Simulation of Automatic Output Operations for Rice Seedlings

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In Taiwan, more than 800 seedling nurseries prepare rice seedlings to be sold for paddy production. Operations relating to seedling production require significant levels of labour, especially when harvesting the seedlings. A new seedling removal system has now been developed to automate the seedling output process. The system has been modified from and integrated with several previously developed units, namely, the seedling tray-loading machine, conveyor, seedling-mat rolling machine, seedling-roll relocating machine, and seedling-roll stacking. The performance of individual units and the collaboration between these units are important in affecting the overall efficiency of the system.

An animated simulation model was developed to conduct an analysis on the output operations for rice seedlings. With this model, the working efficiency and the system throughput under different operational conditions were studied. It was shown that the optimum operational pattern could be found by adjusting the length of working row and the operation rates among units. A row of 30 m in length, for example, has been examined to obtain its maximum system throughput of 1288 trays h\textsuperscript{-1}, under a tray-loading speed of 0.3 m s\textsuperscript{-1}, a tray conveyor rate of 0.46 m s\textsuperscript{-1}, a rolling rate of 5.5 s tray\textsuperscript{-1} for the seedling-mat rolling and a seedling-roll relocating rate at 2.3 s tray\textsuperscript{-1}. Under these conditions, the utilisation rates were found to be 86\% for the tray-loading machine, 65\% for the seedling-mat rolling machine, 81\% for the seedling-mat relocating machine, and 65\% for the stacking workers, respectively.

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1. Introduction

More than 800 rice seedling nurseries in Taiwan supply 726,000 seedlings per year for transplanting. Due to the manual work force required in seedling production, nurseries have started to mechanise field operations so that problems of labour shortage can be partially alleviated. The procedures in a seedling nursery can be divided into four parts: sowing, input operations, seedling growth, and output operations. The sowing operation can be broken down into box supplying boxes, soil filling, water spraying, sowing, pesticide spraying, and soil covering (Chiu \textit{et al.}, 1998). The seeded trays are stacked in a conditioning room for 2 or 3 days to speed up sprouting and then moved to the hardening field for acclimatisation and further growth, thus completing the ‘input operations’.

The established seedlings eventually form a dense root mat in the tray and can be rolled into a cylindrical shape (seedling roll) for transportation and later transplanting. The seedling-mat rolling is a popular method used for distant transportation in Taiwan. The ‘output operations’ include retrieving the seedling trays, rolling the seedling mats, collecting the seedling rolls from trays in units of three finished rolls, conveying, and stacking on the truck for transportation; however, moving the trays around is usually labour-consuming.

Chiu and Fon (1998) conducted a study at nurseries on rice seedling transportation. In the study, various transport tools were designed and tested. It was shown that the transport gantry is the most effective device in moving seedling trays to the hardening fields. The transport gantry is becoming popular in Taiwan for large-scale nurseries. It is designed to carry out both longitudinal and horizontal movements covering the whole hardening field. Established seedlings can also be removed from the nursery field by using the same gantry system to transport these to the paddy field for
transplanting. However, with such system, manual workers are still required to load and unload the conveyor. A poor allocation of labour force leads to an imbalanced workload, restrictions in the workflow and decreased system throughput. Thus, Chiu et al. (2000) were to model a gantry transport system and to analyse the throughput, worker efficiency, and time requirements for a variety of field conditions and operating procedures with a varying number of labourers.

In the output operations, many workers are required to complete this job within a few hours in the early morning. Therefore, a new seedling removal system has now been developed to automate the seedling output process. The integration system is to combine the transport gantry, conveyors, tray-loading machine, seedling-mat rolling machine, and seedling-roll relocating machine (Chiu & Fon, 2000). Results indicated that the working efficiency of the whole system was related not only to its mechanical performance, but also to the compatibility and interactions among the component systems and the peripheral equipments.

To obtain an optimum efficiency of the whole system, an operational research technique adopting computer simulation and system design has been employed. Many successful applications of computer simulation in agricultural production are reported in literature (Chiu et al., 1983a, b). Since many subsystems are involved in the automatic seedling output system, field tests on the prototype are time-consuming and expensive. The objectives of this study were: to model an automatic output system for rice seedling production; and to analyse the system performance for a variety of working row lengths, conveyor speeds, seedling-mat rolling and seedling-roll relocation rates, and employment rates of workers for obtaining the best operating pattern. Validation on the models is performed and their relevant parameters such as system throughput and working efficiency are studied.

2. System description

The seedling output operations include tray loading (retrieving), conveying, diverting and collecting, seedling-mat rolling, seedling-roll relocating and stacking. Figure 1 shows the automatic output system in which seedling trays in the acclimatisation field are picked up by a tray-loading machine, and then sent to a diverter via a gantry conveyer. The incoming trays are divided by the diverter into three lines, leading to three individual seedling-mat rolling machines where the seedling-mat are rolled. The collector, located at the other end, gathers the finished rolls back into one line. A relocating unit then resets the rolls into a manageable three-a-tray for easy transfer to the standing truck using a slant conveyor. One worker is required on the truck to arrange the seedling rolls in stacks.

The tray-loading machine, developed by Chiu and Fon (2001), is a lateral conveyor mounted on the gantry frame. In the loading (retrieving) operation, the machine can pick up seedling trays directly from the field and guide them upward to the gantry conveyor. The machine moves along the gantry with the side conveyor that is sliding on the ground surface to pick up the trays in sequence. As soon as a row is completed, a boundary sensor will activate the system to lift up the side conveyor and move the loading unit back to its starting position, while the gantry is moving to the next row. The side conveyor is lowered again to resume the process. Figure 2 depicts the flowchart on the operational procedure.

The seedling-mat rolling and the seedling-roll relocating machine have been developed that can automatically roll up seedling mats from a 30 by 60 cm tray into a cylindrical shape of 18 cm in diameter and combine three rolls in one tray ready for transportation. The mechanism worked satisfactorily at a speed of 362 trays h⁻¹ (Chiu & Fon, 2000).

The seedling-mat rolling and seedling-roll relocating machine employs a pneumatic mechanism controlled by a programmable logic controller (PLC). The rolling action is accomplished by a set of curved plates. First, the seedling-mat pulling plate presses the top seedlings to bend the mat upward from trays so that the second plate can be inserted in between. The second, or seedling-mat rolling plate, then descends to its lowest position and starts to plough the seedling mat by pushing it both forward and upward, while the third, or seedling-mat forming plate, positioned at the other end of the tray, swings down to hold against the other end of the seedling mat and helps the forming of seedling rolls.

The seedling-roll relocating unit consists of a couple of grippers that can temporarily hold seedling rolls. At the beginning, the first set of gripper holds the first finished roll, while the second holds another. After both are loaded, the two sets of grippers are in sequence waiting above the relocating unit until the third roll finished. The grippers lower the first and second finished rolls onto the tray that contains the third roll. Finally, the three finished rolls are placed in one tray.

The row change time is the time to move the tray-loading machine to the starting position when a row is finished, which includes the time to lift up the side conveyor Tₜ, and the travel time to move back to the starting position of the row and descend the side
The time in which the transport gantry moves sideways to the next row, however, is very short and can be neglected. The row change time $T_c$ in s can be calculated as follows:

$$T_c = T_l + \frac{L_t \times N_t}{V_i} + T_p$$  \hspace{0.5cm} (1)

where: $N_t$ is the number of trays in each row; $L_t$ is the length of each tray (about 61 cm for rice seedling trays; and $V_i$ is the speed of the loading unit in m s$^{-1}$.

### 3. Model development

#### 3.1. The software

The system for rice seedling output operations was simulated by discrete-event technique using computer software ARENA 5.0, which was developed on the basis of SIMAN V and CINEMA V (Pegden et al., 1995). Since the software works in a graphical programming environment, the simulation process can easily be observed and ‘debugged’ directly on the monitor. Nilsson (2000) has applied ARENA to develop dynamic simulation models for grain straw harvesting, while Fang et al. (1990) used SIMAN and CINEMA to develop models for a greenhouse transport system.

SIMAN provides many useful sub-models such as transport vehicles and conveyors, for model developers. In this study, the conveyor sub-model was used. SIMAN has two types of sub-models: the accumulating and the non-accumulating conveyors. The accumulating one, e.g. the powered roller conveyor, allows entities on the conveyor to keep sliding until they hit any entity stopped ahead. The non-accumulating one, e.g. the bucket conveyor or belt conveyor, on the other hand, does not have such property. Since V-belts were used on the gantry conveyor, these were adopted as the non-accumulating sub-model in the current study. Within the conveyor sub-model, the status of operational
parameters (e.g. the number of trays on the conveyor or the conveyor speed) can be changed and monitored. Thus, the programming becomes easier and more time-saving.

An animated simulation module was also developed as shown in Fig. 3. Through animation, a detailed process can be shown in graphical mode. Besides for educational purpose, this system can also be used to facilitate computer program ‘debugging’. The animated module for the processes of the seedling output operations includes truck arrivals and waiting, seedling-tray loading and conveying, tray diverting, rolling, collecting and relocating, rolls stacking, gantry row-changing, and truck leaving. Information such as seedling output, outgoing trucks, number of seedlings and stacks needed for the trucks is also shown, along with the animated simulation pictures. The details of the simulated network model can be obtained from Chiu et al. (2002).

3.2. Data collecting

A typical rice nursery, Koufon, in Taoyuan county was selected for the data collection of seedling output operations. The operational period $x$ started from February 23 ($x = 1$) to March 18 ($x = 24$), or 24 days in total for the first crop in 2001. During that period, 77,527 trays of seedlings were nurtured. The daily seedling output is shown in Fig. 4. The production was high in the middle of the period, on average 5000–7000 trays per day.

The seedling output on the ninth day was selected for further analysis as it bears high production. In this case, both truck arriving and leaving time was recorded. The elapsed time for the output operations and truck loading were also measured. Relevant data were analysed using software Experfit (Law & Vincent, 1997) to obtain a best-fit probability distribution function, in which the maximum likelihood estimation (MLE) method was employed.

The statistical standard procedure suggested by Ang and Tang (1975) was employed to fit the observed operational time to a distribution function for each of the operational tasks. The procedure was as follows:

(1) Distribution histograms were constructed for the observed data.
(2) Each data set was fitted by the theoretical distribution.

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**Fig. 2. Flowchart of tray-loading operations**
(3) The parameters of each distribution were calculated using the method of maximum-likelihood estimators.

(4) The best probability density function was found using the Anderson–Darling test and Kolmogorov–Smirnov test.

(5) The chi-squared ($\chi^2$) goodness-of-fit test was made to obtain a theoretical distribution function that best fitted the observed data.

The theoretical density function that best fitted the observed data and the relevant parameters for each task are shown in Table 1. The average number of trays needed for a truck was 174, in a range of 15–350 trays. The density function $f(x)$ for trays needed $x$ for one truck can be fitted to gamma distribution (Fig. 5), of which the density function is

$$f(x) = \frac{\beta^{-x}(x-\gamma)^{x-1}\exp(-(x-\gamma)/\beta)}{\Gamma(z)}$$

where $\Gamma(z)$ is defined by $\Gamma(z) = \int_0^\infty t^{z-1}\exp(-t)dt$; $\alpha$ is the shape parameter; $\beta$ is the scale parameter; and $\gamma$ is the location parameter. The parameter values are listed in Table 1.

The density function of the arriving intervals for trucks can also be fitted to gamma distribution (Fig. 6). The average time interval $x$ between truck arrivals was 14.41 min, in a range of 0.20–56.82 min. The time $x$ for truck removing from system after truck loading can be fitted to lognormal distribution (Fig. 7), of which the density function can be expressed as Eqn (3). The average time for truck removing was 2.04 min, with a range of 0.02–12.33 min

$$f(x) = \frac{1}{(x-r)\sqrt{2\pi\sigma^2}} \exp \left[ \frac{-(\ln(x-r) - \beta)^2}{2\sigma^2} \right]$$

(3)

The time for workers to move seedling rolls from the conveyor and stack them on trucks (truck loading), as well as the time for truck movements for loading had

![Fig. 3. Animation of rice seedling output operations using the animated-simulation module](image-url)

![Fig. 4. The rice seedling tray output of Koufon nursery for the first season, 2001](image-url)
been investigated and reported by Chiu et al. (2000). Both tasks can be fitted to Weibull distribution and can be expressed as Eqn (4). The average time for truck loading and truck movement were $5.5\text{ s}$ and $57.5\text{ s}$, respectively.

\[
f(x) = x\beta^{-2} (x - \gamma)^{2-1} \exp \left\{ -\frac{x - \gamma}{\beta} \right\}
\]  

\[ (4) \]

3.3. Validation

In order to assure that the models could accurately simulate the real system, the tray-loading operation was chosen to be verified. The parameters involved are the speeds of horizontal, transverse and tray-loading conveyors, and the return speed of the tray-loading machine. In physical systems, the validated outputs can be observed by changes of the three programmable frequency converters, which result in seven treatments for different combinations (Table 2) for verification tests. Each working row in the field has 20 seedling

<table>
<thead>
<tr>
<th>Operation</th>
<th>No. of observations</th>
<th>Probability function</th>
<th>Distribution parameters</th>
<th>Probability value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trays needed for a truck</td>
<td>38</td>
<td>Gamma</td>
<td>4.0, 43.4, 0</td>
<td>0.05, 0.15, 0.10</td>
</tr>
<tr>
<td>Arriving intervals for trucks</td>
<td>36</td>
<td>Gamma</td>
<td>0.9, 16.0, 0</td>
<td>0.25, 0.15, 0.25</td>
</tr>
<tr>
<td>Truck leaving time</td>
<td>38</td>
<td>Lognormal</td>
<td>4.3, 2.1, 0</td>
<td>0.15, 0.05, 0.025</td>
</tr>
<tr>
<td>Truck loading</td>
<td>93</td>
<td>Weibull</td>
<td>5.8, 6.0, 0</td>
<td>0.01, 0.01, 0.01</td>
</tr>
<tr>
<td>Truck movement</td>
<td>23</td>
<td>Weibull</td>
<td>0.8, 21.4, 33</td>
<td>0.01, 0.01, 0.01</td>
</tr>
</tbody>
</table>


*Distribution parameters for location parameters $\gamma$, scale $\beta$, shape $\alpha$. 

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Fig. 5. The best-fit predicted seedlings needed for a truck in comparison with the observed data

Fig. 6. The best-fit gamma density function predicted time interval between truck arrivals in comparison with the observed data

Fig. 7. The best-fit lognormal density function predicted values of the time needed for truck departures in comparison with the observed data
trays. The system throughput and the row change time are two parameters to be compared and verified. During simulation, each treatment had been carried out for ten replicates and the simulated results were averaged out in order to compare them with the observed ones. Table 3 shows the comparison between the simulated and the observed results, in which the maximum mean difference was less than 5.5% for system throughput and 9.6% for the row change time, well falling in an acceptable range. Thus the simulation models are reasonably accurate in predictions.

4. Results and discussion

4.1. Analysis for automatic rice seedling output operations

As the models stated above were well validated for predictions, they can reasonably be used to simulate the rice seedling output operations carried out by the newly developed system. Since validation no. 7 in Table 3 has given a best system throughput of 1074 trays h\(^{-1}\), the related operational parameters (Table 2) of this were chosen as the inputs for the simulation of the tray-loading process of the developed automatic seedling output system. The elapsed time for seedling-mat rolling and seedling-roll relocating was measured by operating the actual machine units. Parameters like the time intervals of truck arriving, seedling trays needed for each truck, and time for truck movement for loading and the time for truck removing from the system were obtained from the density function that was developed from the previous observed data at the Koufon nursery. The simulation time was set for 6 h, in ten replicates. The simulation results indicated that the average working capacity was 733 trays h\(^{-1}\). The utilisation rate was 85% for tray loading, 67% for rolling, 62% for relocating, and 40% for the stacking workers. However, the working capacity of seedling output operations (773 trays h\(^{-1}\)) was 26% less than that of tray-loading processes (1074 trays h\(^{-1}\) in Table 3). The decrease in the throughput may be explained with the developed system being integrated from several sub-systems and run in sequence; some inconsistency may exist during operation.

4.2. Analysis on lengths of working row

Since the size of the seedling trays was standardised (600 mm by 300 mm), the number of trays per row is easily calculated once the working row has its fixed length. The row length can be represented as the number of trays per row. Most nurseries in Taiwan, for example, have a gantry system of length 33 m, which means one row can only have 55 trays. To analyse the effects of the row length on system throughput under various circumstances, the row length, in terms of the number of trays per row, can be in a range of 10–55 trays with an increment of 5 trays for sensitivity analysis on the system performance. In simulation, five operational conditions, cases 1–5 (Table 4), were studied. The simulation results (Fig. 8) indicate that the system throughput be proportional to the row length in case 1. The system throughput has a 92% increase from 464 trays h\(^{-1}\) for the ten-tray row to 888 trays h\(^{-1}\) for the 55-tray row. The length of working row significantly affects the system throughputs on various cases.

4.3. Analysis for the tray-loading speeds

On the other hand, the simulation results also showed that a shorter row with higher tray-loading speeds will result in significant high system throughputs. As the row increase in further length, the difference became less significant. A ten-tray row, for instance, the system throughput under case 5 in Table 4 was 767 trays h\(^{-1}\),
which was 65% higher than that of case 1 (464 trays h\(^{-1}\)), while the system throughputs for a 55-tray row were 889 and 888 trays h\(^{-1}\) for cases 5 and 1, respectively, with only a slight difference.

By studying the animation module, it was found that as the tray-loading unit increases its speed beyond a certain limit, the seedling-mat rolling unit becomes incapable of handling the incoming seedling trays in time, and system finally halts the loading process. This discontinuity tends to discourage the advantage of high operational speed. Since the whole system was integrated by several subsystems, a good collaboration among all subsystems is important. Bottlenecks resulting from any subsystem would eventually affect the system throughput, otherwise.

4.4. Analysis for the utilisation rate of equipment and workers

The simulated results on the utilisation rate for the tray-loading, seedling-mat rolling, seedling-roll relocating machines, respectively, and for the stacking worker are shown in Fig. 9. For the tray-loading machine, the utilisation rate is almost constant at 85% as the system throughput increases from 546 to 998 trays h\(^{-1}\).

4.5. Effect of seedling-mat rolling and relocating rate

To understand the time in handling the unit tray, the rates of different units are expressed in s tray\(^{-1}\). In this case, the seedling-mat rolling rate is 9.3 s tray\(^{-1}\), while the relocating machine runs 2.9 s tray\(^{-1}\). To make a sensitivity analysis on the rates of operations, the conditions at case 5 in Table 4 (which has the highest

![Table 3](image)

**Table 3**

<table>
<thead>
<tr>
<th>Validation no.</th>
<th>Throughput, trays h(^{-1})</th>
<th>Row change time, s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed average (SD)</td>
<td>Simulated average (SD)</td>
</tr>
<tr>
<td></td>
<td>Observed average (SD)</td>
<td>Simulated average (SD)</td>
</tr>
<tr>
<td>1</td>
<td>699 (8.6)</td>
<td>710 (7.4)</td>
</tr>
<tr>
<td>2</td>
<td>758 (7.2)</td>
<td>773 (8.6)</td>
</tr>
<tr>
<td>3</td>
<td>831 (7.3)</td>
<td>826 (6.3)</td>
</tr>
<tr>
<td>4</td>
<td>893 (5.0)</td>
<td>909 (6.5)</td>
</tr>
<tr>
<td>5</td>
<td>1000 (8.1)</td>
<td>1017 (6.1)</td>
</tr>
<tr>
<td>6</td>
<td>1049 (7.8)</td>
<td>1068 (9.2)</td>
</tr>
<tr>
<td>7</td>
<td>1137 (8.5)</td>
<td>1074 (8.1)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Operational conditions for simulation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case no.</td>
<td>Tray-loading speed, m s(^{-1})</td>
</tr>
<tr>
<td>1</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>0.22</td>
</tr>
<tr>
<td>4</td>
<td>0.26</td>
</tr>
<tr>
<td>5</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Fig. 8. Effect of row length on system throughput under five different operational conditions: — , case 1; — × — , case 2; — — — — , case 3; — — — — , case 4; — — — , case 5
system throughput) was used to investigate their influences on the system throughputs. The seedling-mat rolling rate was set in a range from 11 to 5 s\(^{-1}\) in an increment of 0.5 s\(^{-1}\), while the seedling-roll relocating was set from 3.5 to 2.0 s\(^{-1}\) in an increment of 0.3 s\(^{-1}\). Figure 10 indicates that if the seedling-mat rolling rate is slower than 8.5 s\(^{-1}\), the system throughput will not be affected by the seedling-roll relocating rate at all. For the rolling rate at 8.5 s\(^{-1}\), the correspondent system throughput was 974 tray h\(^{-1}\), which is a critical value. Any slow rolling rate will result in an operational bottleneck.

As the seedling-roll relocating rate reaches 3.5 s\(^{-1}\), any increase of seedling-mat rolling rates above 8 s\(^{-1}\) would not help increasing the system throughput (1016 tray h\(^{-1}\)). The seedling-roll relocating machine thus becomes an operational bottleneck. However, if the relocating rate was further increased to 3.2 s\(^{-1}\) or above, the system throughput could be increased to 1103 tray h\(^{-1}\).

Simulated results showed that a maximum system throughput of 1288 tray h\(^{-1}\) could be obtained by setting the seedling-mat rolling rate at 5.5 s\(^{-1}\) and keeping the relocating rate faster than 2.3 s\(^{-1}\) in the mean time. The utilisation rates of tray-loading machine, seedling-mat rolling machine, seedling-roll relocating machine, and the stacking worker were 86, 64, 81, and 65%, respectively.

5. Conclusions

An animated simulation model was developed to analyse the automatic seedling trays output system by using software ARENA. The results show that the system throughput was significantly affected by the working row length and the operational rates of each subsystem. When the speed of tray-loading conveyor was set at 0.14 m s\(^{-1}\), and the speed of horizontal, transverse conveyors, as well as the return speed of tray-loading machine were all set at 0.3 m s\(^{-1}\), the simulated results revealed that mat rolling rate was 9.3 s\(^{-1}\), mat relocating rate 2.9 s\(^{-1}\), the length of working row 6 m (ten-tray row) and the system throughput 463 trays h\(^{-1}\). If only the row length is increased to 33 m (55-tray row), the system throughput will be 888 trays h\(^{-1}\), a 92% increase.

Simulation results also show that a maximum system throughput of 1287 trays h\(^{-1}\) could be obtained should the row length be 30 m (50-tray row), horizontal and transverse conveyor speeds 0.46 m s\(^{-1}\), return speed of tray-loading machine 0.46 m s\(^{-1}\), mat rolling rate 5.5 s\(^{-1}\), and mat relocating rate 2.3 s\(^{-1}\). Under such operational conditions, the utilisation rates for tray loading, mat rolling, mat relocating, and the stacking workers were 86, 64-9, 81-3 and 65-2%, respectively.

Acknowledgements

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References

Chiu Y C; Fon D S (2001). Development of an automatic tray loading/unloading machine for rice seedlings. The 16th Technological and Vocational Education Conference of R.O.C., Hualien, Taiwan, pp 65–74
Chiu Y C; Fon D S; Chen L H (2000). Simulation of conveyor transport operations using a gantry system. Journal of Agricultural Engineering Research, 75, 417–428
Chiu Y C; Fon D S; Wu G J (2002). Simulation of automatic output operations for rice seedlings. ASAE Annual International Meeting, Chicago, USA, ASAE Paper No. 02-3102.