

Forest Operations under Mountainous Conditions

Hans R. Heinimann¹

Department of Forest Engineering, Oregon State University, Corvallis, OR
Hans.Heinimann@orst.edu

1. Introduction

In 1992, the international community accepted the concept of sustainable development as a framework for future development. While many people agree with this general goal, there is still a lack of useful concepts and tools to implement sustainable development on the level of projects and processes. Environmental scientists put forward “efficiency revolution” as one approach for future development (VON WEIZSAECKER, 1997, ODUM, 1989). Taking the improvement of processes and systems as a starting point gives engineering disciplines an essential role in the design and development of sustainable systems. Forest operations are one engineering discipline aiming to maximise efficiency while minimising adverse effects.

The goal of the paper is to outline the broad lines of forest operations knowledge for mountainous terrain. The main dimensions to be considered are (1) technical feasibility, (2) economic efficiency, (3) environmental soundness, and (4) institutional feasibility. Future development of forest operations will integrate these dimensions to provide engineering solutions that will be efficient and find high public acceptance.

2. Forest Operations in Context

At the United Nations Conference on Environment and Development, mountain development was one of the topics on the agenda. In chapter 13 of the final report (Agenda-21), “sustainable mountain development” (UNCED, 1992) focused on the main problem of mountainous areas, degradation of watersheds. Forestry is one of the land use activities, that has large effects on environmental quality. The challenge is to develop and maintain land management systems that provide a balance between land use and conservation of natural processes and systems.

Forest Operations consist of all technical and administrative processes required to develop technical structures and facilities, to harvest timber, to prepare sites for regeneration, to maintain and improve quality of stands and habitats, etc. (SESSIONS AND GARLAND, 1999). It provides forest plans and operations that are:

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Visiting Professor at Oregon State University.

Permanent Address: Swiss Federal Institute of Technology (ETH), CH-8092 Zurich, Switzerland. Voice +41 1 632 32 35, fax +41 1 632 11 46, e-mail heinimann@waho.ethz.ch

- *Technically feasible* considering the physical laws, engineering knowledge, and environmental relationship of the forest,
- *Economically viable* considering the costs and benefits of short and long range consequences,
- *Environmentally sound* considering impacts on the natural and social environment and efficient use of natural resources including renewable materials, non-renewable materials, water, energy, and space, and
- *Institutionally feasible* considering the laws and regulations governing operations, land-owner objectives, and social values.

Harvesting activities must consider stand treatment regimes, and can influence them. Furthermore, they must be consistent with terrain characteristics. Sound engineering practices require a thorough understanding of the above factors. Forest Operations has been developing a broad knowledge for different terrain and stand characteristics. What follows will focus on general lines of development.

3. Problem Areas of Forest Operations

3.1 Road Networks and Harvesting Systems

Accessibility is the most critical factor influencing feasibility of following operations in mountainous terrain. Transportation consists of two phases, off-road and on-road, which are heavily dependent on each other. Four main concepts are available for facilitating off-road transportation: ground vehicles moving on natural terrain, ground vehicles moving on skid roads, carriages moving on cable structures and airships moving in the atmosphere (Figure 1). In non-mountainous terrain, off-road transportation is based on ground vehicles. System complexity increases with the effort to ensure off-road locomotion. Ground vehicles may move on a path over natural terrain or, if the terrain conditions become too complex, over geotechnical structures (skid roads). If terrain conditions become too difficult, cable structures enable the transport of partially or full suspended loads over large distances overcoming various terrain obstacles. Airship-based technologies use the atmosphere as media for transport. Although at a high operational cost, helicopters have found a niche in transport for a number of site-specific situations when road cost are high, speed of operation is important or fragile ground conditions exist.

During the 1980's the *engineering approach* to develop road networks changed. It has been evolving from a technical task of cost minimization to a task that integrates technical processes with public involvement, environmental impact assessment, and public choice (HEINIMANN 1998a). At present, we are moving from an analysis-synthesis-evaluation design principle towards an engineering phase of algorithms and artificial intelligence. Availability of sophisticated computers, smart software, and digital terrain models are the backbone of future engineering work. The most advanced system for the layout of both road network and harvesting patterns, the PLANEX system (EPSTEIN ET AL.) is able to generate plans semi-automatically. Another problem becoming increasingly important is the difference of life spans of on-road and off-road technologies. While the life span of roads is about 30 to 50 years, it has only been about 10 to 20 years for off-road technology. Therefore, a need to re-engineer forest road networks is emerging because off-road equipment is no longer appropriate.

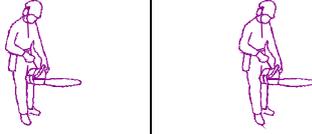
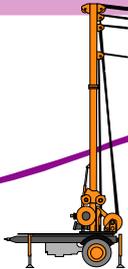
	ground-based		cable-based		airship-based
					
	Skid trails		Skid roads		flight paths
					
					
criteria	10-35% slope economical ecological		35-50% slope economical ecological		economical ecological

Fig. 1 Basic harvesting system concepts. Off-road transportation technology is decisive for the layout of road networks and harvest units.

In trafficable terrain, ground vehicles are the basis for mechanised felling, processing and transportation of trees. Mechanisation of transportation mainly progressed in the 1960's and 1970's resulting in special machines like skidders, forwarders, or clambank-skidders. Mechanisation of felling and processing operations first took place in gentle terrain and slowly evolved on slopes. Beginning in the mid-1980's, manufacturers adapted tracked carriers for the special conditions of slopes. Being capable of processing trees mechanically in the stand increased the application of cut-to-length harvesting systems (CTL), first in thinning operations. In non-trafficable terrain, cable yarders are the determinant technology of harvesting systems. Cable operations have been increasingly used in thinning operations, extracting small size timber. This trend leads to emergence of smaller harvesters, and leaving systems developed for clear cutting, such as high lead, grapple yarding, etc. The most advanced yarders make use of information technology to control speed, to move to load pick-up locations, and to monitor system state automatically.

Despite the options of sophisticated technology, bio-mechanical power (humans, animals) for felling, processing, and transportation is still important in many regions of the world, especially in developing countries. The dissemination of knowledge and the development of human resources in the forestry sectors is therefore an important issue to be emphasized in the future.

3.2 Operational Efficiency

Production economics investigates the interactions of factors of production with the output of production. Due to the complexity of harvesting systems, it is only possible to develop empirical models with a limited range of validity. It is a classical task of forest operations research to analyse and to develop productivity models, which are the basis for estimating production rates (e.g. production rate in m³ per productive system hour), and for optimising systems' performance. Professional literature reports many of those studies. However, comparability is limited due to different standards of study layout, of timber volume measurement, and of time units. A IUFRO work group therefore established a standard (BJÖRHEDEN AND THOMPSON, 1995),

which unfortunately has not yet been widely used. Another problem is that the number of different harvesting systems has reached a variety that demands too much effort when using traditional study methods. Future research will therefore have to concentrate on families of technologies (harvesters, forwarders, yarders, etc.) , and on real-time gathering of operational data using sensors and data loggers. *Optimisation* is another field of forest operations research. Problems are often so complex that the use of traditional techniques of operations research such as linear programming need excessive computing time or is even impossible. Advances in heuristic techniques open new possibilities to optimisation, offering a broad area of future research (see for example BETTINGER ET AL., 1999).

3.3 Environmental and Social Impacts

Since the 1970's, public awareness of environmental concerns has steadily increased. The United Nations Conference on Environment and Development UNCED, held 1992 in Rio, adopted the concept of sustainable development as a programatic goal for future development. However, there has been a lot of debate on how to transfer this concept to the level of operations and harvesting systems. Risk analysis is one approach of studying the impacts of specific processes on safeguard objects. In forest operations the relevant safeguard objects are (1) watersheds, (2) sites, (3) human beings, and (4) natural resources. Human activities affect these safeguard objects in different ways and on different spatial scales.

- Land use activities such as road network construction and harvesting regimes may have *adverse watersheds effects*. Research on erosion and sedimentation processes is complex and needs large-scale spatial data sets of a few critical variables to develop better understanding. Hypotheses (see DUNNE, 1998) postulate that channel networks integrate the cumulative effects of geotechnical and topographical variability, climatic triggering events (rainstorms, fires), and management regimes (roading, harvesting). Road erosion and identification of landslide trigger sites are problems that can be immediately remedied (COLLINS AND PESS, 1997) by considering rules of drainage, and pavement design.
- Harvesting activities such as off-road traffic and felling cause several *site disturbances*. Research has been concentrating on long lasting effects, such as soil erosion and soil compaction. One aim is to understand the behaviour of the vehicle-soil interaction and to provide threshold values to limit possible damages to an acceptable level. Mechanical behaviour of soils depends on its water content. One strategy to limit soil disturbances is to avoid traffic whenever the water content approaches the limit of liquidity, or even is exceeding it. Another approach is to minimise the actions at the wheel-soil interface by using low-ground-pressure tires. A third strategy is to limit traffic on fixed transportation lines (skid trails). Although progress has been made to reduce site disturbances, there are still many unsolved questions. FORSITRISK II, a program established by the Joint FAO/ECE/ILO Committee on Forest Technology, Management, and Training, brings together a team of specialists. Its goal is to prepare guidelines for users of forest machines and equipment and for designers of forest machines in order to minimise the impact on forest sites.
- Forest work may have *impacts on health and safety of the workforce*. Forestry is one of the sectors with the highest accident rates often resulting in heavy injuries or even death. Research investigates stress-strain processes of different systems, as a basis for system improvement and development. The International Labour Office ILO offers information on occupational health and safety, ergonomics, etc. A recent code of practice (ILO, 1998) aims to protect workers from hazards in forestry work and to prevent or reduce the incidence of occupational illness or injury. It is intended to help countries and enterprises that have no forestry-specific regulations, but there are also useful ideas for those with well-

developed prevention strategies. The available body of knowledge is considerable. The problem is how to disseminate it and how to apply the basic rules in firms and enterprises.

- Manufacturing processes are *using energy and materials and releasing wastes* to the environment. Life-Cycle Assessment has become an important tool to assess those energy and material uses and releases to the environment. It forms part of the novel orientation in environmental management, moving away from “end of pipe” to “begin of pipe” approaches (ODUM, 1989). In forestry, use of LCA methodology has just started recently, therefore only preliminary results are available (HEINIMANN, 1998b). The LCA framework is an important step to shift environmental issues from “good feeling” to hard facts.

3.4 Institutional Framework

Recently, institutional feasibility has become more important because of the increasing public interest in environmental concerns. It is therefore necessary to understand the institutional framework that provides the context for action. For a long time, legal compliance was the only requirement to be considered. Increasing maturity of a profession or a scientific community leads to professional rules, such as technical standards, codes of practices, or code of ethics (Figure 2). Professional rules are established on a voluntary basis and therefore cannot be enforced. Technical standards usually describe the rules for the design of engineering structures whereas „state-of-the-art“ rules outline the body of proven knowledge. During the last decade, professional groups made big efforts to establish a set of international rules, even for the forestry sector. The FAO model code of forest harvesting practices (DYKSTRA AND HEINRICH, 1996), and the safety and health code (ILO, 1998) are important on the international level. They should help to improve the quality of forest operations and products, and to minimize adverse effects. Several countries and regions established their own codes of practices, particularly in Anglo-Saxon countries. International technical standards have steadily involved. Ergonomics seems to be the most advanced area in which about 100 technical standards are available, or in preparation respectively (DUL ET AL., 1996).

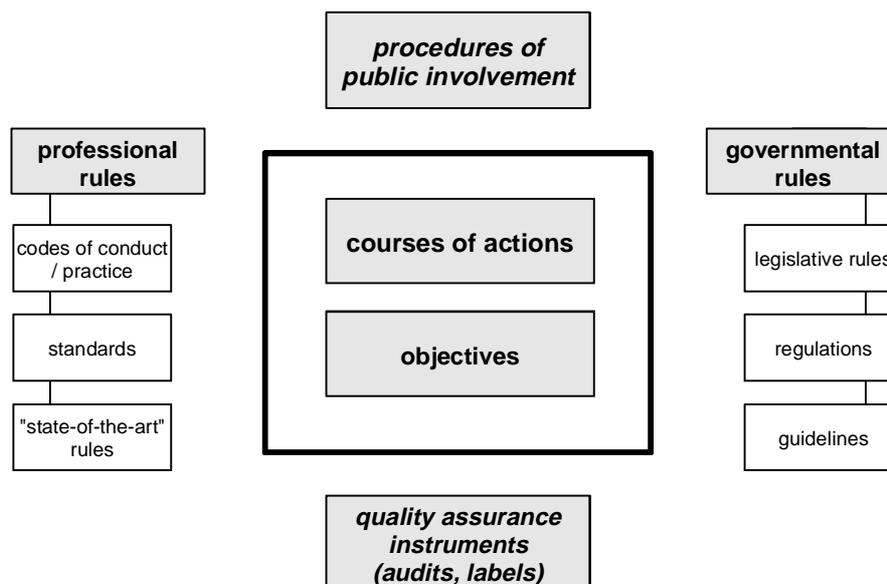


Fig. 2 Institutional framework providing the context for action. Novel policy instruments (public involvement, auditing, labeling) aim to improve public acceptance.

Legal compliance and the consideration of professional rules does not necessarily result in public acceptance of specific courses of actions. Therefore, new policy instruments have been developed. They take into account principles like self-responsibility, public involvement, continuous improvement, or intelligibility. In Forest Operations, public involvement has become part of project planning processes in some countries (for example road network planning), where it is an essential component of environmental impact assessment (EIA) procedures (see HEINIMANN, 1998a). While public involvement takes place in unique plans or projects, tools of environmental management apply to continuous manufacturing processes and organizational units. The international standard organization ISO established the ISO-14000 family, covering instruments such as environmental auditing, labeling, and declarations. Adaptation of these novel policy instruments to the forestry sector is ongoing and will develop its potential in the future.

4. Prospects for the Future

We are looking back on a phase of development that has been dominated by environmental and institutional issues. Many people therefore misjudged the significance of technology and engineering sciences, and their role for sustainable development. Environmentally Sound Technologies (ESTs) are not just individual technologies, but total systems, which include expertise, procedures, goods and services, and equipment as well as organizational and managerial procedures. There is a considerable body of knowledge on forest operations technology, even for sensitive mountainous areas. Improving the understanding of natural processes and their interactions with land use activities is important. However, dissemination of available knowledge and the development of human resources are probably more important, first in mountainous areas where the risk of degradation is high. The forest operations community will continue to improve the technical systems of forestry. The main challenges for future research and development will probably be:

- The shift to a process focus, considering all technical and administrative processes along a whole value chain of production (business reengineering focus),
- The active collaboration in the process of improving and developing the institutional framework (adaptation of policy instruments such as auditing, scientific based environmental standards, etc.),
- Planning procedures based on algorithmic knowledge and spatial data bases,
- The Operationalisation of environmental issues, following the emerging discipline of industrial ecology (quantification of the “industrial metabolism”) using and improving tools such as Life-Cycle-Analysis LCA or Substance Flow Analysis SFA,
- To expand the concept of operational efficiency considering the “eco-efficiency” approach proposed by the World Business Council for Sustainable Development (DE SIMONE AND POPOFF, 1998),
- To develop human resources on all levels of forestry, taking into account future organizational concepts (virtual organizations, network-based structures) and new job profiles (novel training methods, new wage models, teamwork, promotion by performance), and
- To follow a mechatronic’s paradigm of development, providing some “intelligent behavior” to future machines and systems (sensing devices, control systems, etc.).

Sustainable development of the planet depends, in fact, on cycling of resources rather than their extraction and eventual discard following use, and on turning from "end-of-pipe" thinking to forward-looking approaches to product and process design. I hope that this shift in thinking will help to develop sustainable management practices for mountain forest ecosystems.

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