and Table 3 it is possible to identify which items may be omitted or reworked. It is thus possible to question the current use of visibility and illumination diagrams. At least the methods have to be reworked. The methods of measuring the climate control in the cab, training, and mental stress may have to be reworked.

Discussion

The three evaluated procedures for ergonomic assessment of forest machines – (i) Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998), (ii) Ergonomic Checklist for Forest Machinery (Löfroth et al., 2003) used by SMP, and (iii) the procedure established in Germany composed by safety testing according to checklists at DPLF (DPLF, 2003), developed and carried out by KWF, and testing of machine performance carried out by KWF on their own (KWF, 2003) – combine different methods of data collection, which all have proved effective for their purposes. Thus checklists are useful for measurements based on EN or ISO standards. Field tests in working conditions on logging sites are useful for testing such items as vibration and noise, which are difficult to carry out on test premises. Manufacturers' declarations are useful for safety aspects not possible to properly test. Questionnaires and interviews are useful for getting information on the experiences of the users' of the machines. Diaries are means of getting field data on machine performance. These methods – checklists, field tests, manufacturers' declarations, questionnaires, interviews, and diaries – and also group discussions have proved effective also in other studies dealing with technical development issues (cf. Hultåker et al., 2002). For evaluating operator work camera video taping has proved effective (cf. Gellerstedt, 2002).

The problems revealed during our comparative evaluation of the three assessment procedures show quite clearly the importance of carrying out the assessments before formulating the new European ergonomic guidelines for forest machines.

The principal items and sub-elements of the three assessment procedures are very similar. E.g. the minimum applicable tolerance values are usually the same. This is not surprising, since the relevant background standards apply throughout Europe or the world.

Different scale types are applicable for different sub-elements. It is important that relevant scales are used for the different items assessed. Some items are not possible to assess on other than sorted scales, e.g. sharp corners or edges has to be removed for safety reasons. Other items are possible to assess on rank ordered scales, e.g. the distance between the ground and the first step accessing the cab. A rating of individual items is particularly useful if the assessments are aimed to improve the ergonomics of future machines, i.e. the minimum standards must be exceeded to a significant extent. A rating is feasible for items such as cab access, noise, vibration, or operator's seat. Other items, such as operator safety and brakes, are very difficult to classify. For most such items only pass and fail ratings are possible.

Time required

We state that the time required by two test engineers for assessing a machine with the working measurement method we developed is 24.5 hours. In addition to this, the set-up time required by two engineers working on the machine amounted to 11.8 hours. It must be taken into account that not all assessments have to be carried out on every machine. E.g. the assessment of the winch and the remote control is not necessary for most machines. However, this investigation has shown that it does not seem possible for two test engineers to make the measurements required for obtaining an adequate assessment of the machine ergonomics within the stipulated two-day limit. To do this will require leaving out substantial parts of the assessment. There is only limited scope for accelerating the individual measurements of the assessment items. The assessment procedure could be shortened by omitting whole assessment items such as the visibility and illumination diagrams.

Our overall impact from the assessment cases is that there is a need for more than two test engineers in order to carry out all the measurements required for a comprehensive assessment. Time restrictions put strains on the comprehensiveness of the assessments. Test engineers' lack of the experiences of operators having worked with a specific machine also put strains on the assessment. Participation from experienced operators could speed up the measurement work through knowledge of the specific machines. Experienced operators also have access to information regarding the machine that is needed as data for the assessment. The collecting of such data may call for the use of other data collection methods than only the use of checklists.

Essential problems experienced during the assessments

In the assessment cases some specific problems were recognised calling for further methods development. This section is a brief summary of the major problems encountered in practice.

The seat reference point

The seat reference point (SRP) is not clearly defined in any of the three evaluated procedures as the seat surface and backrest is presumed to be flat surfaces. In addition to this, the seat surface and backrest are placed in a horizontal and vertical position respectively. In reality, the surface of the backrest facing the operator is convex in the vertical direction and concave in the horizontal direction. The seat surface is adapted to the form of the buttocks. The seat has a ridge in the centre and troughs on the side. The surface is uneven in all directions.

The new European guidelines for forest machines must include a clear definition of the seat reference point (SRP). Alternatively the seat index point (SIP) (see ISO 5353, 1995) may be used or the SRP could be clearly referred to from the SIP.

Visibility diagram, lighting, and illumination diagram

The measurements of visibility and illumination through diagrammatic methods are so complicated and produce so little of valuable information that they might be excluded from the assessment or call for much effort on methods development.

In fact, the usage of visibility and illumination diagrams is already regularly excluded from the German procedure used by KWF.

The lighting measurement methods need to be developed in order to make it possible to compare halogen and xenon lighting.

Operator's seat
In discussions with operators there often have been demanded that the seat automatically should return to the previous settings of the operator after a shift change. The following adjustments are available for a memory seat (Walker et al., 2005):

- Leg room
- Backrest
- Seat height
- Damping force
- Seat depth
- Lumbar support convexity
- Lumbar support height
- Distance between armrests
- Armrest height
- Armrest pitch
- Armrest length
- Armrest swivel

Other possibilities for adjusting the seats such as lateral tilt and seat swivel do not require automation. The assessment would require a ranking of the automatic seat adjustments. E.g. more than eight automatic adjustments get the highest rating, four or more get the second rating, and two or more third rating. No memory function is placed in the fourth level.

All the three evaluated assessment procedures include restraint systems such as safety belts. However, according to our experiences a harness would be more suitable for driving downhill in a non-tilting cab or vehicle than 3-point automatic safety belts. The ranking of the restraint system should thus better be:

- Harness
- 3-point automatic safety belt
- 2-point automatic safety belt
- Fixed 2-point safety belt
- No restraint system

Problems of machines operating in two directions and asymmetric machines
Figure 4 shows the Ponsse Beaver harvester. In this machine the driving and working directions are not the same. This has an effect on the visibility issue

related to the view of the front wheels. The machine is equipped with a swivel seat. This means that many controls must be usable from both directions. They also have to be measured in both directions. Furthermore, the full range of adjustability is not available in all positions of the swivelling seat. The question is whether we should base the assessments on the full range of adjustability, which is usually available in the driving and operating directions, or should the adjustability assessment be made in a position where the seat can swivel to its full extent?

Figure 4. Ponsse Beaver harvester with different operating and driving directions.

Another problem can be exemplified by the field of view. If the boom is mounted to the right of the cab, the field of view is severely restricted in this direction. The correct assessment of the visibility to the right would obviously result in the lowest rating. According to the Nordic assessment procedure, the visibility should be rated as unacceptable. However, the procedure provide for compensation. A swivelling cab could increase the rating.

Including operators' experiences in assessments of operating the machine and of mental stress and strain

The assessment of operating the machine and of mental stress and strain call for the use of operators' experiences. Test engineers using checklists are not able to fully assess the operating of the machine.

Information could be obtained from questionnaires targeting several users. Furthermore, an interview with the operator would uncover any flaws. A diary may also be a helpful source of information for solving the problems of current methods for assessing the items of operating the machine and mental stress and strain. However, the opinion of one single operator will probably not suffice as a basis for assessing the operation of the machine. The results would probably deviate considerably as each person perceives mental stress and strain differently and because of differing circumstances in different companies and forest harvesting teams. Operators from different companies are required to obtain reliable measurements of the operation of the machine. An experienced test engineer should carry out the final assessment.

An additional possibility for obtaining knowledge about the operation of the machine is to install a camera in the machine to investigate the work routine of the operator. The data could be assessed at a later stage. This method would also be useful for investigating micro-breaks. The effort required would, however, be very high. Probably at least five hours would be required for the assessment in addition to the time taken for installing the camera. This method would also require the specification of unambiguous criteria for assessing the visual data. Since the work routine depends on local operational conditions, i.e. the wood assortments and the terrain, it will be very difficult to make general statements.

Selection of an assessment procedure

The initial objective of a forest machine ergonomic assessment is to ascertain whether the machine complies with present technological standards and norms. As a rule such questions may be clearly answered with yes or no. This permits the formalization of a mandatory safety standard. The evaluated German procedure is suitable for this (DPLF, 2003; KWF, 2003).

A comparison of machines on the basis of their ergonomic merits requires an assessment of the ergonomic state of the machines. This also serves as an incentive for manufacturers to build their machines to the highest possible ergonomic demands. This particularly applies to machines currently under development. For this reason, it is especially important to get acceptance of the criteria from the manufacturers.

One approach for assessing the ergonomics is to assign each assessment item into classes. This is done in the Nordic procedure (Gellerstedt et al., 1998) and the procedure used by SMP (Löfroth et al., 2003). This results in an ergonomic profile of the machine. In the Ergonomic Guidelines for Forest Machines the lowest class attained by an individual criterion determines the final rating of the complete item. A machine that acquires good results for all but one criterion in this assessment item will still be assigned to the lower class. This may reduce the incentives to improve the ergonomics of a machine.

One field of problem is the means of accessing maintenance points. Apart from the access to the cab, a machine may also be equipped with several other means of access . The requirements for the access to maintenance points do not need to be so stringent. E.g. hydraulic operation for the steps to the maintenance access is unnecessary. In the case of machines with several means of mounting and alighting, the relevant German assessment forms are completed for each means of access. A similar mode can be envisaged for the Nordic procedure. However, this is not feasible in the penalty point system according to the procedure in use at SMP. The assessment of several means of access would increase the number of penalty points. However, several means of access are usually better than just one. One solution could be to assess the means of accessing the cab in the cab access item. All other accesses to the maintenance points are then assessed and only the access with the highest penalty points is taken into account in the maintenance item.

Some assessment items do not lend themselves to a rank ordered rating. This is exemplified concerning sharp corners and edges. Either the machine has sharp corners or edges, which must be removed, or the edges and corners are sufficiently rounded. The issue is important for the ergonomics of the machine and must be assessed. However, including this issue in an assessment will always result in the machine attaining the best rating. Otherwise the machine must be modified. If an assessment item contains several issues of this nature, it will be almost impossible for the machine to attain a bad rating in the point system used by SMP. Following the Nordic procedure this is not a problem since only the worst individual rating is taken into account for the assessment of an item. Another example serves to illustrate the problem. According to the standard prEN ISO 2867 (2004) the distance between the first step and the ground or platform must be less than 700 mm. If possible, this distance should not exceed 600 mm. In an assessment based on sorted scales with yes or no answers, such as in the German procedure, steps with a ground to first step distance of 700 mm will not be rejected. The assessment result will be the same as for a machine with an ergonomically preferable ground to first step distance of 350 mm. The same standard prescribes a door width of 450 mm at shoulder level. Here also a wider door is ergonomically more suitable. In addition to this, an emergency exit is necessary for all machines and any assessment should verify that an emergency exit is provided. An assessment should also establish whether the ground beneath the steps can be illuminated. Such lights are either installed or not. The construction of a tracked machine restricts the height of the mounting point of the first step. Consequently, a tracked vehicle will always be assigned to a low class for cab access in the Nordic procedure irrespective of the design of the door or the rest of the steps. The SMP procedure takes this into account. In the SMP procedure the emergency exit will always lead to an upgrading of the class since all machines must fulfil this criterion. The problem can be solved by using a point system for classifying those items that are suitable for an ergonomic assessment. All items that only can be assessed with a sorted scale assessment with yes or no type of questions must be excluded from the point system. A negative response to very important criteria such as the emergency exit should lead to a relegation of the particular assessment item into the lowest class. Less critical issues such as the lighting of the ground beneath the steps should only lead to a downgrading by one class. This item could conceivably lead to an upgrading of the access, since this type of lighting is still an exception in present machines.

The new European ergonomic guidelines for forest machines must also take into account that some assessment criteria will need several specifications to allow for different machine types. E.g. it is still not possible to provide adequate lighting in all areas of the operating envelope of skidders. When working with a 100 m line, the on-board lights for fixing the line can illuminate only one side of the working area. This is unacceptable from the safety point of view. Furthermore, the trees and undergrowth block the light. This means that sufficient daylight is necessary for working with a skidder. Consequently, an assessment of the illumination of the access can be omitted in a skidder. The assessment is nevertheless useful in grapple skidders. The current assessment procedures already take into account the different lighting requirements for harvesters and forwarders. A similar case can be made for the upper limit of the field of view from the cab. A harvester operator needs to have a good upward view. A forwarder operator only requires a limited upward field of view whilst the skidder operator rarely needs to look upward.

Many criteria, such as the actuating forces, are fulfilled in all machines. This means that it is impossible that an item is rated as class E in the SMP procedure. A class D will also be very rare. In contrast the construction of the machines will always mean that there will be a number of sub-elements that will receive a lower rating. This means that a class A rating will also be very rare. The standard classification of the SMP procedure will be a class C. In order to compare different machines it would be better to normalise the total points for an item to give a base value of 100. The assessment would then be based on the number of points obtained for this item. This would make even small differences more apparent. Using the SMP point system, the assessed machines achieved a class C classification for most assessment items. In some cases a class B was attained, whereas class A and D were only rarely allocated. None of the assessment items were classified as class E. In most cases the ergonomic profiles of the assessed machines were similar. E.g. the operator's seat achieved a class C in all machines. In order to compare the ergonomics of the machines the rather coarse class system should be augmented by a numerical value. A normalized ratio of the achieved number of points and the maximum achievable points is best suited for this purpose.

In summary, we can state that some parts of an ergonomic assessment are best assessed by means of a pass or fail type of assessment, i.e. sorted scale. This is the case for sub-elements which either exist or not. That includes ergonomically important sub-elements, i.e. sharp corners and edges, but also elements such as lighting of the ground and steps when accessing the machine. Other items are well suited to be classified on rank ordered scales and classified according to an ergonomic profile. However, some of these items are better assessed using the SMP procedure while the Nordic procedure is better suited for other items. The new European ergonomic guidelines for forest machines being developed have to consider when to use parts of any of the current procedures and when all new procedures need to be developed.

Conclusions and recommendations

In this chapter we summarise the results of the comparative evaluation of three assessment procedures for forest machines – (i) Ergonomic Guidelines for Forest Machines (Gellerstedt et al., 1998), (ii) Ergonomic Checklist for Forest Machinery (Löfroth et al., 2003) used by SMP, and (iii) the procedure established in Germany composed by safety testing according to checklists at DPLF (DPLF, 2003), developed and carried out by KWF, and testing of machine performance carried out by KWF on their own (KWF, 2003). Based on our assessment cases we also summarise our proposals for the European guidelines for forest machines to be developed. The chapter summarizes the amendments suggested as a result of the measurements. The suggestions relate to the Ergonomic Guidelines for Forest Machines as this is the only one of the evaluated assessment procedures published in English.

The new guidelines should include a list regarding specifications of the machine data:

- Machine
- Motor
- Wheels
- Crane
- Articulation joint
- Grapple
- Harvester head
- Winch
- Remote control
- Control
- Software

The item cab access must include measurements of the diameters of the handrails and grips and the relevant clearance. The definition for the clearance must be changed and the three-point contact must be introduced in the assessment criteria. Working platforms should also be included and the criteria for anti-slip provisions in steps and footholds need to be defined. In addition to this, maintenance steps must be accounted for in the procedure and the requirements for an emergency exit must be defined. It should also be established whether the ground beneath the steps is illuminated. There is as well a need to ascertain whether a distinction between ladders and steps must be made for this item. The width and height of the door must be defined more precisely.

The assessment of the working posture should be carried out after the assessment of the cab, seat, visibility, and controls.

The assessment of the cab should take into account that a swivel seat is not required in swivelling cabs. The SRP requires precise definition and the protection measures against crushing has to be assessed.

The visibility assessment requires a precise definition of the front wheels. The visibility to the left, right, and front should be assessed as three separate sub-elements. Instead of measuring the visible height above ground at a distance of 10 m, it is simpler to measure the upper view angle. Camera systems should be included in the assessment. For this item it is also necessary to establish if there is an alternative to the visibility diagram.

The required seat heights do not correspond with the measured elevations. The armrest pitch must be re-defined. A definition is required for the backrest angle required for measuring the seat adjustments. This has also to take into account the seat swivel. The backrest adjustment also requires a more exact definition. The measurement of the lumbar-support is not consistent with modern seat design. The adjustment of the armrests requires a more exact definition. The assessment should also include the pitch sideways, joystick adjustability, and memory seat functions. The presence of an active seat damping should be taken into account in the assessment results. Restraint systems, e.g. safety belts, should be assessed. The assessment of the controls requires a precise definition of the seat adjustment. A steering wheel is no longer mandatory for forest machines. This must be taken into account in the assessment. Probably, the assessment item concerning machine control has to be revised in order to make assessment possible of newly developed joy-stick like controls.

The important elements of the information from the machine need to be transmitted to the remote control.

The dB(A) value is sufficient for assessing noise in the cab. The noise should be measured inside the closed cab as well as in the open cab. The noise emitted by the air conditioner should be measured separately.

The exposure to vibration should be converted to standard time periods.

A simple assessment of the air conditioner is not possible. Air speed should be included in the assessment.

The measurement of gases and particulates may be omitted from the assessment. The method for assessing the lighting must be amended. The lighting diagram could be omitted if it is replaced by a calculation.

The criteria for assessing the operators' manuals need to be revised in order to be more precise.

The SAE list for maintenance work must be revised. The distance between feed inlets and the foothold has to be integrated in the assessment. The assessment must also include an assessment of a vacuum pump.

The feasibility of a full stop brake assessment at full speed must be examined.

A rating and classifying system is not necessary for assessing the safety of the machine. All requirements are mandatory. A number of additions to the current lists are required.

The German procedure has special checklists for winches and remote control systems, items that so far are not included in the other procedures. We suggest that these should be integrated in the future guidelines.

A number of additional questions must be included that require answers from the manufacturer. These issues relate to relevant criteria that are not easily measured on the machine.

The European guidelines for forest machines to be developed has to take into account that the same specifications cannot always be used for the different machine types.

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