Economic Evaluation of Container Seedling Packing and Disinfection Machinery

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Productivity and costs of packing container seedlings were studied in a mechanised line for packing and disinfecting seedling trays. The hypothesis was that adequate cost-efficiency could be achieved when some common principles of mechanisation were applied. Results indicated that the unit costs are lower than those of manual packing, if these principles were applied and the annual number of packed seedlings exceeded 6 million. However, most of the nurseries in Finland are still too small to gain a real advantage from large-scale production.

Keywords mechanisation, packing, container seedlings, nursery technology, economies of scale
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1 Introduction

In Finland, about 90 per cents of all seedlings used for forest regeneration are container seedlings. Seedlings may be packed for silvicultural reasons, to keep the seedlings in good condition during the storing and transportation. On the other hand, packing could be done from a logistic point of view to minimise storage, handling and transportation costs. Therefore, the packing of seedlings is typical distribution packing (Soroka 1999).

In many branches of industry, the economics of scale has led to larger production units. With the extensive reforestation needed each year, some pressure exists to decrease the production cost and consumer price of seedlings. One way to seek cost-efficiency would be to enlarge the capacity of single nurseries and to mechanize and automate their production activities. When the need for a certain piece of nursery equipment is evaluated, the following aspects should be taken into account (Landis et al. 1994):

- Is this piece of equipment necessary to meet the biological needs of the seedlings?
- How much time and money will this piece of equipment save, relative to the savings in labour?
- How amenable is the task to mechanisation?
- Is time to complete the task a major consideration?
- Will the equipment be used for only a short time each year?
- Can the equipment be leased or borrowed?

When analysing the development of harvesters, Harstela (2000) presented the following principles for cost-efficient mechanisation and automation: 1) movements of machines are essentially quicker than manual ones, 2) several work elements could be done simultaneously, 3) many work functions and elements could be combined and done by one machine, 4) multi-processing could be completed, 5) continuous acting could increase efficiency, 6) information technology could be exploited, 7) quality of work could be improved and 8) good productivity, favourable cost ratio and high rate of utilisation could be achieved. In the packing and disinfection line studied many of the goals mentioned above were reached. In particular principles 1–5 were fulfilled, so based on these aspects, the line had potential for cost-effectiveness.

In this study, the aim was to investigate actual mechanised packing of container seedlings from the standpoint of cost-efficiency. The hypothesis used here was that the mechanised line for packing and disinfecting seedling trays is more cost-effective than manual packing and separate disinfection of seedling trays if the following requirements are fulfilled:

– Packing and disinfection operations are combined in the same line,
– Line speed is sufficient,
– Annual amount of packed seedlings is high (rate of capacity utilisation),
– The line is operationally reliable (technical availability)
– On the annual level there are complementary functions for production building and other expensive devices (for example, tractor).

In addition, a common hypothesis was that the advantage of large-scale production could not be reached until forest nursery units are relatively large. This could be one reason for the success of small-scale and by-business nurseries in the seedling business today (Petäjistö and Mäkinen 1999). In other words, the current nursery units of forest nursery companies may not be large enough to obtain advantages from large-scale production.

Table 1. Technical specifications of the seedling trays studied (Lännen Plantek-F 2002).

	Tray dimensions, mm	Cell volume, cm^3	No. of cells per m^2
PL 64F	384 x 384 x 73	115	434
PL 81F	385 x 384 x 73	85	549
PL 121F	386 x 384 x 73	50	820

The figure after "PL" refers to the number of cells per tray

2 Material and Methods

The mechanised production line for packing seedlings and disinfecting seedling trays, developed by Lännen Tehtaat Co. and Fin Taimi Co., was studied. The theoretical impacts of increasing the operation speed of the packing machine on productivity and unit costs were investigated for three different types of seedling trays (Table 1).

Machine interruptions and the ratio of unsuitable to suitable seedlings were observed as part of the packing process. Furthermore, the impacts of annual number of seedlings packed on unit costs were studied. The results were used to evaluate the costs and the need for rearrangement of labour on the packing line.

The most interesting element of the packing line was the automatic packing machine (Fig. 1), which was a prototype in operation for the first season. The trays were brought to the packing line in racks by a tractor. From the rack the seedling trays were moved manually (*worker 1*) to an input conveyor that simultaneously transferred them towards the packing machine and operated as a buffer storage.

First, the packing machine automatically released seedlings from the trays using a special seedling comb. After light horizontal compression, the machine element set the bunch of seedlings down into a small open-top cardboard box (OCB). A worker (*2*) calculated the unsuitable seedlings, and the OCB was filled (*worker 3*) to an objective number of seedlings. After it was filled, the OCB was moved towards final packing by an output conveyor. The next stage (*worker 4*) was to put two OCBs inside one cardboard storage box (SB), then to close the SB and finally bind it with a plastic strap. After binding, SBs were piled onto

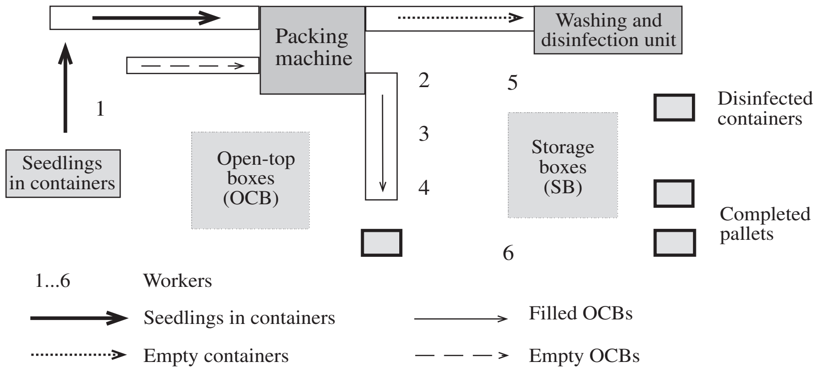

Fig. 1. Flow process chart of the packing line.

pallets (*worker 4*). Each pallet contained twenty SBs ready for storage or transport. Finally, the prepared pallets were wrapped with a plastic film (*worker 6*). *Worker 5* mostly prepared the SBs. All tasks of each worker are presented further in Fig. 2. After the seedlings were removed, the trays continued to the washing and disinfection unit. The trays were shaken to getting rid of seedling wastes, then washed and disinfected mechanically. At the end of the cleaning operation, disinfected trays were stacked automatically.

Video equipment was used to record the operation of the packing line. The recorded material consisted of the packing of Norway spruce (*Picea abies* L.) seedlings grown in 1260 units of Plantek 81F seedling trays (approx. 102 000 seedlings). The workers were the same throughout the study. The total number of packed seedlings in the present season was 1.6 million. The method used in the time study was the work sampling method, which is a method of finding the percentage occurrence of a certain activity by statistical sampling and random observations (ILO 1979). The method is easy to use and also rather short time elements can be recorded manually (Harstela 1991). The sampling interval used was 2 minutes and the total recorded work place time 8 h 3 min. Thus, the time study data consisted of 241 observations. Here the percentage occurrence of different work elements, machine interruptions, idle times and rest pauses were recorded. The rate of utilisation of a tractor in the packing line was also estimated based on the recorded time data. Cost-efficiency of the packing line was determined by making cost calculations. The cost calculations were based on the arguments shown in Table 2. Annual depreciation was calculated by the straight-line method.

Table 2. Cost information of the packing and disinfection line.

Purchase price	100 900	€
Depreciation period	15	years
Salvage value	11800	€
Interest rate	6	%
Insurance	135	€/a
Total fixed costs	18 100	€/a
Number of workers	6	persons
Wages and social expenses	12.6	€/h/person
Other variable costs	24.3	€/h
Total variable costs	100	€/h

The fixed costs shown above included 30% of the total costs of the production hall and 10% of the fixed costs of the tractor. The packing line was located in a production hall that was also used for other activities. The tractor was fully employed by the packing line during the packing period. Other variable costs (24.3 €/h) consisted of hourly costs for the use of the tractor, and electricity, water, spare part and maintenance costs of the packing machinery.

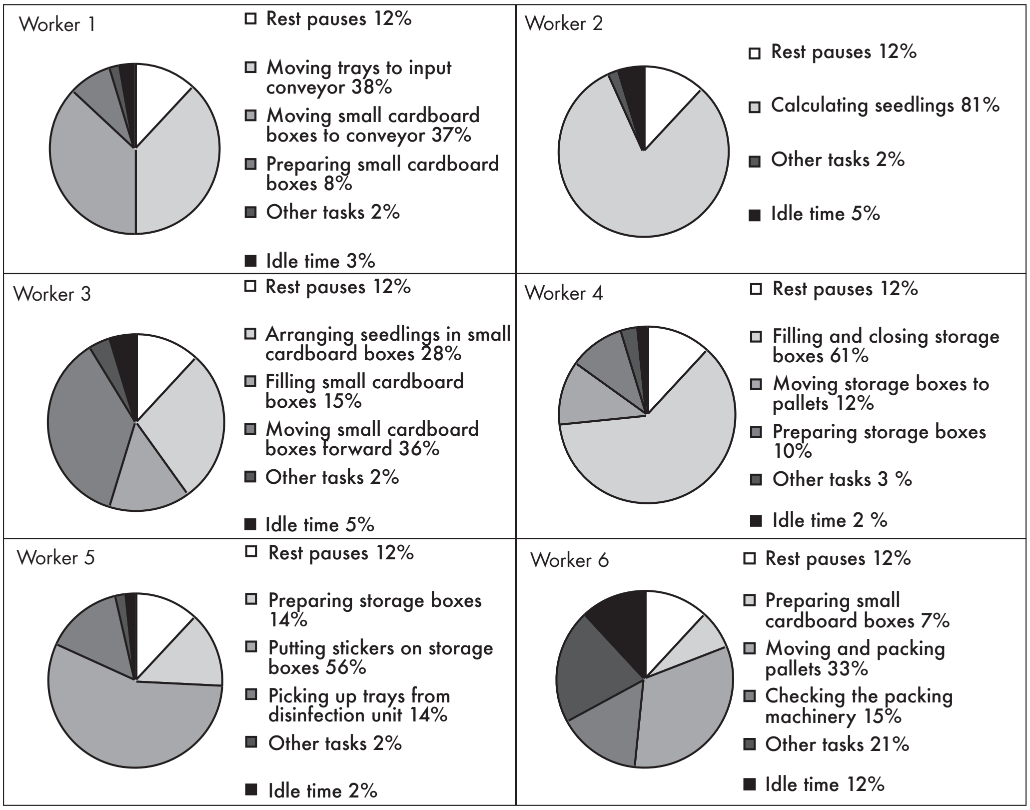

Fig. 2. Work place time (W_0) distributions.

3 Results

3.1 Time Study

Machine interruptions made up about four per cent of work place time (W_0). These interruptions caused idle time, in particular, for workers 2 and 3 (Figs. 1 and 2), who had 5 per cent idle time calculated from W_0. Other workers had compensative tasks so they were not so strongly influenced by interruptions. Worker 6 was the only one who had considerable idle time (ca. 8%), calculated on the basis of effective working time (E_0). It should be noted that, in addition to participating in the productive work, worker 6 was the foreman of the packing line. The percentage of different work elements for each worker is shown in Fig. 2.

3.2 Productivity and Unit Costs

As the cycle time of the packing line shortened, productivity was assumed to increase linearly. The theoretical output of the line was 15 300 seedlings per effective hour and 12 900 per work place hour (Plantek 81F, cycle time 19 seconds, machine interruptions 4% and rest pauses 12% of W_0). Productivity figures for different types of seedling trays are presented in Fig. 3.

Reducing the cycle time increased productivity (Fig. 3). The observed cycle time was 19 seconds, whereas the technical lowest limit for cycle time was 15 seconds. The theoretical seedling unit costs were calculated for three types of seedling trays (Plantek 64F, 81F and 121F). The impact of annual packing volume was also studied. The results of cost calculations are presented in Fig. 4. All tray types were used in the nursery but only

Plantek 81F was actually studied. Shortening of the cycle time from 19 seconds to 15 seconds decreased the unit costs by 6–16%, depending on the annual production volume and the type of seedling tray.

Hourly fixed and variable costs were independent from the tray type. Therefore, the share of fixed costs per seedling increased while trays with higher number of seedlings were packed. Increase in annual production volume reduced the share of fixed costs, respectively. The share of fixed and variable costs for each tray type according to annual production volume are presented in Fig. 5.

Unit costs do not include the costs accumulated by transferring disinfected seedling trays and completed seedling pallets. On the other hand, seedling transportation from the field to the packing line by tractor was included. Material costs, such those for seedling trays and cardboard boxes, were not included in these unit costs.

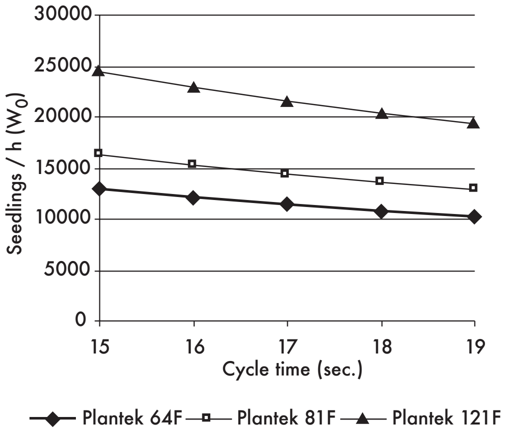

Fig. 3. Productivity of the packing line presented as a function of cycle time.

4 Discussion

Because the work rate of the production line was machine-controlled, the material investigated here may be large enough to estimate the productivity and to analyse the tasks of the workers. It is, however, very limited for estimating the machine interruptions. From the prototype machine it is difficult to obtain enough data for this purpose. Therefore a sensitive analysis was done. Doubling the amount of interruptions (8%) caused only a 2 per cent rise in costs.

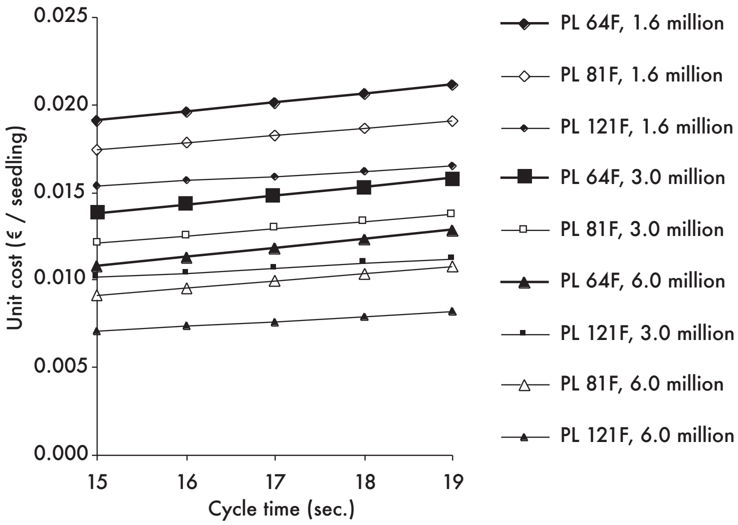

Fig. 4. The impact of the annual number of packed seedlings and machine cycle time on unit costs of seedlings grown in Plantek 64F, 81F and 121F seedling trays.

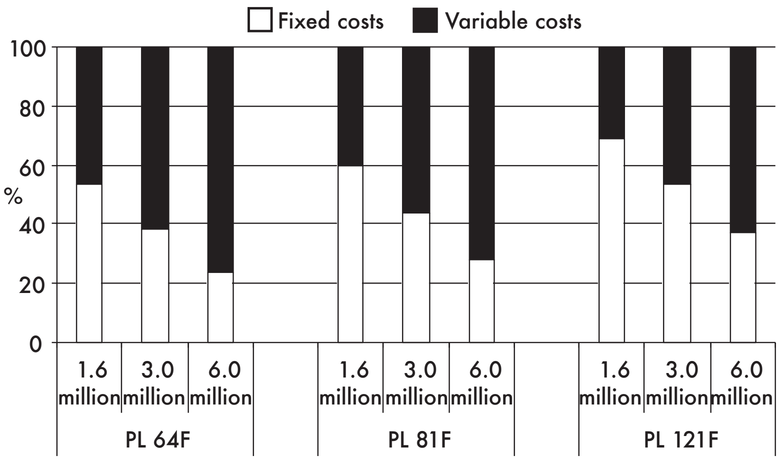

Fig. 5. The share of fixed and variable costs of the total packing unit costs while cycle time was 19 seconds.

The present cycle time of the packing machine was 19 seconds, and the productivity was 12892 seedlings per work place hour (PL 81F, machine interruptions 4% and rest pauses 12%). All six workers were needed for successful use of the packing line and the idle times were not significant. The workers usually had many parallel tasks to do. An exception was worker 2, whose only essential task was to count the unsuitable seedlings (97% of E_0). The proportion of useable seedlings in the trays varies between 80 and 99 per cent. As the deviation is so high, it is necessary to count seedlings and fill the seedling packages to guarantee a good-quality product. Seedlings could also be counted mechanically, in which case a mechanised counter would compensate for one worker. In the present study with an annual packing volume of 3 million seedlings, that would lead to savings of 2900 € per year. An equivalent investment with a 6% interest rate and a 15-year depreciation period would be about 31 600 €.

Disinfection of each seedling tray with the currently used detergents takes about 10 seconds. The present machine disinfected two trays at a time. Thus disinfection would not form a bottleneck in the packing line even if the cycle time would decrease from 19 seconds to 15 seconds. However, higher operation speed may increase the risk of interruptions, but the material used here was insufficient for estimating that effect. Nor could workers ability to manage their tasks faster be observed in practise. Thus the following estimations of cost savings may be optimistic. Theoretically, decreasing the cycle time from 19 seconds to 15 seconds would reduce packing costs by 6–16%, depending on seedling type and annual packing volume.

The packing volume for the year (2000) studied was rather low, only 1.6 million seedlings. Thus fixed costs made up large proportion of the total unit costs (53–74%). For that reason an increase in annual packing volume would reduce unit costs significantly. For example, doubling the annual packing volume up to 3.0 million seedlings would reduce unit costs by 25–32%. Furthermore, if the annual number of packed seedlings increased to 6.0 million, the savings in cost would be 39–51% of the present unit costs. These calculations assume that the technical rate of utilisation remains constant.

According to the practical experience of some nurseries, the average output per work place hour in manual packing is about 1500 seedlings per worker (Plantek 81F). This productivity includes counting seedlings and filling boxes. Stacking the completed boxes onto pallets and packing the pallets take about half of one worker's work place time (W_0). If the personnel costs are defined to be 12.6 € per hour, the unit cost of manual packing would be 0.009 € per seedling.

So that the unit costs for manual packing would be comparable to the unit costs for the packing line studied, they should include the costs of washing and disinfecting the seedling trays. Three workers wash and disinfect 350 pieces of Plantek 81F trays in one work place hour (Tervo 2001). In addition, a tractor with driver is needed for 50% of the washing time to move seedling trays to the washing location. By taking into account these expectations, the total unit cost of manual packing would be 0.011 € per seedling. Thus, mechanical packing apparently is not cost-effective, compared to manual packing, with present technology until the annual packing volume exceeds 6 million seedlings (Plantek 81F). These total unit costs do not include the costs of moving washed and disinfected seedling trays or the costs of moving the completed pallets to storage or to transportation sites.

The cost comparison proves that most of the nurseries in Finland are still too small to gain a real advantage from large-scale production. Relatively competitive unit costs, in addition to local supply contracts, could be one reason for the vitality of a relatively large number of small-scale and by-business nurseries. However, as all the hypotheses presented in chapter 1 come true, the packing line seems to be cost-effective alternative for manual packing. Some nursery managers have said that the critical point for cost-effective production is an annual production of 10 million seedlings. Taking into account that not all seedlings are packed, this idea seems to be reasonable for mechanical packing of seedlings.

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