PROCESS SIMULATION TO EVALUATE STEEP TERRAIN HARVESTING SYSTEMS

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ABSTRACT

To secure the competitiveness of forestry on steep slopes, harvesting systems must be further developed in a systematic, efficient and goal orientated manner. The common "trial and error" method is associated with high development costs. This brings about the question, how can forest harvesting systems be cost-effectively analysed and optimised in the future. A successful concept is the use of computer simulation.

A simulation model prototype for steep terrain forestry systems has been developed. With the simulation environment HaSyS (Harvesting System Simulator) various harvesting systems (chainsaw, walking harvester, and tracked harvester in combination with cable systems) can be analysed. For the first time, the interaction effect of thinning intensity and the productive system was modelled.

The simulation model allows productivity prediction to be made dependant on system, terrain and stand variables. Productivity comparisons between different working systems have shown that through mechanisation of timber harvesting not only the felling and cross-cutting, but that also the cable extraction can be rationalised.

1. INTRODUCTION

Timber production remains the core competency of the forestry industry and therefore defines the competitiveness and the survivability of forestry companies. There are three primary solutions available to increase the competitiveness: (1) product innovation, (2) social innovation and (3) process innovation. The product timber itself is difficult to improve and companies are rarely interested in comprehensive organisational changes. Therefore, emphasis is placed on automation and mechanisation on the process side.

A comprehensive mechanisation concept is available for terrain traversable by wheeled machinery that is widely promoted in Scandinavian countries. A similar concept for steep terrain is not yet available. To guarantee the competitiveness for the future, a push in the area of process innovation is urgently required. This leads to the question, how timber harvesting systems for steep terrain can be further developed in an systematic, efficient and goal orientated manner. While in industry these processes are dealt with in a holistic "Process Design and Planning" approach, such a systematic approach is almost completely lacking in the forest industry. Many harvesting systems have been developed along the "trial and error" principle, which leads to high development costs due to the capital intensive systems. In the future, timber harvesting systems will be mainly developed or optimised with the help of computer simulation.

Computer simulation models were first used for the evaluation of new forest machinery concepts in the 1960's (feller-bunchers, debarking machines and processors). The goal was to optimise carrier platforms with respect to crane geometry for reliability and productivity (NEWNHAM, 1967; NEWNHAM, 1970; NEWNHAM and SJUNNESSON, 1969; SEPPÄLÄ, 1971). Most of these simulation programs had deterministic character. Subsequently, especially in North America, simulation was used as an aid for the analyses of single machinery as well as whole work systems. GOULET et al. (1980) provide an overview of simulation models that were developed prior to 1980. Simulation programs improved with increasing computer performance. Graphic interactive simulation was used for the development of feller-bunchers for use in thinning operations (FRIDLEY et al., 1985; FRIDLEY et al., 1988; GREEN et al., 1987b). GREEN et al. (1987a) stated that the possible result differences from an operator using an interactive simulation model can mimic the real differences caused by the machinery operators' performance depending on training and experience. With the trend towards forestry operations on smaller land areas, silvicultural factors have been increasing integrated into timber harvesting models (WANG and GREEN, 1999; ELIASSON, 1999). BRAGG et al. (1994) developed a method for predicting stand damage depending on silvicultural strategies alongside an interactive simulation program.

The existing simulation models are limited in their ability to compare whole work systems with each other and are usually limited to terrain traversible with wheeled machinery. Differing thinning regimes have only been modelled using basic information. The goal of this work is to develop a modular simulation model for steep terrain timber harvesting systems that can analyse and optimise current as well as future harvesting systems. The effects of silvicultural regimes on the productivity of the systems will be presented.

2. MODEL DEVELOPMENT

The model consists of the following components: Stand generation, future tree search, tree removal and process models. In a following implementation phase these components are incorporated into the simulation environment.

Stand generation

The method of generating a stand can be freely chosen by the user. Real data from forest stands can be imported, or the stand can be generated from distribution information. The most common distributions for stand generation such as Weibull- and Normal distributions can be selected. To create a best possible and random distribution of the trees over the area, x and y co-ordinates are randomly generated. The tree at a given location is assigned a diameter breast height (DBH) using the selected distribution. From the DBH-tree height curve for the stand, an appropriate tree height is assigned to the tree. The tree volume calculation is carried out using the cylinder and taper functions by POLLANSCHÜTZ (1974). The conversion from standing volume with bark to harvested volume without bark occurs through the reduction factor of 0.8.

Process layout

In the current development state of the simulation model, three different work systems are available for timber harvesting in steep terrain (Figure 1): Motor-manual felling and cross-cutting, tracked and walking harvesters. The subsequent timber extraction is carried out exclusively by cable system. Other machinery or work systems can be modelled through minor changes in the simulation program. The tracked harvester can, through a crane reach of 15 metres, work with a distance between extraction corridors of 30 metres. The walking harvester has a boom length of just 7.5 metres and therefore requires additional harvesting corridors. For the extraction using a walking harvester, it is assumed that from a single cable system set-up three harvester corridors can be extracted.

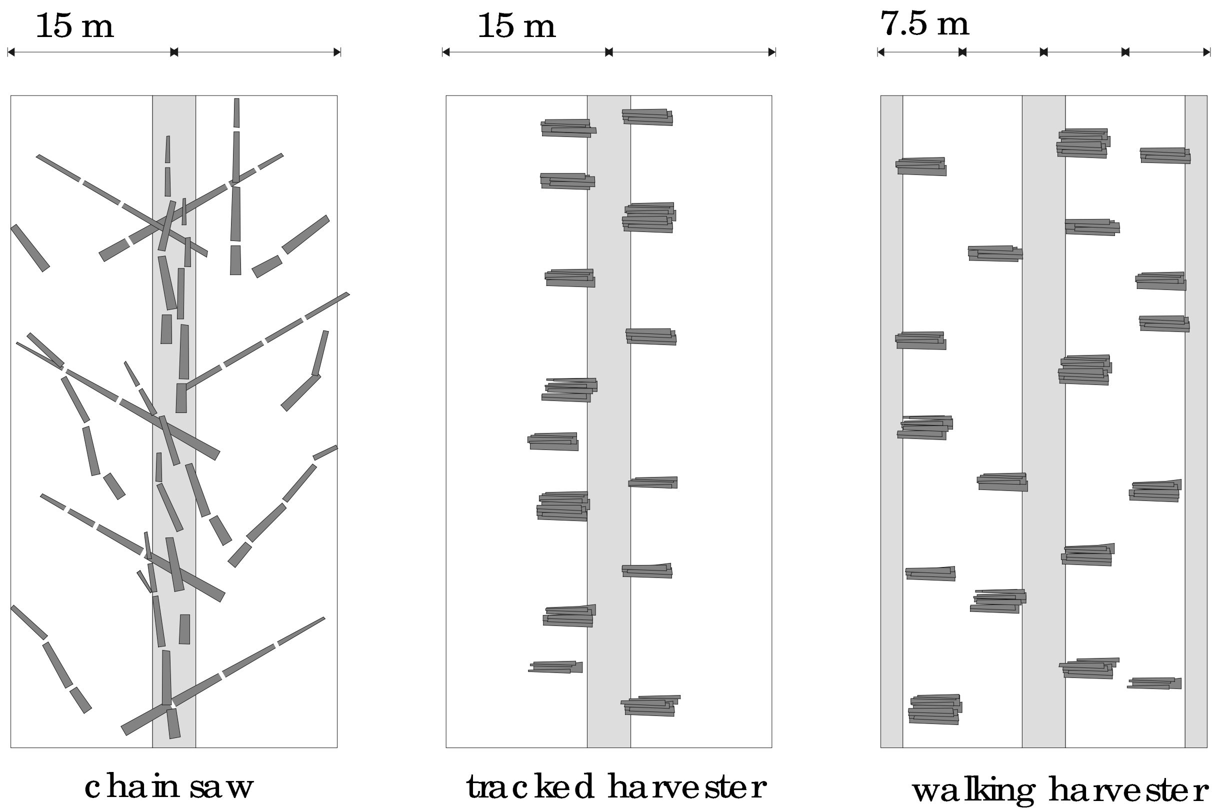

Figure 1: Process layout.

Future tree search

Based on conceptual considerations of SCHÄDELIN (1942) and LEIBUNDGUT (1966) in mid-Europe the forestry regime is based around selecting a number of "future trees" that are to be grown to maturity, and thinning operations are carried out at 25 year intervals whereby the competitor trees are removed. The operations presented here are based on such a thinning regime, which is currently by far the most common forest harvesting activity.

The trees located in the extraction corridor can be excluded as possible future trees. Future trees should have a height to diameter ratio of under 100. This criteria can not be considered in the implementation of the model since the diameter and height of the trees are bound deterministically through the DBH-tree height curve so that similar diameter trees always have the same height ("ideal trees"). Therefore a height criteria of 15 metres was used to indicate the desired future tree quality.

In practice, a number of triangles (= number of future trees) are laid over the harvesting area (without extraction corridors). In every triangle one future tree is chosen with the restriction that an already selected future tree is not within 7 metres distance. Since this method is empirical and currently difficult to convert into the program, two other selection methods have been developed for the search for future trees.

a) Volume heuristic

The trees are sorted according to decreasing height. Within this sorted list future trees are selected one after the other, when:

1. the number of chosen future trees is smaller than the given number of trees in the simulation set-up and
2. all the already marked trees in a stand have a minimum distance of 7 metres from the tree under consideration.

b) Distance heuristic

If the number of future trees in the simulation set-up is very large, it can happen that the volume heuristic method finds too fewer trees. The principle behind the distance heuristic is that future trees are first selected on the basis of having the fewest possible neighbouring trees (trees with a distance less than 7 metres). This ensures that a tree doesn't get selected that would preclude the selection of a large number of other possible trees. The procedure is as follows: the trees are first sorted according to increasing number of neighbouring trees. In the second step the trees are sorted according to decreasing tree height. Finally, from this list the same selection procedure as for the volume heuristic is carried out.

Tree removal

The "A-value" according to JOHANN (1982) is a value for the objective analyses of the competitive tree nearest a future tree (HASENAUER et al., 1996). The basic principle behind this value is that the competitiveness of a neighbouring tree can be measured primarily by the cross-section of the crown, which is linearly proportional to the diameter breast height (HASENAUER, 1994). If the DBH of a tree is weighted with its radius of freedom (j) and its possible competitive trees (i), the distance to the competitive trees to be removed (E_{ij}) can be calculated as shown by equation 1.

$$E_{ij} \leq \frac{H_j}{A} \cdot \frac{d_i}{D_j} \quad (1)$$

(H_j) and (D_j) are the height and the DBH of the free standing tree, (d_i) the DBH of a possible competitive tree. (A) is the value to be given according to the proportionality factor that determines the thinning intensity. As recommended by JOHANN (1982) for same age pure spruce stands, values between 4 and 6 should be used.

The trees are felled in the direction of the nearest extraction corridor and cross-cut to 4 metre lengths, whose y co-ordinates are the same as the original tree. The calculation of the x co-ordinate is depending on the extraction system. However, a common x co-ordinate for all the logs from a tree is assumed. Important for the extraction is the location of the individual logs and whether the logs are bundled (as done by walking or tracked harvesters) or not (motor-manual felling). Quadrants are determined on the whole harvesting area depending on the optimal drag size. For each drag all the logs in one quadrant are taken. If the value exceeds the maximum allowable drag volume then the load is divided.

Process models

For the part processes of felling and cross-cutting, as well as extraction, deterministic models are used with stochastic elements. Further division is made between tree manipulation and locomotion by the mechanised harvesting options. The models for parts of the timber harvesting processes (motor-manual felling, tree manipulation and locomotion with tracked harvesters and extraction using cable machinery) were obtained using empirical studies (STAMPFER, 1999a; STAMPFER, 1999b). The model from FJELD (1994) was used for the tree manipulation component with walking harvester. Additionally, HEINIMANN (1995) had developed a locomotion model for the walking harvester using analytical methods.

3. TIMBER HARVESTING SIMULATOR

For the evaluation of the model the simulator HaSyS (Harvesting System Simulator) was written in the object oriented programming environment VisualWorks (Smalltalk). To ensure a user friendly interface, the display is divided into two windows. In the first the user can enter the simulation specific variables (Figure 2) and in the second the results are displayed numerically and graphically (Figure 3).

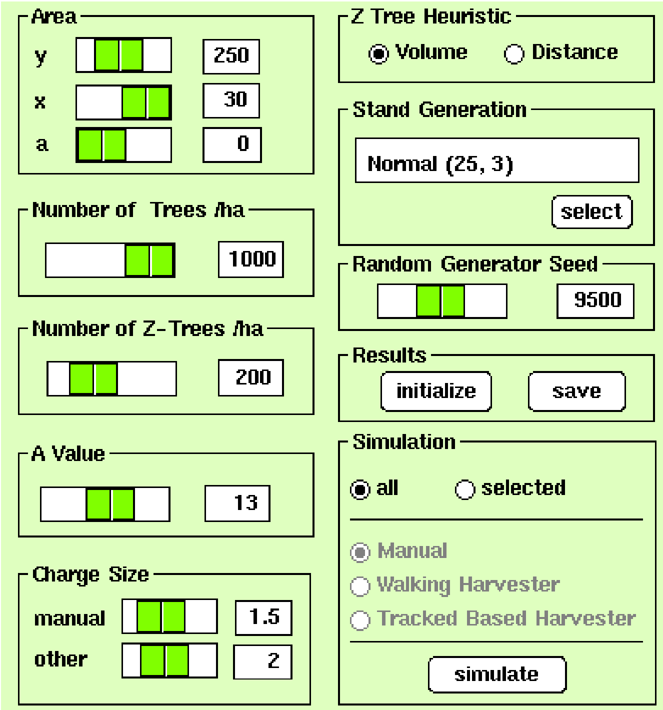

Figure 2: HaSyS Interface.

Simulation set-up

Parameters that are of importance to steep slope timber harvesting can be changed in the simulation set-up. These are the system, terrain and stand variables. The following parameters are considered (Figure 2):

1. Terrain slope.
2. Number of trees per hectare.
3. Number of future trees per hectare.
4. Type and manner of stand generation. The two options are to use distributions or to read in actual stand data.
5. A-Value for the determination of thinning intensity.
6. Two different heuristics to determine future trees.
7. Choice of timber harvesting system (motor-manual, walking or tracked harvester).
8. The desired maximum drag size for the extraction with cable logging equipment.
9. Seed for the random number generator: as an option the seed for the random number generator can be set to be able to retrospectively examine the occurrence of unexpected phenomena. The (pseudo-) random numbers are produced using the linear congruence method.

Presentation of the simulation results

The user has the possibility to write all the simulation specific results to a data file in order to be able to evaluate these results using any statistical analysis program. Additionally, the presentation of the most important results occurs in a separate window (productive data of the harvesting machine by felling and tree manipulation, as well as the extraction). For the various process layouts the extraction corridors are graphically displayed. The various tree types (future trees, trees for removal and the remaining trees) are differentiated using colours (Figure 3).

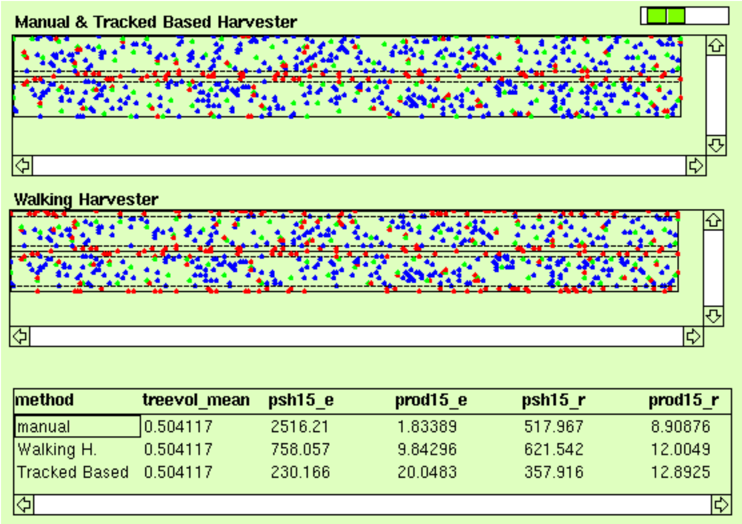

Figure 3: Graphical display for the simulation output.

4. EXAMPLE OF A SIMULATION

To indicate the functionality of the prototype timber harvesting simulator, two different stands are simulated. The stand characteristics are shown in Table 1. In addition to the harvesting system, the thinning intensity was also varied.

Table 1: Description of the simulation stand.

	Stand 1	Stand 2
Corridor length (m)	250	
Terrain slope (%)	25	
Future trees (n/ha)	200	
Age (n)	50	90
Stand density (n/ha)	1500	700
Diameter breast height (cm)	20	32
Stand volume (m^3 without bark)	312	492
Thinning intensity (%)	21-47	27-57

Table 2 shows through the variable productivity (m^3/PSH_{15}[1]) that the mechanised harvesting systems are clearly superior to the motor-manual system option. By the felling and tree manipulation, the walking harvester takes a position between motor-manual and tracked harvester. The productivity achieved is comparable with that of wheeled harvesters. The trend relating thinning intensity to productivity is also visible.

The cable extraction productivity also increases after mechanised harvesting. The pre-bunching of the logs results in faster cycle times and larger average drag volumes. If the bundles must be pulled through the stand as is the case for the walking harvester, the productivity is reduced by only an insignificant amount.

Table 2: Results of the Simulations. All results are m^3 without bark per productive system hour including delays less than 15 minutes.

	Stand 1			Stand 2		
A-Value	8	10	12	8	10	12
Felling and Tree Manipulation						
Chainsaw (m^3/PSH_{15})	1.46	1.45	1.41	2.54	2.52	2.50
Walking harvester (m^3/PSH_{15})	4.61	4.31	3.87	21.50	19.14	18.87
Tracked harvester (m^3/PSH_{15})	14.79	14.64	14.30	25.73	25.55	25.45
Cable Extraction						
After chainsaw (m^3/PSH_{15})	7.42	7.29	6.63	14.99	13.92	13.30
After walking harvester (m^3/PSH_{15})	10.26	9.49	8.58	17.84	16.69	16.64
After tracked harvester (m^3/PSH_{15})	11.28	10.81	9.93	18.76	17.93	17.12

[1] Productive system hour including delays less than 15 minutes.

5. CONCLUSIONS

The goal of this study was to develop a simulation model for steep terrain harvesting to analyse and optimise current and future work systems. One key component was the modelling of the interaction between silvicultural regimes and production systems. The presented timber harvesting simulation model prototype, HaSyS (Harvesting System Simulator), allows for the first time the comparison between varied mechanised steep terrain work systems. Motor-manual felling and cross-cutting, walking and tracked harvesters as well as the subsequent cable extraction can be simulated.

First results show that the mechanised harvesting systems are also superior to the motor-manual ones on steep terrain. This is not just through higher productivity by the felling and tree manipulation, but also through cable extraction productivity increases. The productive potential of the walking harvester lies between what can be achieved using the tracked harvester and motor-manual system. The difference between the cable extraction productivity following either walking and tracked harvester felling is very small. The cable system following the walking harvester used only one central set-up location for every three harvester corridors. VISSER and STAMPFER (1998) also showed this to be the most effective solution based on empirical study results. The results presented are however preliminary and still need to be confirmed using a statistically balanced simulation study.

The developed heuristics for the distribution or determination of future trees with respect to carrying out thinning operations proved to be suitable. However, the options that allows the user to interactively select future trees should remain open. The thinning intensity is determined using the A-value according to JOHANN (1982), with which it is possible to make an objective and comprehensible choice of which neighbouring tree to remove from a competitiveness point of view. HASENAUER et al. (1996) however, have already shown that the A-value can be very variable. For this purpose A-values between 8 and 12 have been shown to be most suitable.

To improve the detail and usability of the model, a number of further developments are still desirable. To be able to react to future machinery development in a more flexible way, an interface will be generated in which the model parameters can also be easily entered by a less experienced user. To complete a more comprehensive timber harvesting system analysis, a stand damage estimate model will be integrated. In general this simulation model provides a flexible analysis tool for steep terrain timber harvesting systems which is also capable of incorporating future machine developments. It provides for significant cost savings potential through system optimisation.

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