Animated Simulation of Greenhouse Internal Transport Using SIMAN/CINEMA

W. Fang, K. C. Ting, G. A. Giacomelli

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Abstract

An animated computer model has been developed using a simulation language SIMAN/CINEMA to simulate greenhouse internal transport systems. The model can be used as a tool to study the performance of materials handling operations within a greenhouse. The potential bottleneck of a transport system can be visually detected on the computer monitor. Statistical analyses on the system parameters, such as the status and utilization of machines, workers and waiting lines, and throughput time of an operation, are performed during the simulation. From these data, the interaction between machines and workers within a greenhouse system can be studied. KeyWords: Simulation, animation, greenhouse, materials handling, stochastic modeling

Introduction

There are similarities between a commercial greenhouse and a manufacturing factory. Both systems anticipate profits by producing goods within planned/controlled environments to meet market requirements. Based on these similarities, greenhouse crop production may be functionally equivalent to highly developed, industrial manufacturing operations.

A substantial amount of technologies have been developed to advance the manufacturing industry, yet minimal attention has been given to the greenhouse industry. Because of the similarity, technologies developed for manufacturing systems can be utilized to benefit the greenhouse industry (Ting, 1987).

Simulation is a useful tool that can bypass many mistakes and generate alternatives before actual installation of complex and diverse real world systems. Discrete event simulation is a technique frequently utilized by the manufacturing industry to study materials handling systems in factories. Its applications can be found in the field of industrial engineering and operations research; however, only a few may be seen in the field of horticultural engineering. Chen et al. (1978) and Jagtap and Verma (1983a, b) applied this technique in studying some aspects of nursery materials handling operations.

The model by Chen et al. (1978) uses the SIMSCRIPT language to simulate the mechanical potting of container plants. Jagtap and Verma's model uses the SLAM language to simulate a continuous soil mixing operation. Both models emphasize the materials handling tasks which occur between the storage area of raw materials and the potting machine. Chen's model does not include a storage area (or otherwise called queue, buffer, or waiting line) following the potting machine; instead, the model includes the assumption that the potting machine is in a ready state, but not operating, should a worker be unavailable to unload. Jagtap and Verma's model also makes a similar assumption to simplify the system. Another assumption used in both models is that the transport distance from the potting machine to field is constant during the simulation. In reality, transport distance is variable and it affects the availability of the unloading worker(s). Therefore, it is one of the important factors of the greenhouse internal transport system.

Although it is difficult to measure the exact cost of materials handling, it normally constitutes a significant portion of the overall operating expenses of a greenhouse operation. This cost may become higher due to the increasing labor cost and the decreasing availability of skilled labor. This problem may be eased by improving the utilization of both machines and labor.

Greenhouse production systems are typically labor intensive in all facets of materials handling. The cultural tasks of a potted plant production system may be grouped into three categories. They include 1) Input tasks: potting, container placement in production area; 2) Maintenance tasks: pinching, pruning, pollinating, watering/fertilizing, insect/disease control, plant support, grading; and 3) Output tasks: harvest, termination, new crop preparation (McAvoy and Giacomelli, 1985). As an example, Table 1 shows the cultural practices of potted tomato production in a greenhouse (Giacomelli et al., 1987). The extent of the labor requirement is indicated by the "Frequency of operation". Since most of the internal transport occurs during the input and output operations, this study has focused on these two aspects of the greenhouse production system.

Materials are transported in the greenhouse production system after the potting or before the harvest operation between fixed locations along predetermined routes similar to the manufacturing line transportation. Determining an appropriate line capacity to satisfy production demand is critical for the proper design of manufacturing lines. In the case of a greenhouse, line capacity is essentially restricted by the size of the storage space for materials, such as production benches or plant containers. This in-line storage

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Article was submitted for publication in April 1989; reviewed and approved for publication by the Ermerging Technologies Div. of ASAE in January 1990. Presented as ASAE Paper No. 88-7514.

New Jersey Agricultural Experiment Station Publications No. D-03130-34-88, supported by State funds.

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TABLE 3. Variables and their values used in the example

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2. Operation	i. input ii. output	i. and ii.
3. Bay size	numeric, benches/bay	20
4. Operation size	numeric, benches/operation	200
5. Work sequence	numeric, order of row no.'s accessed	30, 31,...,39
6. No. of workers	numeric, persons	2 for input 1 for output
7. Transport speed of worker	numeric, m/min	80
8. Speed of potting	numeric, min/bench	3.63
9. Speed of harvest	numeric, min/bench	3.63
10. Input buffer	numeric, benches maximum	20
11. Output buffer	numeric, benches maximum	20
12. Bay width	numeric, m	6.4
13. Bench width	numeric, m	1.6
14. Potting to mainpath	numeric, m	10
15. Harvest to mainpath	numeric, m	10
16. Relocation time, buffer to cart	numeric, min/bench i. normal distr. [mean, std. dev.] ii. poisson distr. [mean]	i. [0.69, 0.1]
17. Relocation time, bay to cart	numeric, min/bench i. normal distr. [mean, std. dev.] ii. poisson distr. [mean]	i. [0.69, 0.1]

example, the system parameter values were based on the situations commonly found in large scale commercial greenhouse production systems. The execution of the model was guided by the menus available to the users on the monitor. Table 3 shows a list of input variables and the types of entries required by the model. Also shown in the table are the specific values used in this example (column 3).

In this example, both an input operation and an output operation were simulated. In each simulation, every row in the growing area was given an identification number. These row numbers were used to specify the order the rows were accessed during an operation. Some of the variables allowed stochastic input values. In those cases, the type of probability distribution and its relevant parameters (such as the mean and standard deviation of a normal distribution) were given.

During the simulation, an animation of the operation appeared on the monitor. Figure 2 shows a snapshot of the animated simulation of the input operation. The worker

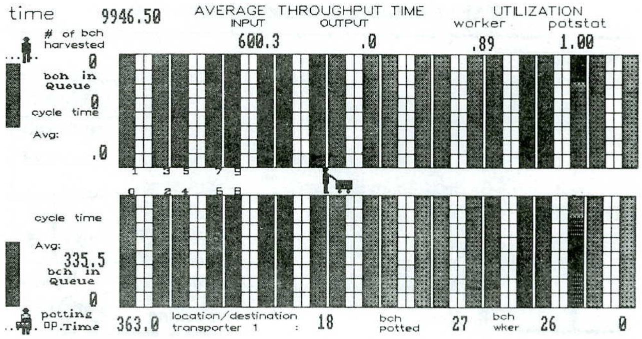

Figure 2–A snapshot of the animated simulation.

(no. 1) shown in the mainpath is transporting the 27th bench (bch potted) via row 18 to row 35 (since row 35 is being filled). The picture also shows a clock (time) and some running statistics, such as the average throughput time (for input operation), utilization of the worker, and the potting machine (potstat, in Fig. 2), the number of benches successfully transported by workers 1 and 2 (bch wker 26, 0), respectively, potting machine operating time (363.0), the number of benches in the input queue (0), and the worker average cycle time (335.5). The unit of time was centiminutes.

At the end of a simulation, the model was capable of producing both tabular and graphical output. Table 4 gives a summary extracted from the tabular output of the example. In this example, the traveling time of the workers between the shed and the growing area was less than the time needed to "pot" or "harvest" a bench. Therefore, a bench never had to wait in the buffer during the input operation; and, there was an accumulation of benches in the buffer during the output operation. With a sufficiently large output buffer, the worker cycle times were identical for both input and output operations. On the average, the bench throughput time was much shorter during the input operation than for the output operation. This additional

TABLE 4. Output statistics of the simulation example*

Parameter, unit	Average	Std. Dev.	Minimum	Maximum
Bench throughput time, min				
input operation	6.00	0.19	5.50	6.48
output operation	38.77	16.50	5.32	63.39
Worker cycle time, min				
input operation	3.34	0.30	2.57	4.06
output operation	3.34	0.30	2.57	4.06
Bench waiting time in buffer, min				
input operation	0	0	0	0
output operation	33.47	16.46	0	58.18
Number of benches in buffer				
input operation	0	0	0	0
output operation	9.18	4.57	0	17
Utilization of worker(s)				
input operation	0.92	0.30	0	2
output operation	0.92	0.28	0	1

*Total time of operation: input operation = 729.08 min
output operation = 729.34 min

TABLE 2. Labor flow and materials flow

Input Operation: MaterialFlow (Benches)	Location, Equipment	:Task	Labor Flow (Worker)
	1. Shed, Potting, Machine	:Potting	
	2. Shed, Near Buffer	:P.M. Idle	
Input Throughout Time	3. Shed, Input Buffer	:Storage	
	4. Shed, Buffer to Cart	:Relocation	
	5. Shed	:Transport	
	6. Mainpath,	:Transport	
	7. Mainpath, Cart to Row	:Relocation	Input Cycle Time
	8. Row	:Pushing	
	9. Row	:Walking	
	10. Mainpath	:Travel	
	11. Shed	:Tavel	

Ouput Operation: Material Flow (Benches)	Location, Equipment	:Task	Labor Flow (Worker)
	1. Shed	:Travel	
	2. Mainpath	:Travel	
	3. Row	:Walking	
	4. Row	:Pushing	Output Cycle Time
	5. Mainpath, Row to Cart	:Relocation	
Ouput Throughput Time	6. Mainpath	:Transport	
	7. Shed	:Transport	
	8. Shed, Near Buffer	:Waiting	
	9. Shed, Cart to Buffer	:Relocation	
	10 Shed, Output Buffer	:Storage	
	11. Shed, Harvest Station	:Harvesting	

Note:
P.M. Idle - potting machine idle when the buffer is full
Transport - worker with loaded cart
Pushing - worker pushing bench on racks in a row
Walking - worker only
Travel - worker with empty cart
Waiting - required when the buffer is full

each task of the input and output operations are listed (center column). Also shown in Table 2 are the tasks contained in the bench throughput time and worker cycle time (outer columns) for both input and output operations.

Tasks of the Labor

At the potting machine and the harvest station, tasks are performed on the potted plants without need for transportation. The remaining tasks of input and output operations primarily involve transportation of empty carts, carts with benches, or workers walking alone. The specific order of tasks performed by the worker(s) are described below for both input and output operations in cycles.

Input Operation Cycle:

1. Obtain a bench from the input buffer at potting machine,
2. Transport to the entrance of a bay,
3. Relocate the bench to its final position in the bay,
4. Return to the input buffer, and repeat 1 - 4.

Output Operation Cycle:

5. Obtain a bench from a bay,
6. Transport to the output buffer,
7. Relocate the bench into the output buffer,
8. Return to a bay, and repeat 5 - 8.

Flow of the Benches

The tasks performed by a worker do not always involve the materials (filled benches, in this case) being transported in the greenhouse. Thus, one must consider the flow of individual benches during the input and output operations. The sequence which the benches can flow through the greenhouse layout during an input or output operation are described below.

Input Operation:

1. Bench filled at the potting machine,
2. Bench waiting in the input buffer,
3. Bench obtained from the buffer and transported to a bay in the growing area, and
4. Bench placed in the bay.

Output Operation:

5. Bench obtained from a bay,
6. Bench transported from the growing area to the shed and placed in the output buffer,
7. Bench waiting in the output buffer, and
8. Bench harvested at the harvest station.

The Computer Model

An interactive, animated, micro-computer simulation model was developed, which has the following features:

1. It is user-friendly, requiring no knowledge of computer programming.
2. The data entry is menu-driven, with existing default values.
3. There are multiple choices of greenhouse layouts.
4. Pertinent system parameters such as type of operation, capacity of each bay, transport speed of worker, etc., can be altered.
5. The animated graphics are optional.
6. The time varying data of system parameters are provided during the simulation and a report summarizing the system's performance is recorded into computer storage files.
7. The animated graphics display the real time statistical information about the utilization of machines and workers, transport cycle time of the workers, and the operating time of potting machine and harvest station.
8. After a simulation run, all recorded data may be analyzed and the results may be displayed in graphic and/or tabular forms.

The computer model is written in a combined continuous-discrete simulation language SIMAN and its associated animation package CINEMA developed by Systems Modeling Corp., Sewickley, Pennsylvania. SIMAN is a FORTRAN-based simulation language for modeling general systems. CINEMA animations are based on simulation models written using the SIMAN simulation language.

Many factors may affect the overall performance of the greenhouse potted plant materials handling process, such as the time-and-motion of the worker(s), the probable downtimes and capacities of the potting machine and the harvest station, and the summation of the travel distances corresponding to a given bench transport sequence. Several factors are probabilistic, such as potential machinery failure and time required for relocating benches at the buffers. Therefore, stochastic modeling techniques were used to simulate this combined continuous-discrete greenhouse system model.

Results and Discussion

The capabilities and functions of the simulation model developed were demonstrated using an example. In this

TABLE 1. Cultural practices of greenhouse potted tomato production

Category	Operation	Frequency of operation per crop
Input	Potting and transplant	1
	Placement into bay	1
Maintenance	Plant support	1
	Replanting	1
	Pinching	1
	Pruning	6
	Pollinating	14
	Pest control	8
	Watering/fertilizing	daily
Ouput	Harvest	1
	Termination	1
	Clean-up	1

space (i.e., buffer or queue) required during the input or output operation reduces the valuable production (plant growing) area in a greenhouse. Therefore, a just-in-size buffer/queue is needed to maintain the line capacity, minimize the potential bottleneck of materials transport, and minimize the space required for the work area.

Materials handling involves the real time processes of handling, storing, and controlling of materials. Computer simulation techniques were applied to analyzing greenhouse materials handling systems by Janssen (1987). He initiated the use of a simulation language SIMAN/CINEMA in his study of greenhouse internal input/output transport operations. SIMAN is a FORTRAN based simulation language suitable for modeling discrete and/or continuous systems normally seen in industrial manufacturing operations (Pegden, 1986). CINEMA is an animation software package which creates cartoon-like real time animation of simulations developed with SIMAN language.

Objectives

The objectives of this study were to expand the work of Janssen (1987) and to develop a user-friendly software for simulating greenhouse internal transport systems (input and output operations) for potted plant production.

Greenhouse Input and Output Operations

The Greenhouse Layout

A standard greenhouse layout can be divided into two major parts, the shed (head house) and the growing area (bays), which are connected by a transport path. The shed normally includes an office, rest area, storage area, and work area for stationary machines. Many input operations begin at the shed, while most output operations end at this location. The growing area is a controlled environment which facilitates plant growth.

A schematic diagram of the generalized greenhouse layout and transportation system studied is shown in Fig. 1. The shed contains a potting machine, a storage buffer after the potting machine (for the benches which have been filled with potted plants), a harvest station, a storage buffer before the harvest station (to receive benches from the growing area), bench transporting devices (carts), and workers. The growing area is composed of a number of

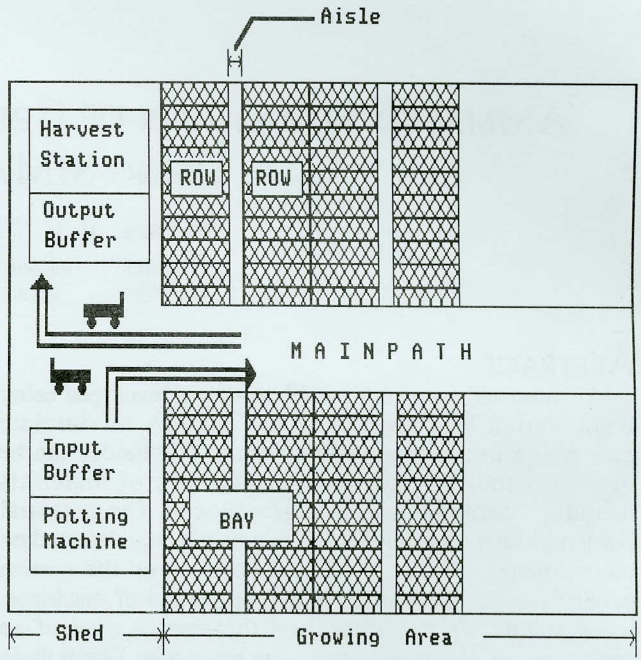

Figure 1–Schematic diagram of the generalized greenhouse layout studied.

adjacent bays. A bay consists of two rows of benches and an aisle in between. The bay aisles connect to a bi-directional mainpath which is located through the center of the growing area and connects to the shed. The benches are the plant production devices in the bay; however, when placed on the transporting carts, they also become a part of the transportation system.

The materials to be transported in the system are potted plants. During the input operation, plants are potted at the potting machine within the shed and placed onto a transportable bench. The bench, which is a rectangular aluminum tray, is placed in a buffer and when available it is relocated onto a transport cart. The cart is then transported along the mainpath to the appropriate bay, and then the bench is relocated from the cart onto the pipe rails of a row in the bay. During the output operation, the benches are transported from the bay to the harvest station within the shed.

Labor Flow and Materials Flow

Labor is utilized within a specific materials handling system for the input and output operations. The transportation of benches in our example requires the input of labor; however, the utilization of labor does not always correspond to the movement of benches. The actions of the labor and the movement of the materials are interdependent; however, each was considered separately for the purpose of evaluating the system efficiencies (such as labor utilization and materials transportation).

The input operation consists of the tasks of moving the benches from the potting machine buffer to the bays, and the output operation includes the tasks of moving the benches from the bays to the buffer of the harvest station. Each was described in terms of the labor tasks and the flow of materials. Table 2 shows the descriptions of labor flow and materials flow for both input and output operations. The location and the equipment used (if necessary) for

TABLE 5. Available time-variation or bench-specific graphs after each simulation run

1. Number of benches in input buffer
2. Number of benches in output buffer
3. Utilization of potting machine, decimal
4. Utilization of harvest station, decimal
5. Utilization of worker(s), number of busy worker(s)
6. Bench throughput time during input operation
7. Bench throughput time during output operation
8. Worker cycle time during input operation
9. Worker cycle time during output operation
10. Bench waiting time in input buffer
11. Bench waiting time in output buffer
12. Bench operating time of potting machine

time was spent in the output buffer.

Twelve graphs were made available to the user after each simulation run. Table 5 contains a list of the available choices. Items 1 through 5 are based on the simulation clock time and Items 6 through 12 are given in terms of each individual bench number. Figure 3 shows the result from choosing Item 2 on the list. The figure gives the number of benches in the output buffer during the entire 729.34-minute output operation where 200 benches were removed from the bay. If Item 5 is chosen after a simulation of an input operation, a portion of the graphical output will look like Fig. 4. The history of the worker utilization can be seen from the figure. Only a part of the graph spanning a portion of the operation time is shown to illustrate the status of the two workers.

Conclusions

1.The combination of SIMAN and CINEMA was helpful in formulating and coding the materials handling and transport problem. Furthermore, they were capable of providing the statistical results of the simulation outcome and dynamic animation of the system.

2. The real time animated graphic display of the model output is particularly useful for the model user to visualize the result of the integration of various components of a complex system. It also helps to verify the model.

3. The model may be used to perform parametric analysis on the greenhouse internal transport system design; especially for those parameters of a probabilistic nature.

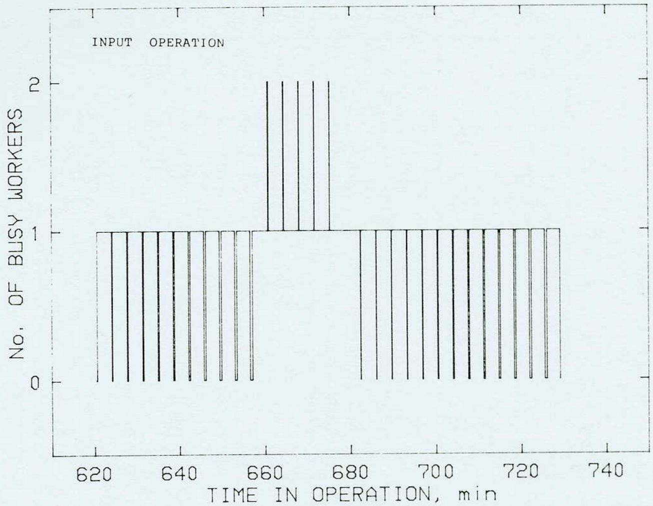

Figure 4–The status of worker utilization vs. operation time.

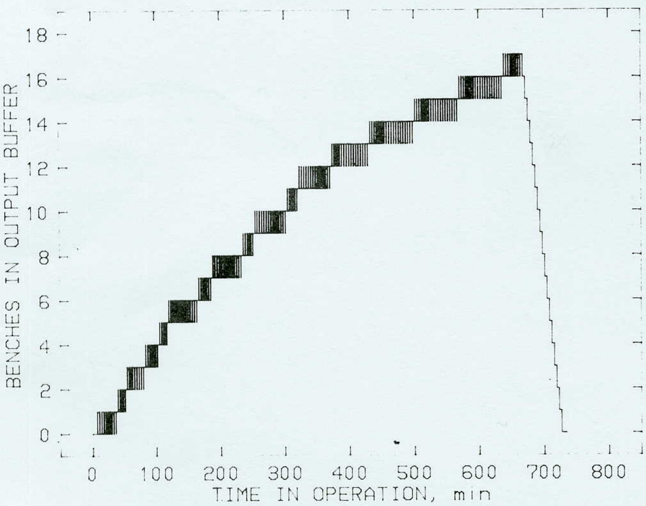

Figure 3–Time variation of the size of the output buffer

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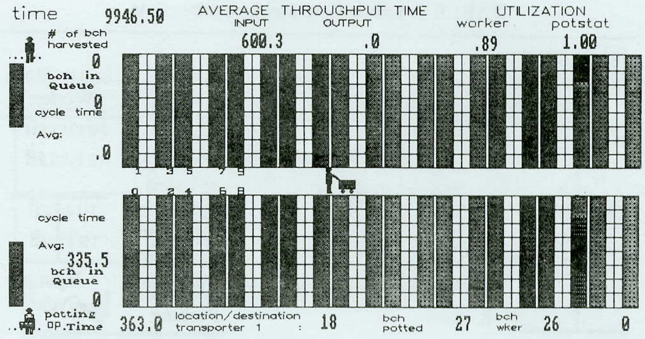

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