O

OPERATIONS

Contents

Ergonomics

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Introduction

Ergonomics is mainly oriented to the adaptation of work to the human being in order to obtain an adequate balance between workers' well-being and productivity. In forestry, there are two important aspects in which ergonomics can make useful contributions. One is the adaptation of heavy manual work. In this kind of job, a man using simple manual tools supplies most of the energy required to carry out his work. The opposite side is represented by mechanized work where human energy is replaced by machines. The workers become progressively more sedentary limiting their activities to perceiving and interpreting information and then executing their decisions with light muscular actions, usually highly monotonous and repetitive.

One aspect that is important to highlight is that forest work has evolved in a different way in developing and industrialized countries. In most developing nations, a high proportion of forest work is done using labor-intensive methods, while in most industrialized countries forest work is carried out using advanced mechanization. In the two types of work, ergonomics has a different approach, but based on a common root which is illustrated in **Figure 1**. This figure shows for two very different activities, such as barking logs manually and sorting logs with a forwarder, that in both cases workers perceive information from the surrounding environment, make decisions, and execute them through mechanical actions. Although the basic scheme is the same, the demands of the work are completely different; the decisions of the manual worker are simple but the physiological demands are high, while the operator of the forwarder makes a minimal physical effort but the complexity of his decisions are significantly higher. In both cases, independent of the kind of work, the workers are in a continuous feedback loop with their jobs, perceiving information, interpreting, deciding, and acting through mechanical actions to let the process flow. Ergonomic design should allow them to fulfill each stage of their job safely and efficiently, no matter whether the activity is manual or mechanized.

The previous description corresponds to the interaction of the man with his tool or machine. However, forest work is carried out in a physical environment where workers can be exposed to heat, cold, noise, and mechanical vibrations. These agents, when they exceed certain limits, may alter physical

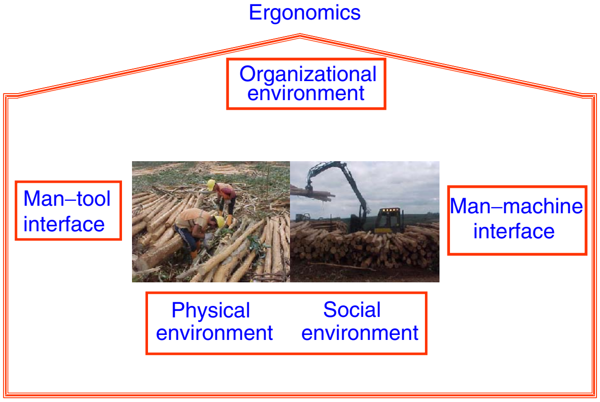

Figure 1 The ergonomic approach to manual and mechanized work.

and mental health and well-being. Some of them originate in the tools and machines, like for example noise and vibrations, while others, such as heat and cold, may have their origin in the environment. Although these agents may be present at levels that do not produce any disease, they may be the cause of occupational stress leading to psychological and physiological strain.

From the ergonomic point of view, there are other factors that are not related to the work station or the physical environment, but to the organization of the system in which each forest task is situated. Therefore, the modern concept of ergonomics considers the activities of a worker as part of a system which, as a whole, has to be efficiently designed. Work processes have an entrance and an exit, passing through a variable number of intermediary stages, where human beings interact with tools and machines to achieve their goals. This way of approaching forest work may be highly efficient, as human adaptation is suited to a multidisciplinary approach, with the participation of the workers and the managers who have the responsibility for planning and optimizing forest work.

One further aspect that cannot be ignored within the framework of ergonomics in forestry, particularly in developing countries, is the social environment. Forest work is usually carried out in isolation far from urban areas. Often, the workers have to remain in forest camps, not by choice. In such cases, forest camps become their temporary homes where they have to stay for different periods of time without the opportunity to choose their own options for food, recreation, or even sleep. Hygiene, privacy, and tranquility are basic requirements for these workers' well-being.

This is a brief synthesis of the purpose of ergonomics. As a summary it can be said that ergonomics provides integrative criteria for the solution of the problems of forest workers, both in manual and mechanized work.

Labor-Intensive Methods

Fundamentals for the Study of Heavy Manual Work

Most manual operations in forestry work are heavy. This statement is supported by a number of publications in which energy expenditure and work load have been reported for forestry tasks. However, a high energy expenditure does not necessarily mean that every worker within a crew will be strained when performing a similar task. To support this argument, it is necessary to answer at least two questions: (1) What is heavy manual work? (2) How can we fix limits of work load for sustained work? The answers are not easy to find because there are many factors determining the heaviness of a job, partly depending on the difficulty of the task and partly on the physical fitness of the workers. In other words, to define the limit of work that can be sustained during a shift, the relationship between the energetic demands imposed by muscular work and the physical working capacity of the laborers has to be established.

Human energetic processes are classified as aerobic and anaerobic. In mild or moderate exercise, oxygen supplied to the muscles is sufficient to oxidize food and thus to provide all energy aerobically. However, if work becomes more demanding available oxygen may not be enough and part of the energy has to be released by means of anaerobic processes. It is known that anaerobic work leads to the accumulation of lactic acid and this is related to muscular fatigue. For this reason, most human physiologists nowadays accept that work should be considered heavy when anaerobic metabolism starts contributing significantly to the total energy release. The higher the participation of the anaerobic processes, the more exhausting the activity is and shorter is the time that the job can be performed without a rest pause. Afterwards, when resting, the aerobic metabolism remains elevated because a major portion of lactic acid is oxidized. This is the reason why, when carrying out anaerobic work, an 'oxygen debt' is contracted which has to be repaid during recovery. As energy metabolism depends on the utilization of oxygen, the measurement of oxygen uptake is a practical method to estimate energy expenditure. It is known that 1 liter of oxygen consumed is equivalent to an energy expenditure of approximately 20.3 kJ (4.85 kcal).

To define whether a job is heavy or not it is not only necessary to determine the intensity of the activity, but also to understand the concept of physical working capacity. From all the factors influencing the aptitude for manual work, nowadays the maximal capacity of the aerobic processes, also known as aerobic capacity or aerobic power, is accepted as an international standard of reference for studying the fitness of world populations. The aerobic capacity can be assessed by measuring or estimating the maximal oxygen uptake, which reflects the combined capacity of the cardiovascular and respiratory systems to obtain, transport, and deliver oxygen to the working muscles, as well as the efficiency of this tissue to metabolize oxygen.

Although the transition from aerobic to a combination of aerobic and anaerobic effort is not clear-cut, in most people doing dynamic work, lactic acid will accumulate at loads calling for an expenditure of no more than 40–60% of the aerobic capacity. The intensity of effort at which anaerobic work starts can be measured with different methods and nowadays is called anaerobic threshold or lactic acid threshold. Based on these findings it is accepted that a laborer, during an 8-h shift, should not be loaded on average at over 40% of his aerobic capacity. This will ensure that the work is carried out under aerobic condition or, more precisely, that the sum of heavy and light operations, after the complete shift, will not exceed this limit. This means that the rest pauses after heavy operations are sufficient to recover and that lactate will not accumulate. It has to be considered that manual labor, carried out for 8 h, varies in energy requirements and, therefore, the limit of 40% of the aerobic capacity is meant to be the average value obtained from heavy and light operations and rest pauses.

In studies of heavy manual forest work, measurements of energy expenditure and cardiac frequency are the most useful for field surveys. Common methods for measuring energy expenditure demand the isolation of all the operations carried out by a worker and the measurement of the time employed in each of them. Afterwards, oxygen uptake can be measured to estimate energy expenditure in each representative activity. It is not easy to obtain reliable information because it is difficult for the forest workers to accept repetitive measurements of oxygen uptake, specially if they are carried out for more than a few minutes in each activity. For that reason, when the purpose is to evaluate the work load it is preferable to measure cardiac frequency since it reflects the demands imposed by work on the cardiovascular system. It may be argued that cardiac frequency also increases when the subject is exposed to other agents, e.g., environmental heat, but in such cases, it is a better indicator of strain than energy expenditure. Cardiac frequency can be registered, during a whole shift, with simple noninvasive methods that do not interfere with the activity of the subject. Nowadays it is accepted that, as an average for an 8-h shift, the cardiovascular load should not exceed 40%. This is because, if the work is carried out in a temperate environment, there is a good relationship between cardiac frequency and energy expenditure, so one can assume that workers will perform as average under their anaerobic threshold. In cases where the work is done in a hot environment, this limit seems also a reasonable load for the cardiovascular system, in spite of the fact that the work is performed at a lower pace due to the heat.

On the basis of the criteria already discussed, systematic studies of workers' physiological responses have proven to be a powerful ergonomic tool in assisting work organization. A number of examples will be given to illustrate this statement.

Selection of Tools and Techniques: Medial Pruning as an Example

Pruning is becoming more and more important in commercial forests to obtain wood of high quality. This activity has the purpose of eliminating branches, cones, and epicornics in order to obtain wood free of knots. To make this job efficient, the worker must have a good technique. If a branch is not properly cut, occlusion will be delayed and the amount of clearwood will decrease.

Until a few years ago a common tool for pruning was a hook which for medial pruning, at heights from 4 to 6 m above ground, was supported by a pole 6 m long. The working posture was very poor and the neck of the worker was kept in a very uncomfortable position. His arms, supporting the tool, were kept high and he had to move them rhythmically to operate the sawing hook at the other end of the pole. All in all, this was a very fatiguing job. The workers complained of pains in the neck, shoulders, arms, and lower back. On the other hand, it is an ergonomic rule that the longer the distance from the work object, the greater is the risk of doing a job of bad quality. Therefore, pruning at a 6 m distance from the ground produced wounds or other defects in the cortex of the tree which delayed occlusion.

An alternative method is to use ladders which the workers fix to the trunk of the tree. Afterwards they climb and when they are close to the branches they proceed to saw them. The advantage of that method is that the worker can do his job close to the work object, which facilitates a better cut. Furthermore, the job is not as uncomfortable for the neck, arms, and shoulders which are kept in a more natural position. The main disadvantage of this technique is that the workers have to climb up and down the ladders, but when they are properly fixed, the risks of accidents are minimal.

Table 1 shows the results of the evaluations carried out to compare both techniques. The workers using ladders to prune could trim an average of 125 trees per working day, whereas the workers on the ground covered only 96 trees per working day. Very important, cardiac frequency was not significantly higher with the more productive method, even though tree trimmers had to climb up and down the ladder. This was because pruning from the ground required constant movement to maneuver into a position where the branches could be seen. Pruning from a ladder also produced a much better quality cut. The

Table 1 Mean values and standard deviations for cardiac frequency and output when pruning was carried out with the laborers standing on the ground using a long pole hook (Method A) and when the job was done with the workers climbing up a ladder cutting the branches close to the work object with a saw (Method B)

Variable	*Method A* (n = 10)		*Method B* (n = 10)	
	Mean	*Standard deviation*	*Mean*	*Standard deviation*
Cardiac frequency (beats per minute)	98	11.3	102	11.8
Output (trees per shift)	96	18.8	125	22.0

workers mentioned that they did not experience arm or leg fatigue, while neck and shoulder complaints were fewer. As can be seen the incorporation of a physiological variable to work studies may help to select productive alternatives less dangerous for the workers.

Scheduled Rest Pauses

When rest pauses are not properly scheduled, the trend is toward diminished output and, in some cases, to an increase in the physiological work load because of insufficient recovery. The following example is based on a study of pruning. In **Figure 2**, a follow-up of trees pruned per hour and cardiovascular load for the equivalent period is shown. As can be seen, work in the first hour of the morning starts with a high level of production and a relatively intense work load. As time goes by, the number of trees pruned per hour tends to decrease but the work load is maintained. In the last hour of the morning, the cardiovascular load increases significantly but the output of the workers decreases. In general terms, an increment of cardiac frequency with a reduction in the level of performance is a signal of fatigue due to the shortness of rest. A very common error is not to schedule the rest in such a way that the workers can take at least 15 min after 2 hours' work. Depending on the type of work sometimes it is even convenient to give 10 minutes of rest per hour. As a general rule, short and frequent breaks are more effective than long and spaced pauses. Of course, the decision has to be evaluated in the field.

To show an example of the positive effect of rest pauses, a study conducted in a group of workers delimbing trees with axes will be described. The workers cut branches without any rest during the whole morning. To evaluate the effect of rest pauses, breaks of 15 min duration were introduced at mid morning and mid afternoon. As can be seen in **Figure 3**, the output of those workers increased 16%, from 2.6 to 3.2 $m^3 h^{-1}$, while the cardiovascular load diminished from 35% to 33%. In other words, the good recovery allowed the workers to do more work with a slightly lower physical work load.

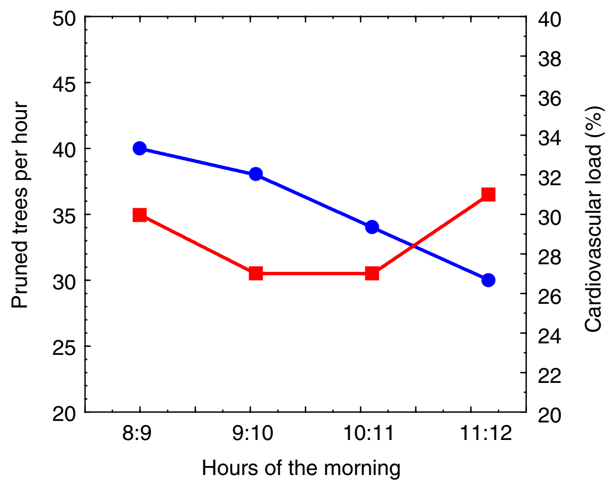

Figure 2 Average number of trees pruned per hour (solid line) and percent cardiovascular load (dashed line) as average of 10 workers controlled during the first 4 hours in the morning.

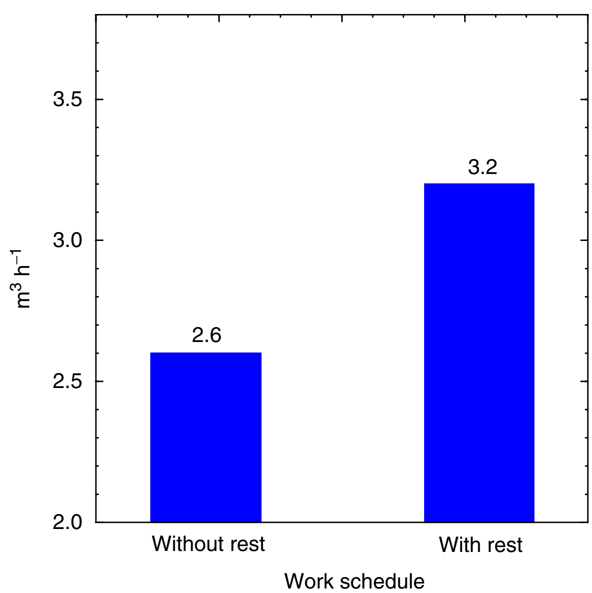

Figure 3 Average output ($m^3 h^{-1}$) and cardiovascular load (%) in a group of ax workers debranching with and without scheduled rest pauses.

Job Rotation

Another aspect which has been demonstrated to be very useful, when working conditions allow it, is to

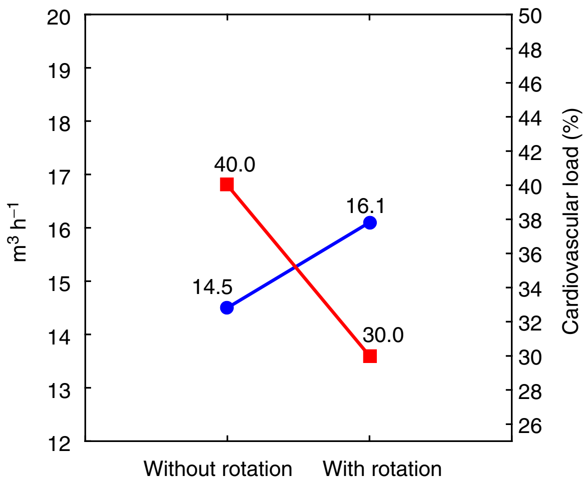

Figure 4 Average output ($m^3 h^{-1}$) (solid line) and percent cardiovascular load (dashed line) for a group of power-saw operators felling trees during the whole shift and rotating job with the power-saw operators who were doing cross-cutting in a log-yard. Rotation was done three times per shift (10 a.m., midday, and 3 p.m.).

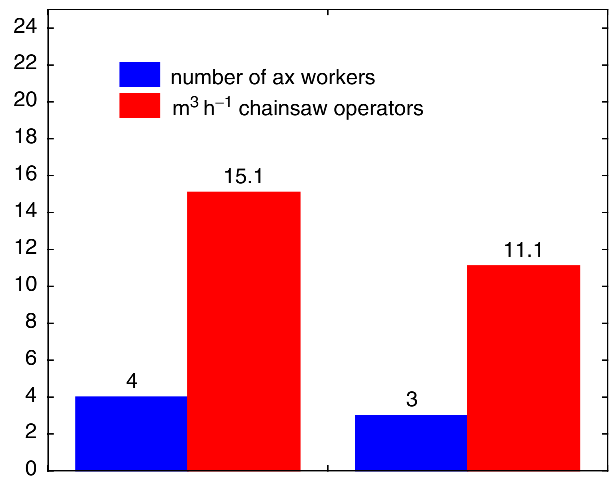

Figure 5 Performance of a power-saw operator felling trees when working with three or four ax workers debranching.

introduce job rotation. Changing activities may reduce the work load for those doing the heavier part of the job.

A clear example is the work of power-saw operators felling trees in the forest compared to that of workers cross-cutting in log-yards. The first activity is far heavier than the second. Therefore, these are the sort of jobs that can be rotated. A good example is a study in which the chainsaw operators started working at 8 a.m. and rotated after 10 min rest at 10 a.m. Then they had 1 hour for lunch at 12 when they changed again and finally after another 10 min rest they rotated at mid afternoon. **Figure 4** shows that, with rotation between felling and cross-cutting, the physical work load was lower than when the workers were only felling trees, and their output was 11% higher.

Number of Workers per Activity

Different studies have shown the importance of the balance within working groups. Although harvesting can be fully mechanized (*see* **Operations**: Forest Operations Management), in many countries it is still carried out with manual tools. In some cases power saws are used for both felling and debranching while in others, axes are used to remove the branches. In this last case, it has been demonstrated that when power-saw operators work with only three ax workers, the work load for the latter can be extremely high, so the recommendation is to organize the work with four persons cutting branches with axes for each power-saw worker felling the trees. It has been shown that power-saw operators can increase their level of productivity, within reasonable levels of work load, if the crews are organized with the correct number of workers. For example, in the study illustrated in **Figure 5**, power-saw operators increased their productivity by 36% (from 11.1 to 15.1 $m^3 h^{-1}$) when they worked with four instead of three ax workers.

Standard Performance as a Basis for the Calculation of Salaries and Incentives

On many occasions it has been confirmed that forest work is a heavy task. However, the question is: How much is too much? To answer this question it has to be considered that output depends on the physical workload that a worker can reach in a sustainable way during his working life without fatigue or other risks and on the difficulties he encounters in carrying out his job, mainly related to type of trees, climate, and ground. In other words, in forestry it is not possible to demand of a worker that he always performs the same amount of work. This makes it difficult to calculate incentives and salaries, specially when workers are paid by piece rate. In the literature several functions for calculating output of different forest activities have been proposed, based on studies in which performance has been measured as well as physical workload and characteristics of the forests, ground, and climate. A brief example will be given from a study of power-saw operators cross-cutting in a log-yard. After a detailed statistical analysis it was found that around 75% of the variation in output of those power-saw operators could be explained by the average volume (AV) of the trees they cross-cut, the time devoted to the principal activities (PT), and the effort they did as judged by the cardiovascular load (%CL), according to the following formulae:

$$\mathrm{OUTPUT}(\mathrm{m}^3\,\mathrm{h}^{-1}) = -7.5 + 0.16 * \mathrm{CL} + 0.23 * \mathrm{PT} + 8.1 * \mathrm{AV}$$

Using the formula, **Table 2** was calculated to show the estimated variation in performance, for two levels of cardiovascular load, for 70% and 80% dedication to principal activities, and for trees of different average volume.

The idea of such tables is to show the companies and contractors that when salaries are paid according to the amount of work that the workers can do, they should consider carefully how much work they can really expect to be done. In a practical sense, with these tables a company engaging the services of a contractor and the contractor himself can plan his job considering part of the difficulties that the worker will find in the field. These tables can also be used to calculate basic salaries and incentives. For example, if a previous sampling of the forest shows that the average volume of the trees is $0.9\,\mathrm{m}^3$, an average worker with a cardiovascular load of 30%, devoting 70% of the time to principal activities, should produce around $20\,\mathrm{m}^3\,\mathrm{h}^{-1}$. To reach this production a fair salary should be paid allowing the worker to fulfill his and his family's needs. Of course, a motivated laborer can still do more work without risk. **Table 2** shows that for the same forest with average $0.9\,\mathrm{m}^3$ per tree, if the laborer devotes 80% of time to the principal activities and makes a higher effort at the limit of 40% cardiovascular load he may produce $24.2\,\mathrm{m}^3\,\mathrm{h}^{-1}$, which is nearly 20% more. So, to stimulate the laborer, incentives should be paid. Although to work at that level is still safe, we are talking of the higher limits of physical performance and that is not possible to obtain if the worker does not feel that his effort is recognized. It has to be warned that incentives should be discontinued over the higher levels given in the table since there are serious risks of fatigue, accidents, and work of poor quality when these limits are exceeded. On the other hand, the main limitation of the system is that we are talking of an average worker and not every human being is alike, so the tables cannot be used in a rigid way; they are more useful in calculating group incentives.

Table 2 Expected output for power-saw operators cross-cutting in a log-yard

AV (m^3)	*CL30%*		*CL40%*	
	PT		*PT*	
	70%	*80%*	*70%*	*80%*
0.3	15.5	17.8	17.1	19.3
0.5	17.1	19.4	18.7	21.0
0.7	18.7	21.0	20.3	22.6
0.9	20.3	22.6	21.9	24.2
1.1	22.0	24.2	23.5	25.8
1.3	23.6	25.9	25.2	27.4
1.5	25.2	27.5	26.8	29.1

AV, average volume; CL, cardiovascular load; PT, time devoted to principal activity.

Mechanized Work

Mechanization in forestry is increasing. The part of the work usually done with great human muscular effort is being replaced by machines. Although mechanized work is physically lighter it involves other risks for the machine operators, e.g., those derived from the working posture, the noise and vibrations produced by the machines, and also a noticeable increment of the mental work load. For this reason, job rotation and scheduled rest pauses are also very important for the machine operator.

The 'man–machine interface' is an imaginary plane across which information is exchanged between man and machine. Man receives information from the displays of the machines. In the use of forest machines the information that the operator obtains from the surrounding environment is also important. The signals received by the worker have to be interpreted based on knowledge which has to be acquired through previous training. In consequence, the laborer takes decisions which usually means decisions to operate the controls of the machine. In simple words, the operators are in a constant feedback with the machine 'perceiving–deciding–acting.' What is important is that at any stage there might be problems leading to errors which may result in accidents, health impairment, and inefficiency. Therefore, well-designed machines should allow the worker to see and perceive what is needed and they should also have well-designed controls so the worker can make fast and precise responses from a comfortable position. It is equally important that the worker should be trained for the correct interpretation of the information received.

We have illustrated very simply some of the facts that may impair the processes of perception, decision, and action in machine work. However, these are not the only problems faced by machine operators. In forest work, machines are used in the open air, where often the workers have additional stresses because of the climate and the terrain. Furthermore, machines produce noise and vibrations.

All the agents previously described can be quantified. However, the main problem is that when machines are not correctly built, it is easy to detect what is wrong, but is extremely difficult to modify the design, mainly because most of the modifications are very expensive and also because some of the required adaptations may produce other problems, leading to a vicious circle. In such cases 'remedy can be worse than disease.'

Foresters, administrators, and in general all those who plan technological innovation should consider not only cost and output but should also add basic concepts of the adaptation of the workers. However, this is easy to write but difficult to put into practice. At present there are ergonomic checklists for machines which allow the evaluation and selection of forest machinery. By definition they contain an ordered list of questions on different aspects to be checked when evaluating a machine. In current literature, several checklists are described for different purposes. Some of them are brief and concise and others are very detailed. Experts state that check lists do not substitute for knowledge; however, they may provide help which will be the more effective the more knowledgeable the user is.

See also: **Harvesting**: Forest Operations in the Tropics, Reduced Impact Logging; Forest Operations under Mountainous Conditions; Wood Delivery. **Operations**: Forest Operations Management.

Further Reading

Apud E and Valdés S (1993) Ergonomics in Chilean forestry. *Unasylva* 44: 31–37.

Apud E and Valdés S (1994) Physical work load and output on grounds with different slopes. In Sessions J (ed.) *Proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations under Mountainous Conditions*, 24–27 July, 1994, Harbin, pp. 181–190.

Apud E and Valdés S (1995) *Ergonomics in Forestry: The Chilean Case*. Geneva, Switzerland: International Labour Organization.

Apud E and Valdés S (2000) Ergonomic research in developing countries as a contribution to increase productivity and social development. In: Krishnapillay B and Soepadmo E (eds.) *Forest and Society: The Role of Research*, vol. 2, pp. 617–627. Kuala Lumpur, Malaysia: Proceedings of the XXI IUFRO World Congress.

Apud E, Bostrand L, Mobbs ID, and Strehlke B (1989) *Guidelines on Ergonomic Study in Forestry*. Geneva, Switzerland: International Labour Organization.

Apud E, Gutiérrez M, Lagos S, *et al.* (1999) *Manual de Ergonomía Forestal*. Available online at http://www.udec.cl/ergo-conce/.

Apud E, Meyer F, and Maureira F (2002) *Ergonomía en el Combate de Incendios Forestales*. Concepción, Chile: Valverde.

Apud E, Gutierrez M, Maureira F, *et al.* (2003) *Guía para la Evaluación de Trabajos Pesados*. Concepción, Chile: Trama.

Bostrand L (1992) *Introduction to Ergonomics in Forestry in Developing Countries*. FAO Forestry Paper no. 100. Rome: Food and Agriculture Organization.

Gellerstedt S, Alnqvist R, Attebrant M, Olov Wikstrom B, and Winkel J (1999) *Ergonomic Guidelines for Forest Machines*. Uppsala: Skogforsk.

ILO (1992) *Fitting the Job to the Forest Worker: An Illustrated Training Manual on Ergonomics*. Geneva, Switzerland: International Labour Organization Sectoral Activities Programme.

Johansson K and Strehlke B (1996) *Improving Working Conditions and Increasing Profits in Forestry*. Geneva, Switzerland: International Labour Organization Sectoral Activities Programme.

Wilson J and Corlett N (eds) (1992) *Evaluation of Human Work: A Practical Ergonomics Methodology*. London: Taylor & Francis.

Logistics in Forest Operations

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Introduction

Logistics concerns the organization of business operations in order to maximize the total benefit. Besides the flow of material (in forestry mainly wood), personnel, machinery, capital, and information are important factors. Different strategies may be chosen for the supply chain depending on the overall conditions. Harvesting operations in most of the industrialized world have changed from a seasonal activity to a round-the-year occupation. Due to uncertainty in the planning process a buffer in the wood supply needs to be met. This can be done by storing wood, but also by having an overcapacity in the harvesting organization. A supply chain management perspective is important not to suboptimize a system. Transport planning is the final subprocess in the wood supply chain from forest to mill. The high number of possible transport methods, combinations, and the restrictions applied to transport planning make it difficult to achieve economically optimal transportation without the help of computerized planning functions. This article explains the basic content of and requirements for planning functions for truck transport. The implementation of these functions relies upon an advanced information and communication (ICT) infrastructure. Mobile data systems (MDS), consisting of