A Discrete-Event-Simulation Approach for Logistic Systems with Real Time Resource Routing and VR Integration

Gerrit Alves, Jürgen Roßmann, Roland Wischnewski

Abstract—Today, transport and logistic systems are often tightly integrated in the production. Lean production and just-in-time delivering create multiple constraints that have to be fulfilled. As transport networks often have evolved over time they are very expensive to change. This paper describes a discrete-event-simulation system which simulates transportation models using real time resource routing and collision avoidance. It allows for the specification of own control algorithms and validation of new strategies. The simulation is integrated into a virtual reality (VR) environment and can be displayed in 3-D to show the progress. Simulation elements can be selected through VR metaphors. All data gathered during the simulation can be presented as a detailed summary afterwards. The included cost-benefit calculation can help to optimize the financial outcome. The operation of this approach is shown by the example of a timber harvest simulation.

Keywords—Discrete-Event-Simulation, Logistic, Simulation, Virtual Reality.

I. INTRODUCTION

DISCRETE-event-simulations are often used in scenarios where optimization of existing and planned systems is necessary. In factory simulations, it is common to use discrete-event-simulations to find bottlenecks and generally optimize the production. The field of transport and logistics is also a very fertile area for simulation models. Simulation has traditionally been used in warehousing and inside the distribution centers or processing hubs in the trucking and package delivery sectors, for baggage systems and passenger queuing in the airline industry, and for detailed models of terminals and yards in the railroad industry. In addition, simulators are used for certain specialized applications, such as airspace applications and line-of-road railroad applications. Other non-simulation models based on optimization, networks and heuristics have dominated many other areas of transportation and logistics, especially large-scale supply chain issues such as logistics network design, vehicle routing, facility location, and scheduling [1].

It is no easy task to create trust in the results of a simulation. The user has to be able to understand the decisions of the simulation system to gain confidence in the results of the simulation. Therefore, it is very important to allow the user to see parts or the complete simulation run in detail to rely on its accuracy.

Transport networks and their associated topologies of hubs and terminals have often evolved over a long period of time. Therefore, it is very expensive and often consumes an enormous amount of time and effort to make radical changes to the network [1]. This makes it necessary to build a model as close to reality as possible at first. Afterwards, this model can be altered for optimization.

To allow for model changes and to support a wide array of different strategies and allow for the use of future algorithms it is essential to create a system that is capable of using plugins. These plugins contain a single strategy that can later on be chosen to control a part of the simulation.

The simulation is coupled with a 3-D real time visualization to enhance the trust in the simulation as it is possible to observe the progress of the simulation in detail. The speed of the simulation can be altered by the user which allows skipping over iterative parts to events of interest.

The simulation system is integrated into a Virtual Reality system. This allows the use of VR metaphors to select the input elements of the simulation and gives direct feedback to the user about changes on the simulation parameters.

In the following, the simulation elements that are used to create the simulation are presented. The plugin system is shown in detail and afterwards the two simulation modes *pure discrete-event-simulation* and *3-D visualization* are described. A section about the simulation controller finishes the system presentation.

To show the function of the proposed system, the timber harvest simulation created for the project "Virtual Forest" [2] is shown. This includes a comprehension of the results created with this simulation model.

Prof. Dr.-Ing. J. Roßmann is head of the Institute of Man and Machine Interaction at the RWTH Aachen, Aachen, 52074 Germany (e-mail: rossmann@mmi.rwth-aachen.de).

Dipl. Inf. G. Alves and Dr.-Ing. R. Wischnewski are with Dortmunder Initiative zur rechnerintegrierten Fertigung (RIF) e.V., Dortmund, 44227 Germany (phone: +49231-9700-776; e-mail: gerrit.alves@rt.rif-ev.de).

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:3, No:10, 2009

II. SIMULATION ELEMENTS

Each simulation conducted with our simulation system uses three different types of simulation elements that work together to create the final simulation model. *Processes* use *resources* and can create or manipulate *products*. While there are multiple different types of resources only the repository resource can create and remove products as they form the beginning and the end of a process chain which is a number of connected processes.
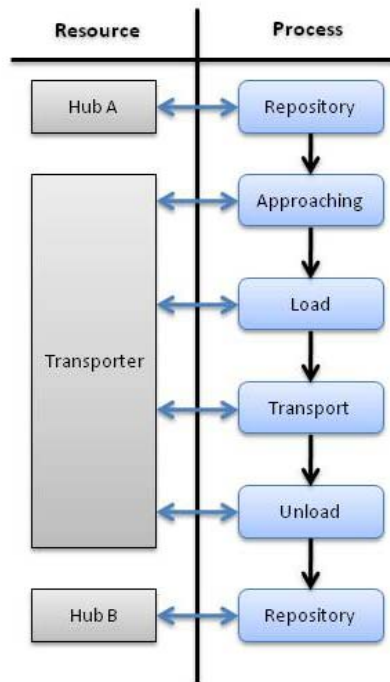

Fig. 1 Simple process chain

Fig. 1 shows a simple process chain which can be used to simulate a simple transporter that moves goods from place A to place B. There are two repositories, one at the top and one at the bottom end of the process chain representing the hubs on place A and B. A product is created by the top repository and handed to the first process. Each process operates on this product and hands it over to the next process in line until it reaches the repository at the bottom. In this case, the product is a transporting good that is first loaded onto the resource "Transporter" which transports the good to its destination. There, it is unloaded and placed into the repository.

Resources and processes have multiple states. They can be used to trigger certain behaviors. A resource in error state could for example trigger a rerouting of other resources to compensate its outage. Table 1 shows the states in detail.

Resources can trigger processes and stop the execution of the process chain by introducing and removing orders to processes. As the processes connected to a resource use the resource to define their behavior, the resource has full control over its attached process chain.

The proposed simulation system uses only one type of product that moves through the simulation model. This product is called an order. It is a collection that may contain multiple other products.

TABLE I
RESOURCE AND PROCESS STATES

State	Description
Idle	The resource/process is idle and waits for the next product. If all connected processes are idle the connected resource is also idle.
Working	The resource/process has received an order and is working.
Waiting	The resource/process has finished working and is waiting for the next process in the process chain to become idle to forward the order.
Pause	The resource/process is paused.
Error	The resource/process has encountered an error and needs time to be repaired.
Obstructed	The resource cannot continue at the moment. This can be due a blocked one way line or a hub with no free port.

III. PLUGIN SYSTEM

To allow for a variety of strategies to be tested with this system, it is built to support plugins in multiple key areas.

A. Routing

Typically, a logistics and transportation system is built on a network composed of one or more terminals or hubs connected by a set of traffic lanes. These networks and the associated topologies may have evolved over a long period of time. Therefore, it is very expensive and often consumes an enormous amount of time and effort to make radical changes to the network.

To represent these circumstances all mobile resources run on a graph that is supplied by the user. It can be a directed or an omnidirectional graph. Hubs are placed on points on the graph where the transporters should load or unload their goods.
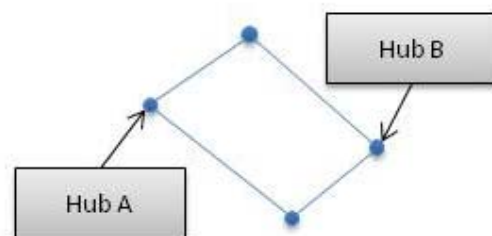

Fig. 2 Simple routing graph

Fig. 2 shows a simple routing graph with two hubs. The movement of a resource on this graph is depending on the

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:3, No:10, 2009

selected routing plugin for that resource. The routing plugins communicate with each other via the controller. This allows the creator of the model to build representations of mechanisms like communication errors and human error, but also to test new routing strategies or how the use of modern communication systems would affect error handling. This could be done by choosing the point of time at which messages about the availability of other resources should be delivered to the moving resource.

Resources can block a route. This can be mapped by longer driving times on this route segment which in turn allows a routing algorithm to decide if circumvention of the area would be more efficient.

B. Repository

Each repository has a storage plugin that decides which product should be created for which resource. This can be useful if the products have different sizes while not every resource is able to handle every product size. It also allows for the use of storage strategies and for a repository to be full. Depending on this information, a routing plugin for a resource could decide to change directions and head on to another repository.

C. Stochastical distribution

The stochastical distributions that are used during the simulation are also interchangeable. They can be used for the pause and error length calculation as well as for the duration of processes that are not connected to a resource. Special distributions like predefined pause times can be included as a plugin.

IV. 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 displays the results of the simulation run afterwards.

The other mode shows a full 3-D visualization. All resources, products and ways 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 [3].

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 a simulation run. This can be used to step over uninteresting parts of the simulation or observe important moments in slow motion.

V. SIMULATION CONTROLLER

The progress of the simulation is driven by a single controller that calls the appropriate plugins for the selected behavior. For the simple example depicted in Fig. 1, a run would produce the following calculations: At first the transporter finds that all its connected processes are idle. Therefore it requests the next order from the connected repository. The repository checks where the transporter should head next and creates an order containing the goal position for the transporter. This order is given to the approaching process. It may also contain the product that should be loaded by the transporter if it is already known. This starts the movement of the resource over the way graph towards the goal. Once the transporter reaches the destination, the order is forwarded to the load process. If no product is included in the order the load process asks the connected repository for an appropriate product that is then included into the order. The resource has two options now. If its capacity is not filled yet it asks the repository for another order. Otherwise it starts the transport process by handing it the order. Using this mechanism, it is possible to build an arbitrary routing with multiple load and unload operations. The plugin controlling the transporter has the complete control over the operation of the resource.
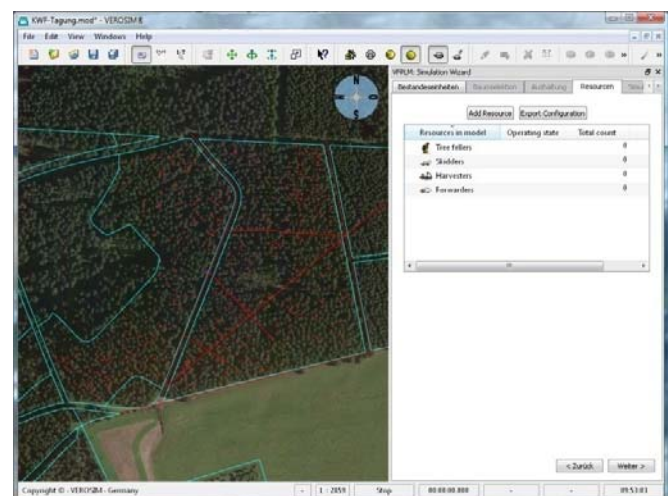

Fig. 3 Top view of a 3-D forest model for selection of input elements for the simulation

VI. TIMBER HARVEST SIMULATION EXAMPLE

The following describes a simulation model that has been created using the proposed simulation system. It is used to calculate the costs and benefits of a timber harvest operation and uses many of the features provided by the simulation system. The data used to create this simulation comes from the project "Virtual Forest" which contains a virtual reality environment and a database with data about forests containing approximately 260 million trees located in North Rhine-Westphalia (NRW), Germany. To allow for a simple selection

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:3, No:10, 2009

of the simulation elements, a 3-D model is used as seen in Fig. 3. Fig. 4 shows the 3-D visualization of the simulation which can also be used in VR environments.

A. Products

In addition to the order, we have two types of products. Trees to be felled at the beginning and logs at the end of the simulation. The trees and logs have a number of properties which are used to describe their appearance and to limit their handling. For example trees above a certain diameter cannot be felled by some resources.

Fig. 4 3-D visualization inside a VR environment

B. Resources

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

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 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 a 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 into 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 be delimbed and cut by the harvester.

The skidder is used to tow logs felled by a 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.

All resources in the simulation have their own routing that

is applied to them during simulation. The tree fellers for example move from tree to tree. 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.

C. Processes

The simulation model depicted by Fig. 5 consists of processes and resources. In our model, only some processes are assigned to resources. Orders are created in the repository at the top of the model and run through the connections and processes to the drain at the bottom where they are consumed.

TABLE II
HARVESTER FORMULAS FOR PROCESS DURATIONS

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
BHD – Breast height diameter
(See also [4])

World Academy of Science, Engineering and Technology
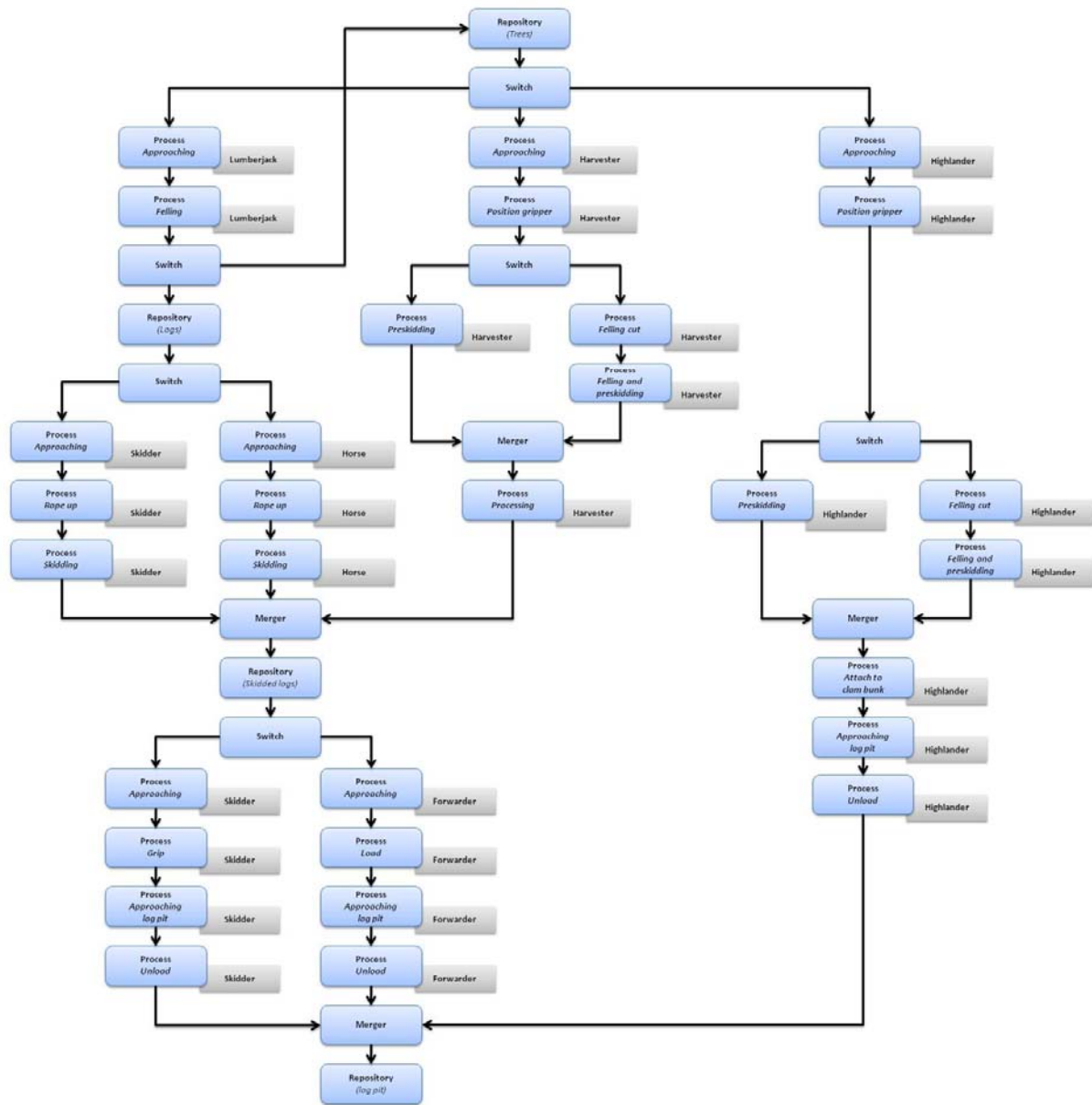International Journal of Computer and Information Engineering
Vol:3, No:10, 2009

Fig. 5 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 the logs within the order. They calculate their runtime by formulas that incorporate properties of the tree or logs in the bundle. Table II 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.

The presented model is currently under evaluation by the Academic Chair of Forest Work Science and Applied

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:3, No:10, 2009

Computer Science (FVAA) at the TU Munich to ensure the accuracy of the used formulas and calculated results.

VII. RESULTS

Fig. 6 shows a summary of the results generated during a single simulation run. It displays the work duration for every resource, the amount of cropped wood, the expected revenue for the timber and the resource costs, broken down to single resources. The total profit and the profit per solid cubic meter are also displayed. The detailed results also contain work diagrams for each resource, the felled timber over time, and an overview about the forest stand. 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.

The timber harvest simulation has been run multiple times with different parameters and resources. The results of these simulation runs have been compared to optimize the financial outcome of the harvest operation.
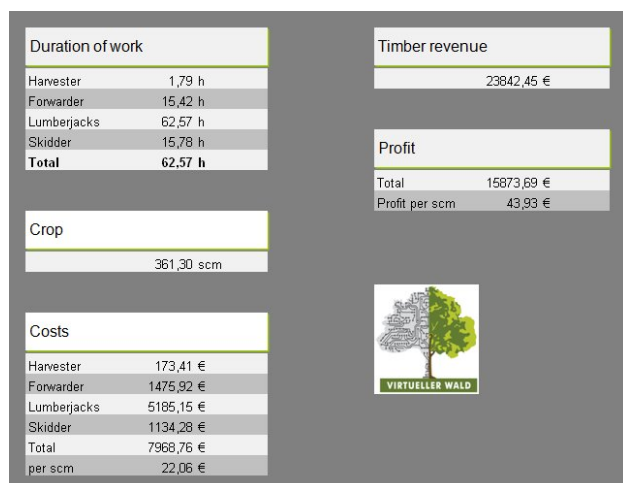

Duration of work	
Harvester	1,79 h
Forwarder	15,42 h
Lumberjacks	62,57 h
Skidder	15,78 h
Total	**62,57 h**

Crop	
	361,30 scm

Costs	
Harvester	173,41 €
Forwarder	1475,92 €
Lumberjacks	5185,15 €
Skidder	1134,28 €
Total	7968,76 €
per scm	22,06 €

Timber revenue	
	23842,45 €

Profit	
Total	15873,69 €
Profit per scm	43,93 €

Fig. 6 Page of results of s single simulation with
a fixed set of resources

VIII. CONCLUSION

As seen by the described simulation model, the presented approach is capable of simulation complex mixed production and transport systems with arbitrary strategies and behaviors for each resource. The simulation can be run in two different modes that either show a complete 3-D visualization to the user during the simulation or just present the results. These modes can be switched during a simulation run. The calculated results can be compared to find the optimal collection of resources for a specific scenario.

Future work will combine the proposed simulation with a factory simulation to allow for the optimization of complete supply chains and the corresponding production.

REFERENCES

[1] J. Carson et. al., „Panel On Transportation And Logistics Modeling", Proceedings of the 1997 Winter Simulation Conference, pages 1244-1250, 1998
[2] J. Roßmann and M. Schluse, "The Virtual Forest: Robotics And Simulation Technology As The Basis For New Approaches To The Biological And The Technical Production In The Forest", Proceedings of "The 13th World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI 2009", 2009
[3] J. Rossmann and G. Alves, "Parallel Timestepped Simulation Scheduling (PTSS) with Variable Time Increments for Factory Simulation", Proceedings of IEEE International Conference on Emerging Technologies and Factory Automation, pages 1392 – 1399, 2008
[4] R. Pausch, "Time comsumption, productivity, fuel consumption and costs of timber harvest – a calculation base", Lehrstuhl für Waldbau – TU Munich, self publishment, 2004