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.

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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 vehicle PCs linked on-line to a central company server, represent one such configuration of an ICT infrastructure. This article explains how transport planning is implemented and the role of such an ICT infrastructure in efficient implementation.

General Logistics

Logistics may be defined simply as methods for planning, execution, and control of operations governing the flow of material, machinery, personnel, and information. The role of logistics in forest operations is to coordinate roundwood supply with mill demand. This is in the context of demands for high capacity utilization and low levels of roundwood storage, in a geographically dispersed supply chain subject to numerous climatic disturbances.

Logistics in forest operations can be based on two different supply chain strategies efficiency and flexibility. With lower degrees of customer orientation (harvest-to-stock) it is primarily efficiency of forest operations which is in focus. With an increasing degree of customer orientation (harvest-to-plan for pulpwood or harvest-to-order for saw-logs) increasing flexibility and control is demanded (**Figure 1**).

Figure 1 Logistics in forest operations. The supply chain strategies (below the line) corresponding to different degrees of customer orientation (above the line).

The whole wood supply process can generally be divided into five subprocesses; prognosis planning (yearly horizon), demand and supply planning (rolling 3-month horizons), delivery planning (confirmed harvesting teams production aimed for specific mills on a monthly horizon), and finally harvest planning and transport planning (on weekly horizons). The supply chain from forest to mill can be described in terms of three nodes (forest harvesting, roadside inventory, and mill inventory) and two connecting links (extraction and transport). Each link with its connecting nodes is the basis of planning of delivery, execution of supply, and control of flow for harvesting and transport.

These two planning, execution, and control (PEC) cycles are used to adjust the rates of flow from both forest to roadside and from roadside to mill to meet varying mill demand under varying conditions (**Figure 2**).

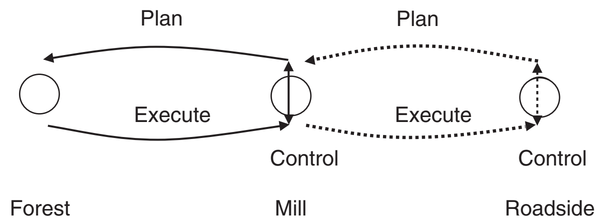

Figure 2 Planning, execution, and control (PEC) cycles for harvesting and extraction (forest–roadside) and transport (roadside–mill) operations.

Harvesting

In many parts of the world forest operations used to be a seasonal activity. Winter was in many places preferred for harvesting, the increased flooding in spring was used for river driving and silvicultural operations were conducted during the growing season. Changes in technology, employment law, and costs for inventories have altered the wood procurement process as well. Today, all year round harvesting and wood delivery are most common. But this also put new demands on the logistics of the operations.

Normally, the prognosis planning (yearly horizon) is based on the predicted harvesting, estimated by known factors if the forest is in control by the organization or experience if the harvesting is done for other landowners. In the latter case, the identity of harvesting objects may only be known at very short notice, depending on the type of agreement made by the seller of the harvesting and the buyer. The task of prognosis planning is to allocate known and anticipated harvestings in time and space to match the requirements from industry, the machinery and personnel available, and probable seasonal variation in harvesting conditions. If conditions change during the period, e.g., the demands of industry or weather, plans must change as well. The very nature of forestry makes it susceptible to climatic uncertainty. Heavy rain may cause terrain and roads to be inaccessible and harvesting plans must be changed accordingly. The role of harvesting planning is to make as good decisions as possible with the information available. The closer a specific harvesting is in time, the more accurate information is at hand and the more precise the planning can be made. However, harvesting planners must act with a great deal of flexibility.

One feature of forestry that makes it somewhat different from many other businesses is that it has a divergent flow of materials. Different assortments, based on use and tree species, cause one harvesting to produce material for many industries. Saw timber, pulpwood, wood for board mills, and wood for energy are examples of such assortments, and most often the industries are tree-species specific. This complicates the planning further. As an example, if there is an increased demand for pulp from hardwoods, as these trees very often grow in mixed stands other tree species will be in the harvested volume as well, and so will hardwood saw timber.

To achieve the flexibility in meeting fluctuations different strategies can be chosen. One way is to have large inventories. Inventories buffer the harvestings from changes, allowing a longer time to respond. However, inventories cost money in terms of capital and degrading quality. Another way is to have a very flexible harvesting organization that can adapt very fast to changes. Good planning routines can achieve some of this flexibility, but some overcapacity in the organization is required. This also costs money. A balance between those strategies must be found, and logistics theory emphasizes the importance of looking at the cost and benefits for the whole supply chain. Otherwise, suboptimizing is a big risk. Forest operations may solve a problem in a way that is very efficient for the harvesting, but which introduces costs into other parts of the supply chain that may well exceed those benefits. Hence, the growing interest in supply chain management which is based on a holistic perspective of the problem. This also points in a direction where harvest planning is much more integrated with the other parts of the supply chain: transport, industry, and customers. Without doubt, this is a development that is only just beginning.

Transport

Transport work from forest to mill has undergone considerable changes during the last 50 years. Structural changes in the forest products industries have led to a reduction in the number of roundwood destinations with a corresponding increase in average transport distances from forest to mill. At the same time road standards and transport capacity has increased.

Transport planning is the final subprocess of five in wood supply and is therefore subject to the greatest number of planning constraints. The high number of possible transport methods, their combinations, and the restrictions applied to transport planning make it difficult to achieve an economically optimal transport organization without the help of computerized decision-support tools. The most common transport method for short distances (<100 km) is truck transport. Rail and boat transport dominate on longer distances.

There are two general classes of trucks: self-loading trucks that work alone and trucks that work in groups and require a separate loader. For truck transport there are two general classes of planning functions: roundwood destination and vehicle routing. Destination aims to minimize the loaded transport distance between all forest supply nodes (active landings) and demand nodes (mills). This is done within the supply and demand restrictions imposed by the supply and demand planning process. Vehicle routing aims to maximize capacity utilization of the transport fleet within the constraints imposed by destination. Different goals may be used and minimizing the unloaded distance from mill back to forest by locating backhauls is one of the most common. Typical planning horizons are less than a month for destination and less than a week for routing.

Destination Functions

The destination function in transport planning can be studied from different perspectives. The first is that of the large forest companies with long-term wood supply responsibilities to major mills. The second is that of forest owners' associations or wood procurement groups who act as independent traders purchasing roundwood and selling to mills on short-term contracts on an open market.

Destination of roundwood may be optimally solved as a network model with the application of the classic transport algorithm and linear programming to minimize the loaded transport distance. This formulation may be well suited for large forest companies with long-term wood supply responsibilities to their own mills. There are important differences in the model formulation between the independent trader perspective and the forest company case. Independent trade aims to maximize the net revenue between price paid to the forest owner and the price received from the customers. Since contract prices for wood received may be at forest roadside or at the customer's location, this must be included in the model. This ensures that when the price is based on delivery at the roadside, the transport costs for wood transported from forest owner to customer is not taken into account. When the prices are based on delivery at mill site the transportation costs are included in maximization of net revenue. Often the prices paid to forest owners are also reduced with increasing transport distance to the nearest mill according to an agreed norm. Prices paid by the pulp mill, on the other hand, are determined through negotiations for each delivery contract specifying the prices for roundwood, and the delivery location.

There are also differences between assortments of roundwood which are important in the rigidity of restrictions of delivery. With the cut-to-length system it is more difficult to change the destination of wood which is already cross-cut for specific sawmills. Pulpwood, however, is often a by-product which it is possible to deliver to a number of different customers. Deviations from the delivery plans may therefore be compensated for by purchase from other suppliers. In this case it is therefore possible to relax the constraints of delivery precision.

Vehicle Routing Functions

Routing of timber trucks demands the comparison of a great number of possible driving patterns and combinations. For this reason mathematical techniques creating smaller subproblems involving the use of heuristics have been common for optimal routing. These subproblems are then easier to formulate and solve by a simpler algorithm such as the 'traveling salesman' algorithm. More exact methods such as tree-searching or 'column generation' (where each possible route represents a column) followed by tree-searching are efficient methods for solving more complex problems. While general vehicle routing problems have been in use for many years, roundwood transport represents a special case where the number of restrictions are especially large. This includes, for example, factors such as the geographic movement of supply nodes (active landings) and the specificity of certain landings for certain truck types. The influence of climate on infrastructure standards and the effects of roundwood freshness (time from harvest to use) for mill processes and product quality are also critical restrictions. Examples of successful implementation are to be found in ASICAM in Chile, EPO in Finland, and SMART in Sweden.

The probability of successful implementation increases with the stability of operational conditions and the simplicity of the planning function. Under stable conditions relatively advanced tools will function well. While under changing conditions, the number of restrictions increases, leading to the need for real-time operational data. Destination is the simplest of decision-support tools. Requirements concerning both computational capacity and operational data are limited.

Transport Administration Systems

A wood supply system which gives complete control should include the following modules:

- communication with both external and internal networks
- delivery follow-up in real time
- transport infrastructure databases
- decision support for optimizing transport plans
- mobile data systems.

Implementation decision support for optimizing transport planning requires an advanced information and communication technology (ICT) infrastructure. Mobile data systems (MDS), consisting of vehicle PCs linked on-line to a central company server, represent one such configuration of an ICT infrastructure. MDS consists of hardware and software with the following functions:

- distribution of transport orders and plans
- monitor with navigation aid to forest site (global positioning systems (GPS)/geographical information systems (GIS))
- reporting of transport volumes.

MDS support is a necessary element for future wood supply where structural changes create larger procurement areas which grow beyond each truck operators' area of local knowledge.

In transport planning there are two key interfaces where complexity management is important: (1) an external interface between the transport environment and the transport organization, and (2) an internal interface in the organization between its operating system (trucks, operators) and its management system (planners). Because of the complexity of the system as a whole, most of the organization's management capacity is aimed at handling the complexity of its operating system. The remaining capacity can be focused on handling the complexity of the environment (a multitude of roads, roadside inventories, and disturbances in operating conditions or supply).

In the absence of computerized decision-support systems and ICT infrastructure, the most common response to the complexity of transport planning is to reduce larger routing systems to a number of smaller subsystems through decentralized transport planning. Responsibility for operative planning is then moved from the company or regional level to the district level, reducing the number of possible transport combinations to a number readily solved with local knowledge and routines. This leads to each district's roundwood flow being executed independently of transportation in neighboring districts or companies, with drawbacks including difficult coordination and reduced backhauling. Reducing uncertainty of the transport system by real-time access to current information (e.g., road conditions and inventory volumes) is important to meet disturbances within these complex systems. The most advanced transport planning solutions with optimized functions, however, offer direct countermeasures to system disturbances.

See also: **Harvesting**: Roading and Transport Operations; Wood Delivery. **Operations**: Forest Operations Management.

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Nursery Operations

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Introduction

Forest regeneration is the very foundation of sustainable forestry. While many forests are regenerated using natural techniques, increasing annual wood harvests will depend upon plantation forestry. Moreover, planting is necessary for afforestation on degraded lands, abandoned agricultural lands, or anywhere that trees are to be reintroduced without a natural seed source. According to the most recent Food and Agricultural Organization (FAO) Forest Resource Assessment, there are close to 4.5 million ha planted each year. If one assumes that planting area is also a reflection of nursery production and using an estimated average spacing of 3×2 m (1666 trees ha^{-1}), this is an annual nursery production of 7.5 billion seedlings. Asia has the largest planting area with 62% of the world total, followed by Europe with 17%. Pines occupy 20% of all plantations worldwide, other conifers 11%, and eucalyptus 10%. The stock used for planting these areas almost invariably come from forest tree nurseries. Nursery managers are responsible for producing a seedling of suitable quality in a reasonable amount of time at a reasonable cost, which can withstand the rigors of processing, storage, transportation, planting, and what is more likely as not, harsh environmental conditions. If the stock does not survive, more is lost than just the cost of the planting stock. Also forfeited may be the cost of preparing the site, growth forfeited until the next planting date, and the expenses incurred if additional weed control, fertilization, or other cultural practices must be conducted. These costs may be, and usually are, substantially greater than the cost of planting stock. It is no wonder that organizations dependent upon successful plantation management consider nursery operations to be the heart of their regeneration program.

As a general rule, there are two types of planting stock – bareroot and container. The decision to rely on bareroot or container technology depends upon many factors. Certainly the physiological requirements of the species is tantamount in importance. Certain genera, such as *Eucalyptus*, are invariably grown in containers and survive poorly when planted bareroot. Other genera, such as the pines, are commonly produced bareroot. Even so, certain pine species, particularly those in the tropics (e.g., *Pinus caribaea)* require containerization. Boreal species may be containerized to shorten their time in the nursery. Whereas producing plantable bareroot stock may take 2–3 years for some boreal species, the environment of container production can produce smaller planting stock in far less time. The ability to control the growing environment is also important when producing vegetatively propagated material which is high in value and/or may require more exacting conditions to root and/or develop. Finally, planting adverse (droughty) sites may require the use of containerized stock. A possible disadvantage to containerization is a substantial increase in cost. In the southeastern United States, for example, the price of container grown stock is generally four to five times higher than the same species grown bareroot. Container stock is also more expensive to transport.

Bareroot Production

Site and Facilities Requirements

The selection of a good site is of paramount importance to the efficiency of a bareroot nursery. The most important characteristics are soil texture and water quality. Only a few decades ago, a medium textured soil was generally considered a requirement for a good bareroot nursery site. Older nurseries tend to be found on loams and silt loams. These soils, however, are not always conducive to using machinery during the wet season which is also frequently the