telemetric system based time–motion studies to develop productivity functions. Time–motion study allows for objective and systematic examination of all factors which govern operational efficiency of a specified activity in order to effect improvement. With respect to forest machines, this may lead to improvements in harvesting procedures and planning for the necessary access locations during establishment of forest stands.

Post-Process Assessments

These are systematic checks that are required after an operation is completed. They are mainly geared to reverting a site to its original condition and to preventing secondary environmental degradation. For example, poor maintenance of access roads, extraction tracks, and landing areas may cause accelerated soil erosion and depreciation of water quality in the streams and water sources in the vicinity of a harvesting area, long after the operations are completed. Inadequate or poorly maintained roads incur high transportation costs. Therefore routine maintenance, rehabilitation, and upgrading of forest road networks should be implemented.

See also: **Harvesting**: Forest Operations in the Tropics, Reduced Impact Logging; Forest Operations under Mountainous Conditions; Roading and Transport Operations. **Operations**: Ergonomics; Forest Operations Management; Logistics in Forest Operations.

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Forest Operations under Mountainous Conditions

H R Heinimann, Swiss Federal Institute of Technology, Zurich, Switzerland

Introduction

About 28% of the world's forests are located in mountainous areas, where forest management aims at simultaneously providing goods and welfare services while maintaining ecosystem functions at prudent, sustainable levels. Forest operations aims at delivering plans and operations that are technically feasible, economically viable, environmentally sound, and institutionally acceptable. To achieve this, there is a need to know best practices and to continuously improve them. Design, implementation, and control of forest operations for the specific conditions of mountainous areas are challenging due to difficult terrain conditions and high risks of adverse effects on environmental functions and values. Off-road transportation technology is the critical part of steep slope harvesting operations, and cable-based systems are often the backbone of harvesting systems. The main challenges for future developments probably are: the continuous improvement of practices and technologies for nontrafficable terrain, operationalization of environmental performance by quantifying the 'industrial metabolism' of operations, and development of both human resources and local capacity aspects of technology choices.

Significance and Characteristics of Mountain Forests

Mountain regions occupy about one-fourth of the earth's land surface (**Figure 1**). They are home to approximately one-tenth of the global population and provide goods and services to about half of humanity. Accordingly, they received particular attention in Agenda 21, endorsed at the United Nations Conference on Environment and Development (UNCED) in Rio in 1992. Chapter 13 of that document focuses on mountain regions, and states:

> Mountain environments are essential to the survival of the global ecosystem. Many of them are experiencing degradation in terms of accelerated soil erosion, landslides, and rapid loss of habitat and genetic diversity. Hence, proper management of mountain resources and socio-economic development of the people deserves immediate action.

The global mountain forest area covers about 9.1 million km^2, sharing about 8% of the global land area, and about 28% of the world's forests (**Figure 1**). One-half of the mountain forest area is located in temperate and boreal zones (west of North America, Europe, Far East), while the other half is located in subtropical and tropical regions (Central America, Eastern Andes of South America, continental and insular Southeast Asia, especially Borneo and Papua New Guinea). Mountain forests are fragile ecosystems, which are important for (1) the maintenance of life support services, (2) the supply of renewable resources (biomass, water), and (3) the provision of welfare services, such as mitigation of natural hazards, recreation, or intellectual stimulation.

While the supply of renewable resources, including fuelwood, timber, and other products, has been an important and familiar part of the economy, it has been less appreciated that natural ecosystems perform fundamental life support services (e.g., habitat, biodiversity, nutrient cycling, biogeochemical cycling, food-web functions). This array of services is generated by a complex interplay of natural cycles powered by solar energy and operating across a wide range of space and timescales.

The challenge is to develop land use policies and practices for mountain forests that will provide goods and welfare services simultaneously with maintaining ecosystem functions at prudent, sustainable levels. There is a need to incorporate major ecological considerations into silvicultural practices, e.g., imitating natural processes, reducing forest fragmentation, avoiding harvest in vulnerable areas, or restoring natural structural complexity to cutover sites.

Forest Operations in Context

Forest operations consist of all technical and administrative processes required to develop technical structures and facilities, to harvest timber, to prepare sites for regeneration, and to maintain and improve quality of forest ecosystems on a wide range of space and timescales. It aims at providing plans and operations that are:

- environmentally sound considering impacts on the natural and social environment and efficient use of natural resources including nonrenewable materials, renewable materials, water, energy, and space
- technically feasible considering the physical laws, engineering disciplines, and environmental aspects of the forest
- economically viable considering the cost and benefits of short- and long-range consequences
- institutionally acceptable considering the laws and regulations governing forest operations, landowner objectives, and social values.

The United Nations Environment Program UNEP has been promoting the concept of environmentally sound technologies (ESTs) to significantly improve environmental performance relative to other technologies. These technologies use resources in a sustainable manner, are less polluting, protect the environment, recycle more of their wastes and products, and handle all residual wastes in a more

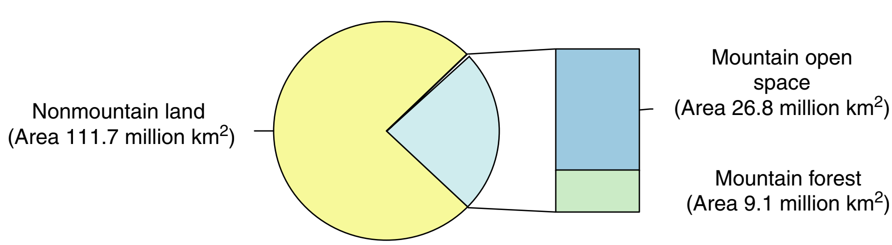

Figure 1 Proportions of the world's mountain forests.

environmentally acceptable way than the technologies for which they are substitutes. Additionally, they have to be compatible with nationally determined socioeconomic, cultural, and environmental priorities and development goals.

Forest operations technology aims at providing best practices that are the result of a continuous process of suiting harvesting practices to silvicultural regimes, and of improving economic and environmental performance. Best practices (BP) consist of strategies, activities, or approaches that have proven to be both effective and efficient.

Forest Operations Technology for Mountainous Terrain

Development and Deployment of Forest Operations Technologies

Accessibility is the most critical factor influencing feasibility of 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: (1) ground vehicles moving on natural terrain, (2) ground vehicles moving on skid roads, (3) carriages moving on cable structures, and (4) aircrafts moving in the atmosphere (**Figure 2**). In nonmountainous 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 fully suspended loads over large distances overcoming various terrain obstacles. Aircraft-based technologies use the atmosphere as the medium for transport. Although at a high operational cost, helicopters have found a niche in transport for a number of site-specific situations when road costs are high, speed of operation is important, or fragile ground conditions exist.

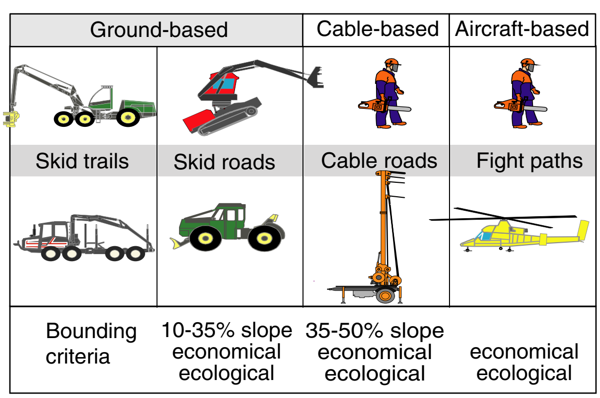

Figure 2 Basic harvesting system concepts. Off-road transportation technology is decisive for the layout of road networks and harvest units.

During the 1980s the engineering approach to developing road networks changed. It evolved from a technical task of cost minimization to a task that integrates technical processes with public involvement, environmental impact assessment, and public choice. 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 systems for the layout of both road networks and harvesting patterns are able to generate plans semi-automatically. Difference in the lifespans of on-road and off-road technologies is another problem becoming increasingly important. While the lifespan of roads is about 30–50 years, it has only been about 10–20 years for off-road technology. Therefore, a need to re-engineer forest road networks is emerging because off-road equipment has been altering its capabilities.

In trafficable terrain, ground vehicles are the basis for mechanized felling, processing, and transportation of trees. Mechanization of transportation progressed mainly in the 1960s and 1970s resulting in special machines like skidders, forwarders, or clambunk-skidders. Mechanization of felling and processing operations first took place in gentle terrain and slowly evolved on slopes. Beginning in the mid-1980s, 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, first in thinning operations.

In nontrafficable 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 loads to pick-up locations, and to monitor the state of the system automatically.

Despite the options of sophisticated technology, biomechanical 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.

Cable Systems: The Backbone of Steep Slope Harvesting Systems

Cable yarding technology has a long tradition in Central Europe, in the Pacific Northwest of North America, and in Japan. In other regions of the world, it has been introduced only tentatively.

The basic structural model consists of a cable suspended between two points (**Figure 3**). A configuration is designated standing if the cable is fixed at support points A and B. A live line configuration has the cable fixed only at one support point B, with a mechanism to control the tensile force in the line at support point A. A running line configuration has a mechanism to control tensile forces at both support points (A, B). To make such a system operable, the two control mechanisms are integrated at the head end (A) while a pulley at the tail end diverts the tensile force. A difference between tensile forces is required to produce lift, and to move a load.

The simplest cable system configuration consists of an uphill yarding system (**Figure 4**). The load-supporting structure consists of (1) the skyline, (2) the head spar, (3) the tail spar, and (4) the anchors, which have to be designed and setup specifically for each cable corridor. The yarding process requires (5) a carriage moving on the skyline, (6) a mainline to pull the carriage, and (7) a mechanism to slackpull the mainline, to lift the load, to attach it to the carriage, and to release it at the landing. Gravity moves the carriage downhill to the location where a load is picked up. A mechanism clamps the carriage to the skyline, and the mainline is slackpulled manually to the position where chokers attach logs to it. The winch pulls in the mainline until the load attaches to the carriage and releases the clamp. The load then moves partially or fully suspended to the landing.

A downhill yarding configuration (**Figure 5**) requires additional lines and mechanisms. The yarding process requires – as for uphill yarding – (5) a carriage moving on the skyline, (6) a mainline to pull the carriage, and (7) a mechanism to slackpull the mainline, to lift the load, to attach it to the carriage, and to release it at the landing. A haulback line (8) moves the carriage uphill to the location where a load is picked up. A mechanism clamps the carriage to the skyline, and the mainline is slackpulled mechanically to the position where chokers attach logs to it. There are several slackpulling mechanisms available: driving a sheave by the yarder's slackpulling line, by an electromechanical engine, by a fuel engine, or by a hydraulic pump. The winch pulls the mainline in until the load attaches to the carriage and releases the clamp. The load then moves partially or fully suspended to the landing, simultaneously controlled by the mainline and the haulback line.

Operational efficiency depends far more upon rational organization of work processes than upon equipment capabilities, or workers' skills. It is therefore important to understand the essence of the workflow organization of cable-based harvesting systems. A harvesting system is designated 'tree length' if the conversion of trees to logs is done after the extraction operation at the landing or at mill site. This means that only felling is done at the stump site, either motor-manually or using steep slope feller-bunchers. Directional felling and bunching affect productivity positively. Several trees are chokered to a single load, which is attached to the mainline and extracted by a

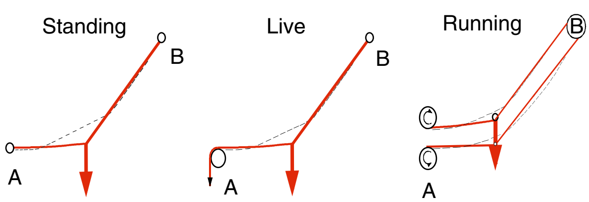

Figure 3 Types of load-supporting cable structures.

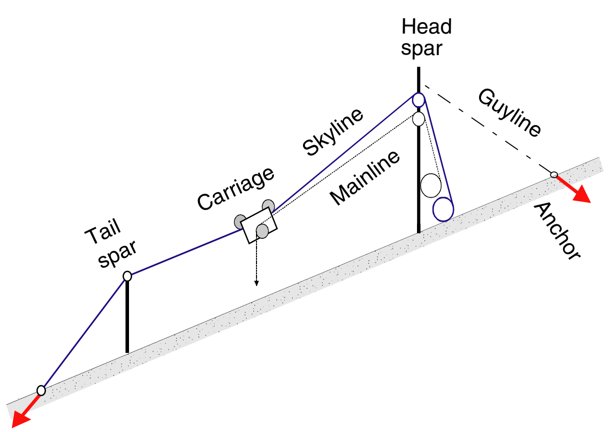

Figure 4 Components of a skyline yarding systems for uphill yarding.

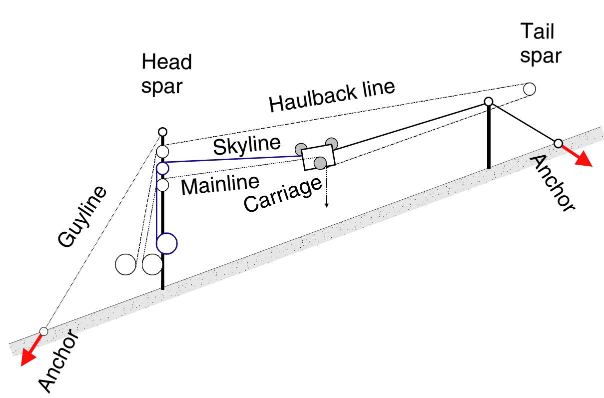

Figure 5 Components of a skyline yarding system for downhill yarding.

cable yarder to the landing. At the landing, the following operations have to be done: releasing the load, limbing, bucking, and piling. These operations may be mechanized by using an excavator with a stroke-delimber, which is common in North America. In Central Europe, a boom with an attached processor head is integrated into the yarder. A standard crew consists of one or two choker setters, one yarder operator, one processor operator, and one chaser. In countries with high labor cost, such as Central Europe, rationalization efforts have led to automated systems which can be operated by a two-man crew: one choker setter and one yarder operator. The yarder moves the load automatically from the stump to the landing and the empty carriage from the landing to the stump site. The yarder operator therefore gains additional time which can be used to process trees to logs while the carriage is moving automatically. Such a system requires radio-control of the yarder. Future developments aim to introduce bucking-to-value and bucking-to-order procedures as they are implemented in the Nordic wheeled harvester systems.

A harvesting system is designated cut-to-length (CTL) if the conversion of trees to logs is done at the stump site before the extraction operation. Felling, limbing, and bucking are all done at the stump site. Motor-manual systems use workers equipped with chainsaws. Mechanized systems are based on steep slope harvesters with the capacity to level the swing table. Several logs are chokered to a single load which is attached to the mainline and extracted partially or fully suspended by a cable yarder to the landing. A grapple attached to a boom handles the logs and piles them. In North America, an excavator-based loader usually does this operation, whereas in Central Europe the boom is integrated into the yarder. A standard crew is of the same size as for tree-length harvesting, and the minimal crew size consists of two, one choker setter and one yarder operator. As in tree-length harvesting, a crew size of only two requires radio-control of the yarder and the carriage. CTL systems may be used in both thinning and clear-felling operations. However, CTL cable yarding is best to minimize damage to residual trees in thinning operations.

Improving Operational Efficiency

Production economics investigates the interactions of factors of production with the output of production. It is only possible to develop empirical models with a limited range of validity due to the complexity of harvesting systems. Forest operations research has been analyzing and developing productivity models, which are the basis for estimating production rates (e.g., production rate in m^3 per productive system hour), and for optimizing systems' performance. The 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. 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. Optimization has been another field of forest operations research. Problems are often so complex that the use of traditional techniques of operations research, such as linear programming, needs excessive computing time or is even impossible. Advances in heuristic techniques open new possibilities to optimization, offering a broad area of future research.

Minimizing Environmental and Social Impacts

Since the 1970s, public awareness of environmental concerns has steadily increased. The UNCED conference adopted the concept of sustainable development as a programmatic goal for future development. However, there has been much 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 scales of space and time.

Watersheds

Land use activities such as road network construction and harvesting regimes may have adverse effects on watershed processes. 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 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 by considering rules of drainage, and roadway design. Imperviousness is an indicator for cumulative impacts at the watershed scale, which can be easily measured at all scales of development, as the percentage of area that is not 'green.' Current research converges toward a common conclusion:

that it is extremely difficult to maintain integrity of catchment processes when development exceeds 10–15% impervious cover. There seems to be a strong relationship between imperviousness and runoff, water quality, stream warming, stream biodiversity, and other dimensions of aquatic quality.

Site Disturbance

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 behavior of the vehicle–soil interaction and to provide threshold values to limit possible damages to an acceptable level. Mechanical behavior of soil 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 exceeds it. Another approach is to minimize 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.

Health and Safety

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 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.

Life Cycle Assessment

Manufacturing processes are using energy and materials and releasing wastes to the environment. Life cycle assessment (LCA) 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. In forestry, use of LCA methodology has just started recently; therefore only preliminary results are available. The LCA framework is an important step to shift environmental issues from 'good feeling' to hard facts, and to establish a set of operational performance indicators (OPIs), as proposed by international standards on environmental performance (ISO 14031).

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. 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 re-engineering focus)
- 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 databases
- operationalization of environmental issues, following the emerging discipline of industrial ecology (quantification of the 'industrial metabolism') using and improving tools such as LCA or substance flow analysis (SFA)
- expansion of the concept of operational efficiency considering the 'eco-efficiency' approach proposed by the World Business Council for Sustainable Development
- development of 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)
- use of a mechatronic's paradigm of development, providing some 'intelligent behavior' to future machines and systems (sensing devices, control systems, etc.).

Sustainable development of mountain areas depends on recycling 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. There is a big potential for this shift in thinking to develop sustainable management practices for mountain forest ecosystems.

See also: **Harvesting**: Forest Operations in the Tropics, Reduced Impact Logging; Roading and Transport Operations. **Hydrology**: Snow and Avalanche Control; Soil Erosion Control. **Operations**: Forest Operations Management; Logistics in Forest Operations. **Site-Specific Silviculture**: Silviculture in Mountain Forests.

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HEALTH AND PROTECTION

Contents

Diagnosis, Monitoring and Evaluation

M Ferretti, LINNÆA ambiente, Florence, Italy

Introduction

Over the last 30 years forest health became a popular issue together with the concern about acid rain, air pollution, and climate change. Terms like forest decline, and the German 'Waldsterben' (forest death) and 'Neuartigen Waldschäden' (new type of forest damage) became frequent in scientific literature as well as in popular media. This concern resulted in an unprecedent effort to study and monitor forest health. Since then the situation has evolved and now forest health diagnosis and monitoring is relevant to a much broader area of interest, including recent (e.g., climate fluctuation and change, biodiversity, sustainable resource management) and 'traditional' issues (e.g., pests, diseases, forest fire). Broadly, forest health diagnosis, monitoring, and evaluation aims to identify forest health problems, track forest health status through time and identify its relationship with environmental (biotic and abiotic) factors. It embraces a variety of activities and involves several topics and scientific disciplines. Forest health diagnosis, monitoring and evaluation is addressed here in terms of (1) definitions, factors affecting forest health