Applicability of an Interchangeable Platform Truck for Timber Transport in Finland

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ABSTRACT

Finnish timber harvesting changed considerably in the late 1980s and early 1990s. For example, the interaction of machines has become more important. Simultaneously, this has brought forth a new problem: a single grip harvester and a forwarder can act together well in a conventional harvesting system, but it is difficult to join a timber truck to the system. One solution could be the use of interchangeable platforms. We built a simulation model for harvesting with CADmotion software. Furthermore, thirteen stands were generated for use as input-data in the simulation by Pukkala's Conifer Stand Simulator. The time consumption and the productivity of forest machines and trucks were calculated by recently published models. In addition, the delays of machines were simulated.

In Finnish conditions the total productivity of the interchangeable platform truck is lower than that of the conventional truck. The most important reason is the transport of empty platforms between stands. The other reason is that in the conventional system the buffer can be kept appreciably larger than in the interchangeable platform system. Evidently, improvement of the truck does not improve the performance of the whole system. In the so-called hot-logging sequence, extra waiting time decreases the benefit caused by shorter loading time.

Keywords: *Timber harvesting, mechanized harvesting, simulation.*

INTRODUCTION

Many large changes occured in Finnish timber harvesting during the late 1980s and early 1990s. For example, the proportion of mechanized logging has doubled in three years; 74% of the timber logged by the forest industry is cut by machines [5]. In addition, information systems used to control timber logging and transport have developed rapidly. The work of a harvester can be controlled from the office of the firm that will use the timber. Timber trucks receive their drive commands through computers connected to a mobile phone. Trucks are orientated with the help of satellite navigation. Furthermore, the storage times for timber have also decreased appreciably, which means that timber goes through the procurement process faster than before. It can be said that timber harvesting resembles an industrial process. Both in timber harvesting and in an industrial process, raw material is refined and transported from one place to another. As a result, the interaction of machines has become more important: if one part of the harvesting system does not work, the productivity of the whole system decreases.

Organization of timber procurement has also changed considerably. Previously a cutting man was working for firms that used the timber; nowadays an independent entrepreneur fells, processes, prehauls and transports trees from marked stands to mills [9]. A single grip harvester and forwarder can act together well. On the other hand, it is difficult to join a timber truck to a harvesting system because the productivity of the truck depends strongly on hauling distance. In addition, a large part of the timber truck's work time is consumed by loading the timber from a storage pile to the truck's loading space. Loading one truck with its own loading device takes about 36 minutes, and the total time at landing is about an hour [1]. If this loading time can be decreased, a bigger part of the work time could be used for transport of timber, the purpose for which the truck has been designed.

One solution could be to use interchangeable platforms. In this solution a forwarder loads the timber directly onto interchangeable platforms, which a timber truck pulls onto its own chassis. When the timber truck pulls platforms to the chassis, this takes a much shorter time than normal loading. Changing empty platforms to filled ones takes about six minutes, and the total time at a landing would be about 30 minutes. In comparison with the conventional system, the proportion of time at the landing would decrease and the productivity of the truck would increase. Trucks equipped with interchangeable platforms could also be modified easily for transportation of other goods, such as construction

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material, wood chips, etc., by changing to a suitable platform set. The question is: How does this solution affect the productivity of the whole system of timber procurement in Nordic conditions?

The hypotheses of this study are: 1) Use of an interchangeable platform truck decreases loading time and at the same time the productivity of a timber truck increases. 2) Because the timber storage by the side of a forest truck road decreases, extra waiting times of a harvester, a forwarder or a truck can decrease the productivity of a truck and of the whole procurement system.

MATERIALS AND METHODS

Simulation models have been used for research on timber harvesting systems, especially in North America. The developed models are, for example, Harvesting System Simulator (HSS), Auburn Harvest Analyzer (AHA) and STALS-3. AHA and STALS-3 are not, however, suitable for describing Nordic timber harvesting while HSS is antique and difficult to use by today's standards. It is characteristic of Nordic timber harvesting that the cutting areas are small (< 5 ha) and workers must very often move from one marked stand to another. In addition, only one harvester, forwarder and truck work on each site at the same time.

Simulation is especially applicable for analyzing the operation of systems over time. Simulation models can be used to solve problems that include nonlinear functions, random variables, interdependencies of system elements and behaviour of dynamic systems [7, 10]. In this study, simulation is especially applicable because the time horizon of the model is operational and scope of the model is detailed. Productivities of system elements are nonlinear and include random variation. For instance, the productivity of a one grip harvester is described by a nonlinear function. If the productivities were calculated by using the average stem volume in the formula, the productivity would be heavily biased. In addition, machine delays occur randomly. Perhaps the most important reason for choosing simulation as the method of analysis is the interdependencies of the elements of the system [7,10,11]. If logging and trucking activities took place independently, the cost of harvesting could be estimated simply by summarizing the costs of cutting, forwarding and trucking. In the case of interchangeable platforms, however, trucking takes place immediately after logging and therefore the interdependencies between forest operations and trucking affect the productivity. Furthermore, the inventory size between a forwarder and a truck is limited: the platforms limit the maximal number of trees in the buffer.

The simulation model for harvesting was built with CADmotion software, which has been developed for simulation of manufacturing processes. It is a typical discrete-event simulation package with graphic animation facility. The simulation can be presented as a flow chart (Figure 1). The simplified sequences of activities for each type of machine are presented in Figures 2, 3 and 4.

Thirteen stands were generated for use as input-data in the simulation by Pukkala's Conifer Stand Simulator [8]. Four of the stands were thinnings and seven were final fellings. The stands were harvested twice, which equals 12 700 m^3 of timber. This amount represents about a three-month output of a harvesting system in Finland. Information on stands is presented in Table 1.

The time consumption and productivity of forest machines were calculated by the models of R & D Department for Wood Procurement and Production of the Finnish Forest Industries Federation [3]. The time consumed by the harvester's moving from tree to tree was calculated by Functions 1 and 2.

Final felling

$$t_m = \frac{-0.6347 + 0.000219N + 945.36 / (N + 1060)}{P_{ter}} \tag{1}$$

Thinning

$$t_m = \frac{-0.07255*(\ln(0.000414N - 0.03039))}{P_{ter}} \tag{2}$$

in which

t_m=moving time from tree to tree, min/stem
N=drain, stems/hectare
P_{ter}=terrain parameter,
1=easy terrain, 0.765=moderate

Processing time of a tree was calculated with the following function:

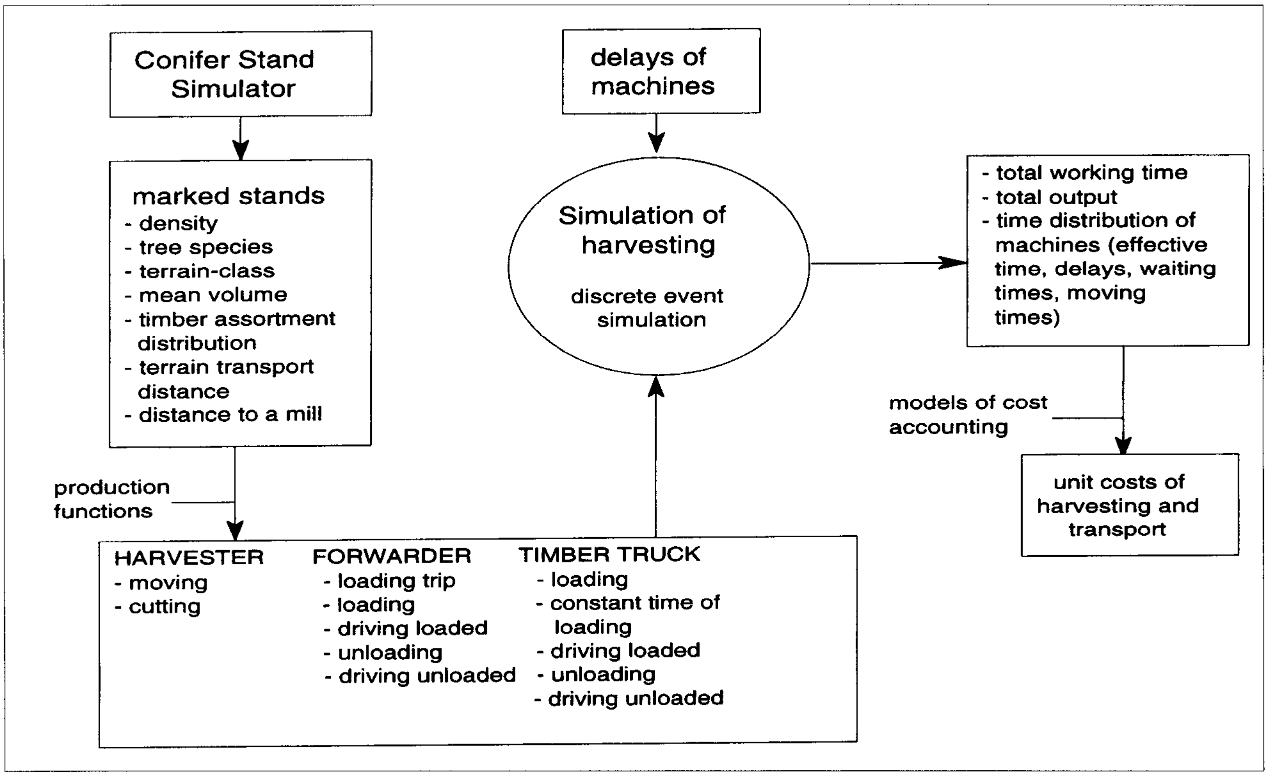

Figure 1. The simulation model for harvesting.

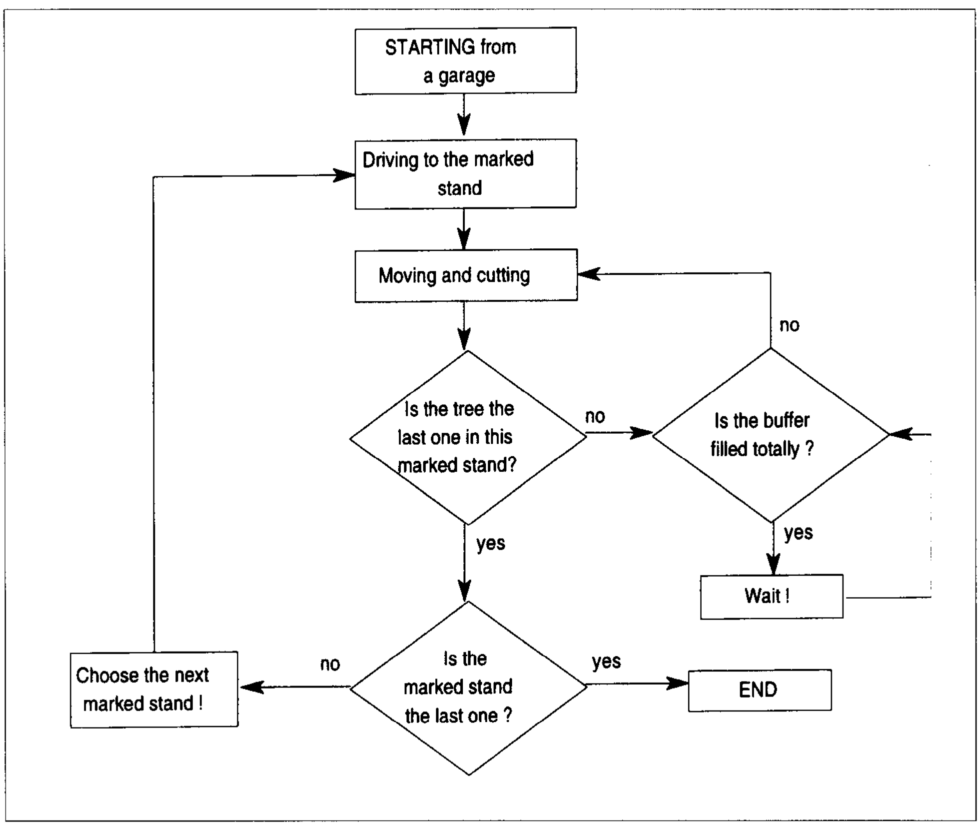

Figure 2. Activities of a harvester.

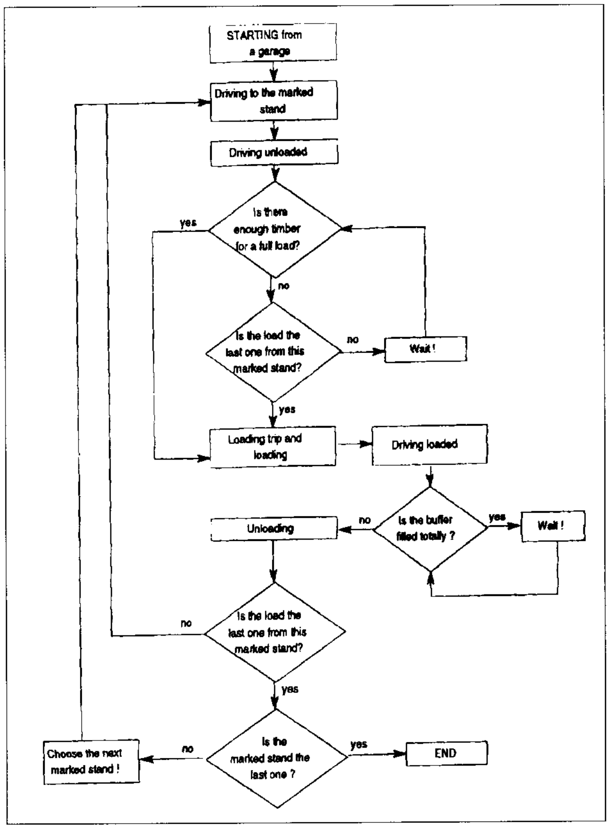

Figure 3. Activities of a forwarder.

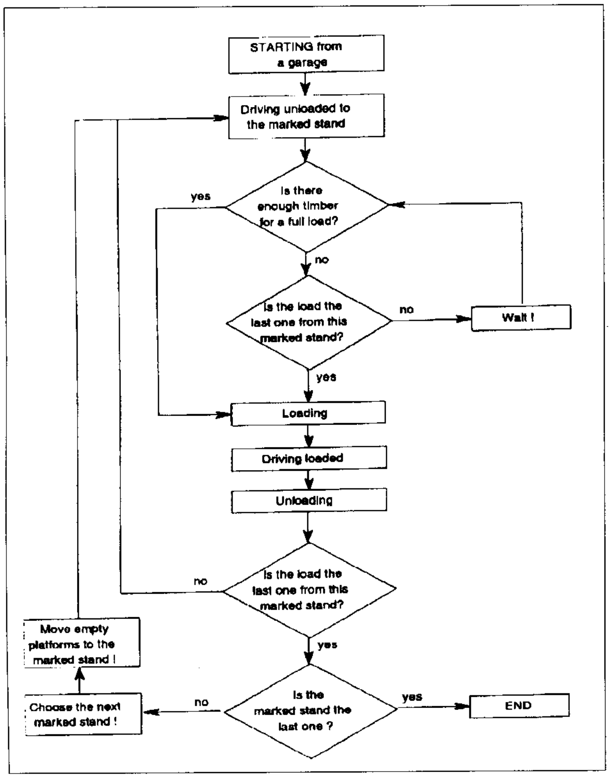

Figure 4. Activities of an interchangeable platform truck.

$$th_p = p_1 + 1000 p_2 v_m + p_3 / (1000 v_m - p_4) \qquad (3)$$

in which

th_p=processing time, min/stem

vm=volume of stem, m^3

parameters p_1, p_2, p_3 and p_4:

Final felling

	pine	spruce
p_1	0.52967	0.44472
p_2	0.00089	0.00094
p_3	-205.89	-146.17
p_4	-719.45	-862.05

Thinning

	pine	spruce
p_1	0.65739	0.50001
p_2	0.00041	0.00059
p_3	-85.413	-22.386
p_4	-201.34	-85.621

The loading time of a forwarder was calculated by Function 4.

$$t_1 = 0.11 + \left(p_1 + p_2 * p_3 \sqrt{d}\right) / p_3 \sqrt{d} \qquad (4)$$

in which

t_l=loading time, min/m^3

d=volume of timber, m^3/100 m trail

parameters p_1, p_2 and p_3:

Final felling

	log	long pulpwood
p_1	0.1504	0.1596
p_2	0.616	0.894
p_3	0.33599	0.26415

Thinning

p_1	0.0942	0.1642
p_2	0.839	1.1838
p_3	0.32428	0.21249

The time consumed in a loading trip was calculated as follows:

$$t_d = \frac{0.04 V_1 / V_p + 100 V_1 / (vd)}{V_1} \qquad (5)$$

Table 1. Information about the marked stands generated by Conifer Stand Simulator.

Information of Marked Stand	Marked Stand 1	2	3	4	5	6	7	8	9	10	11	12	13	x
Basal area, m²/ha	23	33	24	31	29	24	32	24	28	30	22	26	27	26
Number of stems/ha	440	700	600	640	900	460	640	580	100	600	420	540	540	537
Tree species composition														
spruce, %	100	80	100	100	100	20	100	60	100	100	100	100	40	77
pine, %		20				80		40					60	23
Diameter, cm	30	27	26	29	23	29	30	26	30	29	31	30	29	29
Height, m	21	20	20	21	17	20	21	19	22	21	22	21	20	21
Density, m³/ha	212	299	223	278	222	215	290	207	245	278	207	237	242	238
Total volume of merchantable wood, m³	530	453	558	695	698	538	725	518	613	695	518	593	605	595
Mean volume, dm³	482	363	372	434	499	467	452	357	533	464	493	439	448	446
Drain, m³/ha	212	118	223	278	92	215	290	207	83	278	207	87	242	195
Terrain-class	1	1	2	1	1	1	2	1	1	1	2	1	1	1.2
Terrain transport distance, m	350	350	200	150	450	300	300	250	200	250	400	350	400	304

in which

t_d=driving time during loading, min/m^3
V_l=size of load, m^3
V_p=size of work station, m^3
d=volume of timber, m^3/100 m trail
v=driving speed, m/min:
easy terrain, v=29
moderate, v=24
difficult, v=21

The time consumed by driving loaded and unloaded was calculated by Functions 6 and 7:

$$t_{dl} = \frac{0.19 + (l_l / 100)(p_l - 0.346 \ln(l_l / 100))}{V_l} \quad (6)$$

$$t_{du} = \frac{0.27 + (l_u / 100)(p_u - 0.389 \ln(l_u / 100))}{V_l} \quad (7)$$

in which

t_{dl}= time of driving loaded, min/m^3
t_{du}= time of driving unloaded, min/m^3
l_l= distance of driving loaded, m
l_u= distance of driving unloaded, m
V_l= size of load, m^3
parameters p_l and p_u:

terrain-class	p_l	p_u
1	2.01	2.37
2	2.34	2.88
3	2.83	3.48

The unloading time of a forwarder was calculated by Function 8.

$$t_u = 0.02 + 0.30 / V_l + t_{ud} \quad (8)$$

in which

t_u=time of unloading, min/m^3
V_l=size of load, m^3
t_{ud}=0.57 min/m^3 (log)
0.56 min/m^3 (long pulpwood)

The proportion of delays of forest machines were obtained from a follow-up study in which the working of 14 harvesters and 12 forwarders was studied [2]. There was no detailed information available on the delay pattern of the forest machines. According to the previous studies, the time between failures can be described in terms of exponential distribution [12]. The delay or service time can be expressed in terms of lognormal, Erlang or exponential distribution. It was assumed that the length of delays and the time between delays are distributed exponentially. The mean time between delays was 49 min by the harvester and 2 h 35 min by the forwarder. The mean delay was 26 min by the harvester and 25 min by the forwarder.

The time consumption of the timber truck was calculated according to the functions presented by Kukko et al. [4]. The driving speeds of the truck loaded and unloaded were calculated by Functions 9 and 10.

$$v_l = -0.44591 + 31.695 * \log(l) \quad (9)$$

$$v_u = 5.7917 + 30.630 * \log(l) \quad (10)$$

in which

v_l=driving speed, loaded, km/h
v_u=driving speed, unloaded, km/h
l=driving distance, km

The proportion of truck's delays were obtained from the study of [1] and the shapes of the distributions were assumed to be exponential. The mean time between delays was 2 h 30 min and the mean delay was 23 min.

In simulation experiments the number of empty platforms varied from three to nine and the trucking distance from 30 to 60 km. Comparative simulations were done with the conventional system in which the trucking distance was 30 km. The loading and preparation time for the interchangeable platform truck was 30 minutes, while for a conventional truck the loading and preparation time was 63 minutes. Simulations were run with the same input values three times—only the random number seed was changed.

The cost comparison between the conventional system and the system with the interchangeable platform truck was made for a trucking distance of 30 km. The costs of the productive machine hours and waiting hours used in the calculations are presented in Table 2. The waiting times were priced as the sum of fixed and labour costs. Hourly costs were calculated by the models of R & D Department for Wood Procurement and Production of the Finnish Forest Industries Federation [6]. The value-added tax (22 %) is excluded.

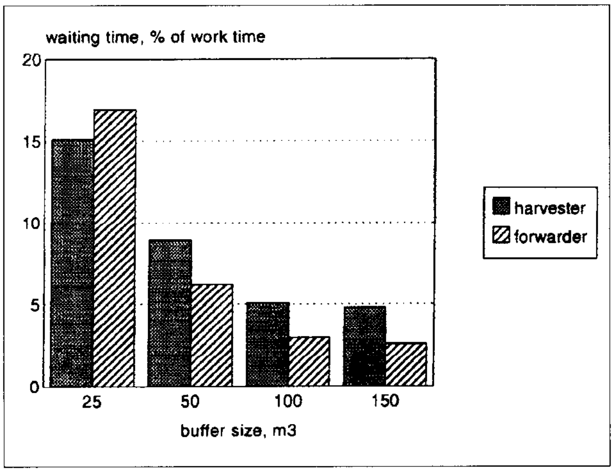

Figure 5. Effect of buffer size between a harvest and a forwarder on the proportions of waiting time.

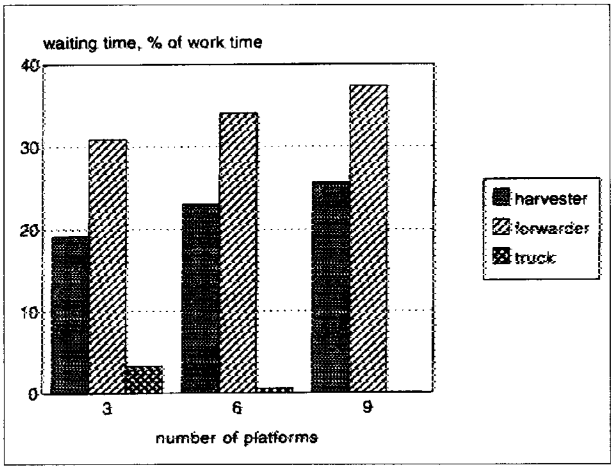

Figure 6. Effect of buffer size between a forwarder and a timber truck on the proportions of waiting time.

Table 2. Costs of productive machine hours (PMH) and of waiting hours (WH) used in the calculations.

	Harvester	Forwarder	Truck
FIM/PMH			
conventional	370	238	328
3 platforms	"	"	328
6 platforms	"	"	332
9 platforms	"	"	337
FIM/WH			
conventional	289	188	196
3 platforms	"	"	196
6 platforms	"	"	201
9 platforms	"	"	205

RESULTS

When the size of the buffer between a harvester and a forwarder was increased in these simulations, the proportions of waiting time decreased (Figure 5). The simulations were made without immediate trucking; thus, only the interactions between a harvester and a forwarder are considered. If the buffer size between a harvester and a forwarder exceeds 100 m^3, the interactions between these two machines do not affect the productivities appreciably. If the buffer is smaller, the delays start to reduce the productivity. For instance, if the harvester has a long delay, the buffer is too small to ensure continuous working of the forwarder.

When the buffer size between a forwarder and a timber truck was increased in the simulations, the proportion of waiting time of forest machines increased (Figure 6). On the other hand, the proportion of waiting time for a truck decreased. In these simulations immediate trucking (platform truck) was implemented. The trucking distance was 30 km and the buffer size was measured as the number of platforms. The maximal buffer size between a forwarder and a truck affects the productivity of the system significantly. If the buffer size is expanded, the waiting times for a truck decrease rapidly.

When the average trucking distance was increased in the simulations, the proportions of the harvester's and forwarder's waiting time increased and that of the truck decreased (Figure 7). In these simulations the number of the platforms (the size of the buffer) was three. The system does not reach the balance even when the average trucking distance is about 30 km.

The numbers of productive machine hours and of waiting hours in both systems are presented in Table 3. These numbers were used in the cost calculation. The productive machine hours included delays shorter than 15 minutes. In the case of the conventional system the costs/m^3 at the mill or terminal were 47.3 FIM/m^3 and in the interchangeable platform system they were over 51 mk/m^3. This was the case even if we tried to find the most favourable situation for an interchangeable platform truck.

When the work time distributions of the conventional system and the interchangeable platform system are compared, the proportions of waiting times are much smaller in the conventional system than in the platform system (Figures 8 and 9). Even in the

Table 3. Productive machine hours, waiting hours and cost comparison.

	Harvester	Forwarder	Truck	Sum
PMH				
conventional	477.5	500.7	891.6	
3 platforms	514.5	517.3	730.0	
6 platforms	519.9	521.4	758.2	
9 platforms	534.6	531.4	786.6	
WH				
conventional	5.7	56.4	0.0	
3 platforms	169.1	273.1	29.6	
6 platforms	217.4	321.6	4.8	
9 platforms	263.9	384.0	0.4	
COSTS, FIM/M³				
conventional	14.0	10.2	23.0	47.2
3 platforms	18.8	13.7	19.3	51.9
6 platforms	20.1	14.5	19.9	54.5
9 platforms	21.6	15.6	20.9	58.1

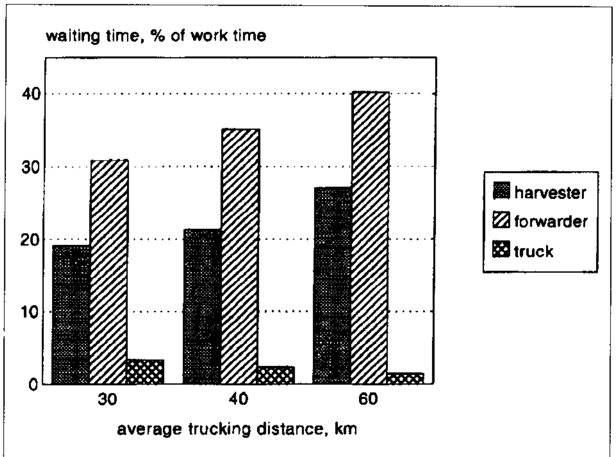

Figure 7. Effect of average trucking distance on the proportions of waiting time.

best balanced platform system (30 km trucking distance and nine platforms), the interactions between a forwarder and a truck cause a high proportion of waiting times for the whole system. If these waiting times are converted to harvesting costs, the conventional method is clearly more profitable and also allows greater variability in the trucking distance.

The inventory costs do not change the situation. Let us assume, that the inventory time is 4 hours in the platform system and 48 hours in the conventional system, the binded capital of the inventory is 200 mk/m³ (stumpage prize = 150 mk and harvesting cost 50 mk), and the interest rate 10 %. Thus, the inventory cost is 0.01 mk/m³ in the platform system and 0.11 mk/m³ in the conventional system. The inventory costs at mill are excluded.

DISCUSSION

The individual machine operator affects the system balance considerably. In this study, the calculations were made with functions, which give the average productivity in certain conditions. The residual sum of squares of the functions was not available. The delays used in the simulations include also the delays caused by the driver, which may partly compensate for this shortcoming of the model.

The model was mechanistic, containing no options for internal adjustment to match the volumes at roadside. On the other hand, the adjustment of machine performance causes costs in the long run. For instance, if a forwarder works continuously under its capacity limits, its annual output will decrease, which in turn raises the hourly costs.

Although the loading time for the interchangeable platform truck is less than 50 percent of the loading time for the conventional truck, its total productivity is lower. The reason is that the buffer can be kept appreciably larger in the conventional system than in the interchangeable platform system.

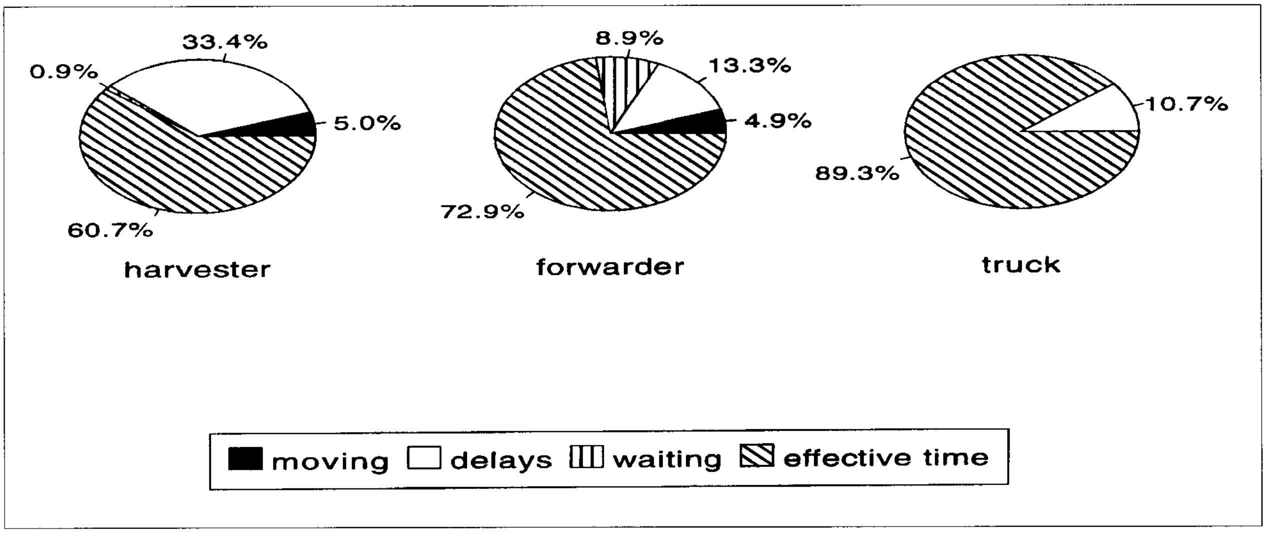

Figure 8. Work time distribution in the conventional system (30 km transport distance).

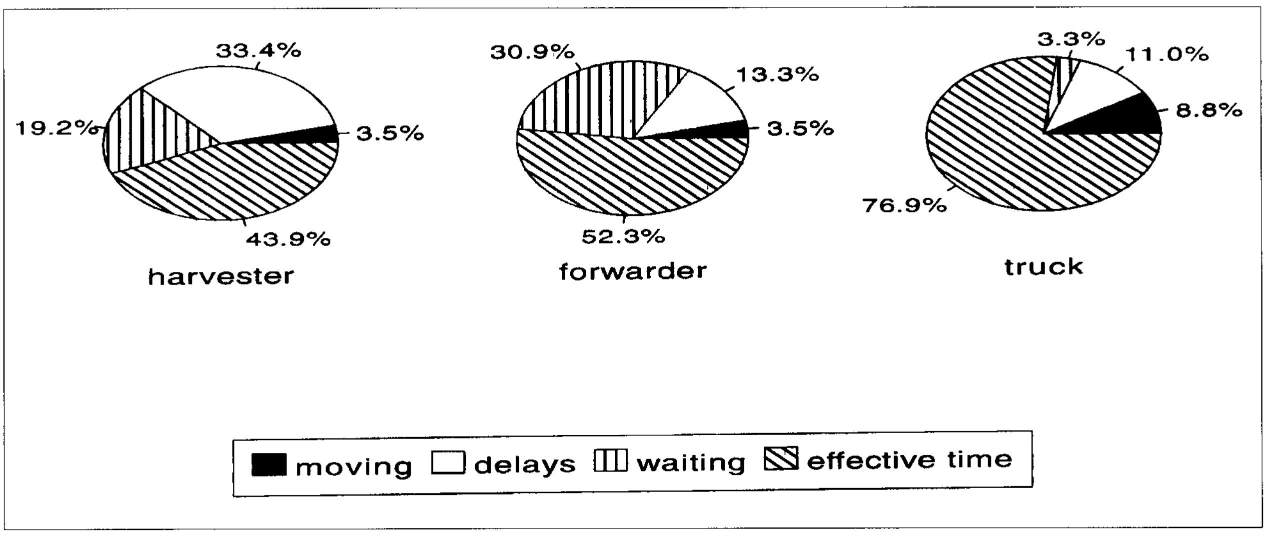

Figure 9. Work time distribution in the interchangeable platform system (30 km transport distance, 3 platforms).

Because enlarging of maximal buffer size requires investments in the case of the interchangeable platform truck, the fixed costs of trucking increase. In the case of the conventional truck, no extra investments are needed and thus fixed costs remain constant. Furthermore, the many extra interchangeable platforms cause difficulties when the logging system moves to the next harvesting site. Improvement of the truck does not improve the performance of the whole system. In the so-called hot-logging sequence, extra waiting time decreases the benefit caused by shorter loading time.

On the other hand, the use of interchangeable platform trucks can compete in transportation of chips, because here interaction between machines cannot be avoided. Chipping must be done directly onto an ordinary platform or interchangeable platforms. In a large working place, interchangeable platform trucks probably can also compete, because in that case the size of the buffer can be enlarged and the logging sequence can be balanced by changing the number of machines. In the Scandinavian countries working places are seldom large enough, but in Russia and eastern North America, for example, large working places are common. Also in Nordic countries several logging systems and interchangeable platform trucks could operate under centralized control. Nevertheless, the control of such a system would be complicated and could not be applied by comprehensive contracting entrepreneurs.

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