A Detailed Timber Harvest Simulator Coupled with 3-D Visualization

Jürgen Roßmann, and Gerrit Alves

Abstract—In today's world, the efficient utilization of wood resources comes more and more to the mind of forest owners. It is a very complex challenge to ensure an efficient harvest of the wood resources. This is one of the scopes the project "Virtual Forest II" addresses. Its core is a database with data about forests containing approximately 260 million trees located in North Rhine-Westphalia (NRW). Based on this data, tree growth simulations and wood mobilization simulations can be conducted. This paper focuses on the latter. It describes a discrete-event-simulation with an attached 3-D real time visualization which simulates timber harvest using trees from the database with different crop resources. This simulation can be displayed in 3-D to show the progress of the wood crop. All the data gathered during the simulation is presented as a detailed summary afterwards. This summary includes cost-benefit calculations and can be compared to those of previous runs to optimize the financial outcome of the timber harvest by exchanging crop resources or modifying their parameters.

Keywords—Timber harvest, simulation, 3-D, optimization.

I. INTRODUCTION

THE demand for wood has proliferated in the last years. This makes it necessary to increase and optimize the wood production. Till the 1990s it was common in Germany for a forester to enter the forest in order to mark the trees to be felled with a spray can. These marked trees would then be felled and prepared with the chain saw manually. Today, more and more mechanized fellers are used to increase the productivity and lower the costs [1]. But these mechanized fellers are usually not able to go deep into the forest since they depend on skidder trails. As they are heavy, their use leads to soil compaction and they cannot drive through narrow passages between trees or on steep slopes. They also have a

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higher setup cost which makes them less useful on small scales. This makes it a complex challenge to choose the right resources for a given felling operation.

The presented simulator uses the data about trees and tree structure gathered by the project "Virtual Forest II" which is based on a database of approximately 260 million trees located in North Rhine-Westphalia (NRW), Germany. It allows the simulation of timber harvest within these forests with a variety of cropping resources. The simulator is based on a discrete-event-simulation, a technique that is widely employed in industry for process optimization and was adopted for this area of application. The simulation is coupled with a 3-D real time simulation to enhance the trust in the simulation as it is possible to follow the course of a single cropping resource on its way through the forest. This allows the user to supervise the simulation and gain confidence in the results.

II. RESOURCES

Fig. 1 shows the variety of data providers that are employed to create the "Virtual Forest". All the data gathered by these sources is used to create a most precise model of the trees in NRW. Each covered tree has a list of properties that represents its position and characteristics. Table I shows a list of these properties. This level of detail is necessary to create a very fine grained simulation.
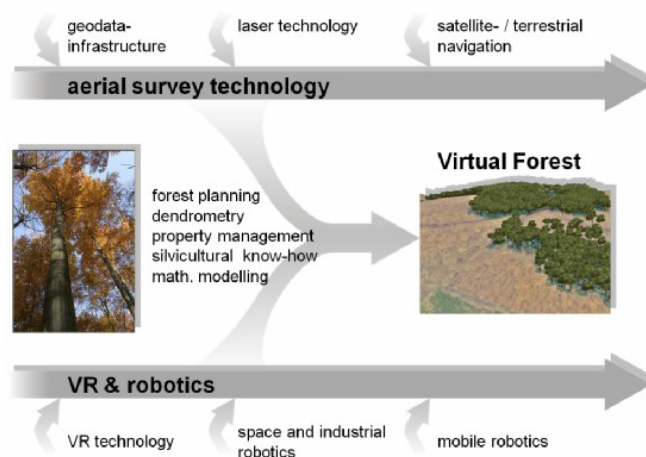

Fig. 1 "Virtual Forest" data providers [2]

To allow for the comparison of different cropping approaches some manual and some mechanized crop resources

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have to be available for a simulation run. Each crop resource has a list of properties that is used to describe its behavior during the simulation and constrain its movements.

TABLE I
TREE PARAMETERS

Property	Meaning
Position	XYZ – in Gauss-Krüger-Koordinates
Species	E.g. Spruce
Volume with bark	Volume of the tree with bark
Volume without bark	Volume of the tree without bark
Height	Height of the tree
Crown diameter	Diameter of the crown
Breast height diameter	Diameter at breast height
Planting date	Planting date
Felling indicator	Indicates if the tree should be felled during a simulation
Crown base	Height of the crown base
Elite tree	Indicates if the tree should be treated carefully

The harvester is a highly mechanized tree feller. It has a crane with a grip claw and a chain saw at the end. To fell a tree, this grip claw is attached to the tree which is then chopped by the chain saw. Afterwards, the tree is drawn through the grip claw where it is delimbed, debarked and cut into logs that are placed at the border of the skidder trail. A harvester is often followed by a forwarder. The forwarder is essentially a truck with a gripper attached to a crane. It collects logs at the skidder trails and delivers them to a log pit once its collection basket is full.

The lumberjack is a human forester that uses his chain saw to fell trees. He is not bound to trails but can walk directly from tree to tree. He can chop, delimb and cut trees to logs, but if a harvester is present and the tree to be felled is close to a trail but too far away for the harvester to grip he can also fell the tree so that it falls in the direction of the trail. The resulting timber will then afterwards be delimbed and cut by the harvester.

The skidder is used to tow logs felled by the lumberjack to a skidder trail. It has a long chain that is connected to one or more logs while the skidder stands on the trail. Then the chain is retracted so that logs are pulled back to the skidder.

Table II shows all properties for the resource type harvester. Some of these properties like *fuel consumption* and *fuel price* have no influence on the simulation and are only used in the cost-benefit calculation. Other properties like *grip range* and *minimal* and *maximal crop diameter* are vital to the simulation as they indicate which trees the resource can reach.

The property *work degree* represents the experience of the worker. A novice worker needs more time to achieve the same

results as an expert worker. Therefore all work durations that are calculated for a resource during the simulation are altered by this parameter. The value for this property should be between 40% for a novice and 160% for an expert worker.

TABLE II
HARVESTER PARAMETERS

Property	Unit
Speed on rackways	[km/h]
Speed on forestry roads	[km/h]
Fuel consumption	[l/h]
Fuel price	[€/l]
Grip range	[m]
Setup time	[min]
Work degree	[%]
Minimal crop diameter	[m]
Maximal crop diameter	[m]

III. SIMULATION MODEL

The simulation model depicted by Fig. 2 has been created in cooperation with the FVAA Munich. It consists of processes, resources and products. A process performs an action on a product by using a resource. In our model only some processes are assigned to resources. There is only one product, the order. An order is created in the *repository* at the top of the model and runs through the connections and processes to the d*rain* at the bottom where it is consumed. Each order is a container that can carry a tree or a bundle of logs on which calculations are performed during each process that modify the order's content.

TABLE III
HARVESTER FORMULAS

Process	Formula
Positioning	= 13s + (20s - 13s) / 10 * distance tree – road center [m] + (random between 0 and 1) * 20
Tree cutting	= 0.5063 + 0.0031 * circular area [cm²] + 7.9 * 10 – 7 *circular area [cm²]
Felling and extracting	= 3.2346 + 0.0928 * BHD [cm]
Rate of feed (incl. limbing)	= 1.841 + 0.197 * segment length [m] + 2.595 + log volume [scm w.b.] + 2.051 + log volume [scm w.b.]
Separating cut	= 0.0262 * trunk diameter [cm]

[scm w.b.] – solid cubic meter with bark
(See also [3])

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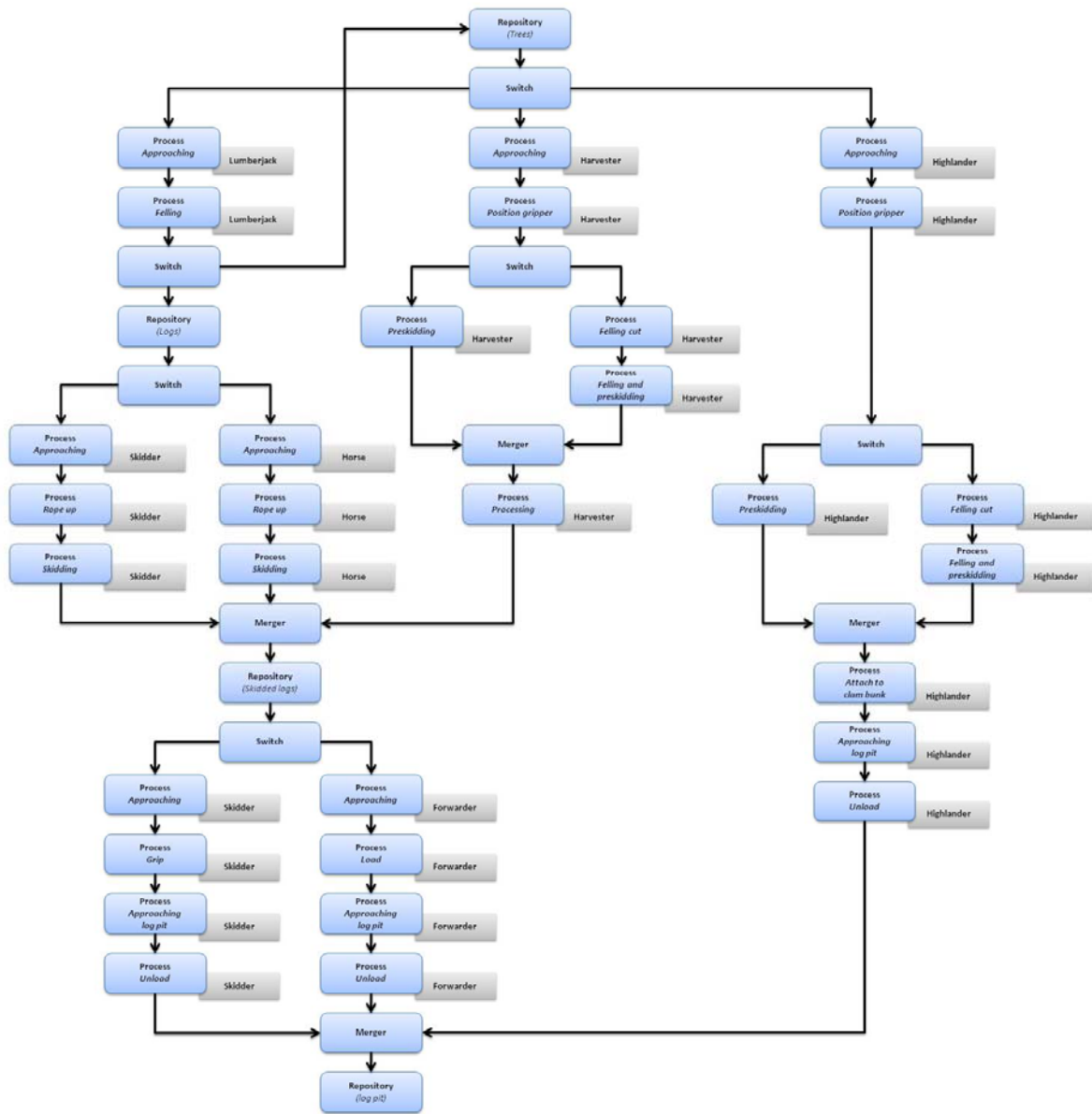International Journal of Computer and Information Engineering
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Fig. 2 Simulation Model

There are three types of processes: terminal processes (*repository/drain)*, branch processes (*switch/merger)* and *work processes*. *Repository* and *drain* are responsible for creation and removal of orders at the beginning and end of the simulation model. *Switches* and *mergers* are used to route the orders through the model. They are controlled by a special controller that handles the routing of the resources. Whenever a resource has finished its task, and therefore its associated processes are all in idle mode, it requests a new order from the controller. The controller uses the routing module to find the next tree that should be processed by this resource. This tree is bundled into an order which is dispatched by the *repository*. When this order reaches the *switch*, it is automatically directed to the associated resource branch. *Work processes* are associated with a resource. They represent a single procedure that is conducted on the tree or logs within the order. They

calculate their runtime by formulas that incorporate properties of the tree or logs in the bundle. Table III shows some of the formulas that are used by the processes for the harvester.

The resource branches are created automatically during the setup of the model. Each resource has a set of processes that it is associated with. When a resource is created, it generates its associated processes and adds them as a resource branch to the simulation model where they are connected to the *repository* and *drain* via a *switch* and a *merger*.

During the setup of the model, the user can choose which resources should be used during the simulation. To make it easier to rerun a simulation, one can save single parameterized resources or even complete groups of resources to a file that can be loaded back into the simulation.

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IV. ROUTING

All resources in the simulation have their own routing that is applied to them during the simulation. The tree fellers for example jump from tree to tree as they are paid by a special tariff that is based on the trees they have to fell. Therefore, their traveling time between the trees has no influence on the result.

All other resources move on skidder trails and forestry roads. As these tracks are often very narrow it is not possible for a resource to pass another one on the same track. So resources block a track if they are working or traveling on it. Other resources have to decide whether it is better to wait for a resource to clear the track or to take a way around the blockage. Therefore all simulated cropping resources estimate how long they will block the track. The routing algorithm can use this information to decide whether a resource should wait or try to find a way around.

All the routing happens in the process *approaching*. It calculates the best path to the desired location and sends the resource to the next crossing. This step is repeated till the resource has reached its destination. At this point the process hands the tree to be felled to the next process.

This routing is necessary to create much finer grained results than what would be possible with a solely statistical approach. This way, working conflicts by occupation of trails, collision avoidance in the dynamic routing and realistic driving times for resources can be simulated.

V. SIMULATION MODES

During simulation, the user can switch between two simulation modes. One is a pure discrete-event-simulation mode. The simulation runs as fast as possible and produces an Excel workbook which contains the results of the simulation run. This file will be discussed in detail in section VI.
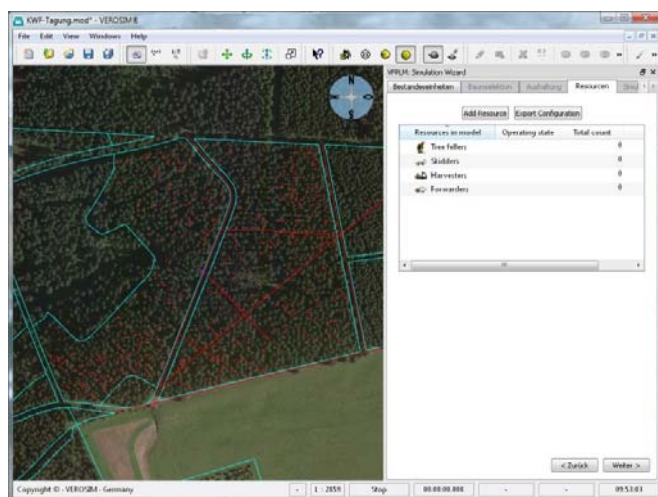

Fig. 3 Resource selection

The other mode shows a full 3-D visualization. All resources, trees and trails are rendered and the movement of the resources is animated during simulation. This mode is particularly useful to see how the resources are routed. The simulation runs in a timestep fashioned manner. The user can adjust the speed of the simulation with a slider between 0.1x realtime to 1000x realtime. Within this mode the discrete-event-simulation is conducted time driven. The next events are only executed if their time code is lower than the last execution time plus the realtime difference between the last execution and now, multiplied by the simulation speed. To animate the movement of the resources, the processes dispatch move orders which contain the goal position and a time code when the resource should start and end this particular movement. These move orders are interpolated by the controller in the time between the execution of events. This mode is based on the scheduling algorithm presented in [4].

As the 3-D visualization is driven by the same discrete-event-simulation that is used to calculate the results in the first mode, it is possible to switch between the two modes during one simulation run. This can be used to step over uninteresting parts of the simulation or observe important moments in slow motion.

Fig. 4 3-D visualization

Figs. 3 and 4 show two different views of the 3-D visualization. It is possible to zoom and pan the visualization window to switch between a general overview and a detailed view on particular resources. It is also possible to attach the camera to a single resource to see how it performs over time.

VI. REPORTS

The simulation software reports its results at the end of each simulation run. The generated report is presented as an Excel workbook that can be used to compare results of different simulation runs. The design of this Excel workbook has been developed in cooperation with the FVAA Munich. It processes the results and displays them in formatted tables and diagrams.

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Fig. 5 Report main view

Fig. 5 shows the main view of the report, where all basic information is shown in a most comprehensive form. Here, a cost-benefit calculation shows the commercial outcome of the simulation. There are further pages that provide details on all resources that have been used during the simulation. Fig. 6 shows a sample work diagram for the harvester. There are also a few calculations that are done in the report. For example, the user can enter the price a solid cubic meter of a given type of wood would achieve at the market. This value is then included in the cost-benefit calculation. There is also a full machine cost calculation included which makes it possible to determine the costs of the resources in more detail.
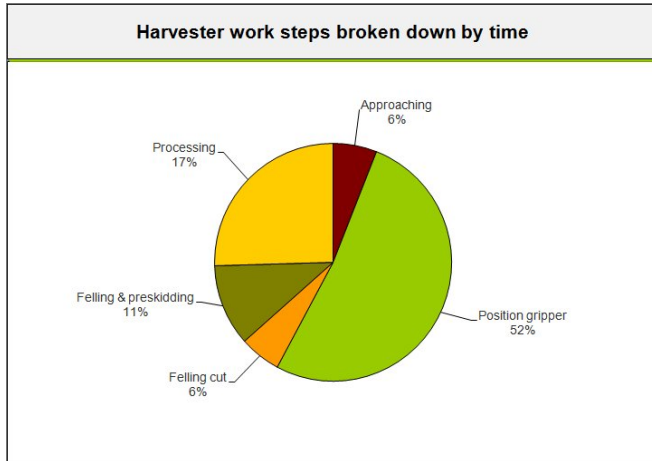

Fig. 6 Work diagram harvester

VII. TEST CASES

To show the advantages of the simulation, we compare the results of three simulation runs. All resources used in these simulations have a work degree of 100% and otherwise use sensible default values for each property.

As a test bed we use a tree population unit near the town of Schmallenberg in North Rhine-Westphalia, Germany. It consists of a group of spruces with a forestry road net and two places to stack the logs. It is pictured in Fig. 3. The light gray lines indicate the border of the selected area.

The trees to fell are marked with the help of the tree growth

simulation SILVA [5]. The segmentation is done by the software "Holzernte" as described in [6].

The simulation units are interpreted as seconds to allow for a realistic comparison between the simulation runs.

A. Motor Manual

In this first simulation run, the trees will be cropped by three tree fellers, while a skidder drags the wood from the forest to the forestry roads and from there to the stacking places. This was a typical scenario in Germany till the 1990s. In the following, it is used as a comparison scenario to a mechanized approach.

All resources start at the same position. The skidder starts a little later than the tree fellers to allow them to produce the first logs that should be town by the skidder.
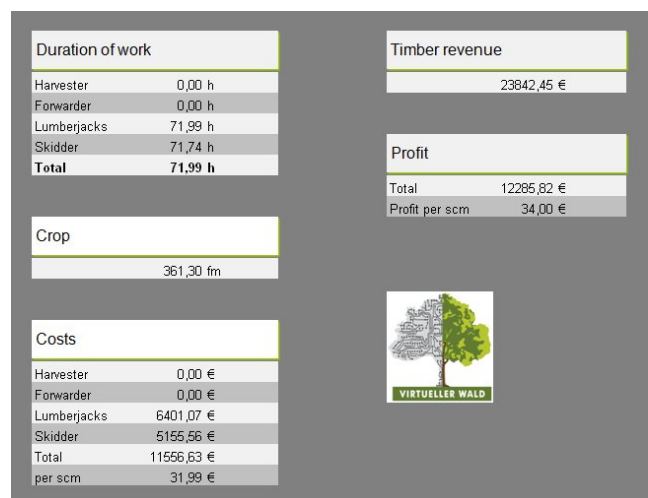

Fig. 7 Results motor manual

B. Mechanized

For the second simulation run we use a workforce of two tree fellers, one skidder, one harvester, and one forwarder. The tree fellers go first but skip all trees that can be cropped by the harvester.
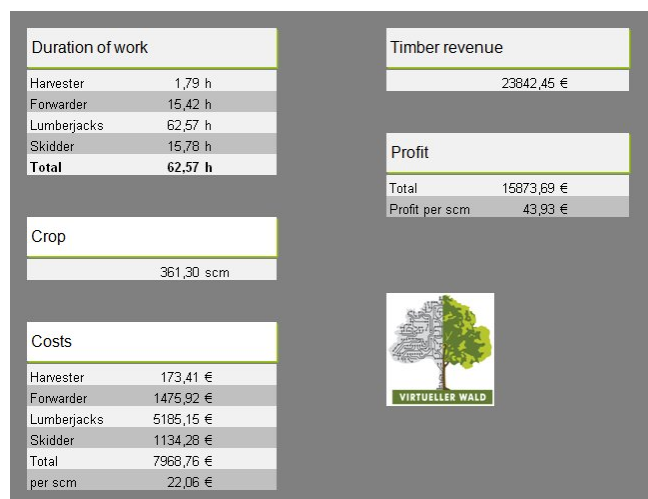

Fig. 8 Results mechanized

C. Results

By comparing the results of the two simulation runs as seen on Fig. 7 and Fig. 8 it becomes clearly visible that while harvesting the same trees the costs per solid cubic meter are almost a third lower with the mechanized approach.

VIII. CONCLUSION

As seen in the test cases, the presented simulation software is capable of simulating wood crops using the database of the Virtual Forest. Each resource can be customized to show the behavior that fits the circumstances best. The results can be compared to find the optimal collection of resources for the specific scenario. The simulation can be run in two different modes that either present a complete 3-D visualization to the user during the simulation or just show the results. These modes can be switched during a simulation run.

Future work will analyze if there is another routing algorithm that delivers better results for the dynamic routing. The FVAA Munich is working on the evaluation of the simulation results. This work should enhance the formulas used by the simulation to calculate the length of each process.

A next step in the development is the incorporation of 3-D terrain data in the simulation. This will offer more detailed information about which trails are passable by which resources. In this context, we will also add additional resources like the highlander to the simulation, and add surcharges for work in difficult terrain to the calculation.

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