Implementing process improvement and automatic systems in a small ornamental plant nursery farm

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Abstract: Process improvement and automatic systems were implemented to a small-scaled ornamental plant nursery farm primarily to tackle the problems of increasing labor cost and turnover. The implementation of automatic systems came with issues different from that in the large-scale farming. A framework formulated from various approaches was applied as the guideline for specialists to work effectively together with the owner and workers in the implementation. Improvements were made to most activities in the nursery process. The irrigating and replanting operations were improved further by changing into fully-automatic and semi-automatic systems, respectively. The solutions were simple, economic, and easy to adapt. The labor time for the original production capacity was reduced by 66%. Other improvements including transportation time, production capacity, working condition, and land utilization were also realized. The improved replanting cycle time and land utilization led to 47% increase in the production capacity. The details of implementation were discussed and the critical issues were addressed.

Keywords: automatic, farm, framework, improvement.

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1 Introduction

Automatic systems had been widely applied in various sectors. For agriculture, studies reported numerous benefits; e.g., boosting labor productivity (Baudron et al., 2015), increasing land productivity (Faleye et al., 2012; Sims and Kienzle, 2006), shortening production lead time (Baudron et al., 2015; Singh, 2006). Recent advancement in technology and significant reduction in price had made them possible and affordable for most applications and gave freedom to designers in creating solutions. Implementing automatic systems to agriculture in some regions, however, was relatively limited due to obstructing factors such as lack of information, equipment and specialists, small and scattering land, limit of capital resource, political interference, and institutional weakness (Negrete, 2015; Van Loon et al., 2020). It was not merely a process of replacing labor with machinery. Several aspects such as operation, technology, tooling, management, adaptation, maintenance and investment had to be taken into account. It required a systematic approach to integrate and to execute all the aspects in harmony. Consequences and problems were sometimes difficult to predict (Harlin et al., 2006). Complications in activities such as establishing specifications, selecting suitable solutions, and estimating investment were common (Borges and Tan, 2017). The keys to success laid in finding, selecting, acquiring, and implementing the right type and level of automation suitable for the needs and the goals (Säfsten et al., 2007). In addition, the work process needs to be improved otherwise wastes and inefficiencies will continue their existences into

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the automated process and multiply if the capacity is expanding (Bortolotti and Romano, 2012). It also needs to be adjusted to allow the implementing systems to work in harmony with humans (Winroth et at., 2006).

Process improvement and automatic systems were applied to a small-scaled ornamental plant nursery farm, as a case study of tackling problems that small agricultural businesses in the region had been facing: i.e., continual increase in labor cost, frequent turnover of labor force, and scarcity of land for business expansion. Discussion was on the details of implementation, assessment, and learned lessons that could be applicable to other small farms of similar nature.

2 Materials and methods

2.1 Plant nursery description

To find a potential candidate for the study, site visits and interviews had been done with the owners of 30 ornamental plant nursery farms across East Java region in Indonesia – this region accounted for 40% of Indonesia's ornamental plant production (BPS, 2020). Information regarding the production capacity, variety and method, and the perspective on automatic systems was collected. An ornamental plant nursery farm located in Batu was selected for this pilot study by three reasons. Firstly, the owner was willing to participate in the study. Secondly, the farm conducted the whole nursing process in-house. Lastly, it shared the similarities in sizes, product varieties, and processes with many nurseries scattering across the region. The farm has an area of 5,000 m^2 and annually produced 35,000 plants from 20 varieties, creating a turnover of 20,000 USD and a market share of 0.1%. Plants were mass-produced to supply local retailers and landscape professionals.

2.2 Plant nursing process

The process of plant nursery (Figure 1) began with propagation. Approximately 70% of plants in the farm were propagated by stem cutting, and the rest were done by air layering. The optimal root propagation required a time period between 20 and 45 days at either the nursing or the parental plant stations depending on the types of plants and the methods of propagation. The propagated plants were transferred to another station where they were replanted in a plastic bag pot filled with growing media (rice husk). They were then sent to rest under the shade for 15 days at the recovery station, before moved again to the growth station where they were nurtured under the sunlight for 3 to 5 months. The plants that had grown to saleable sizes were sent to the display station at the front of the farm.

In order to save cost and justify the requirements of the main buyers, who were local retailers and landscape professionals, variations in the process were controlled. Plants, regardless of the varieties, were intentionally grown in every step to a similar size and form, and they were potted in the same size of plastic bag pot; only plants that were left unsold for a long period of time were replanted in larger plastic bag pots. Only rice husk was used as the growing media.

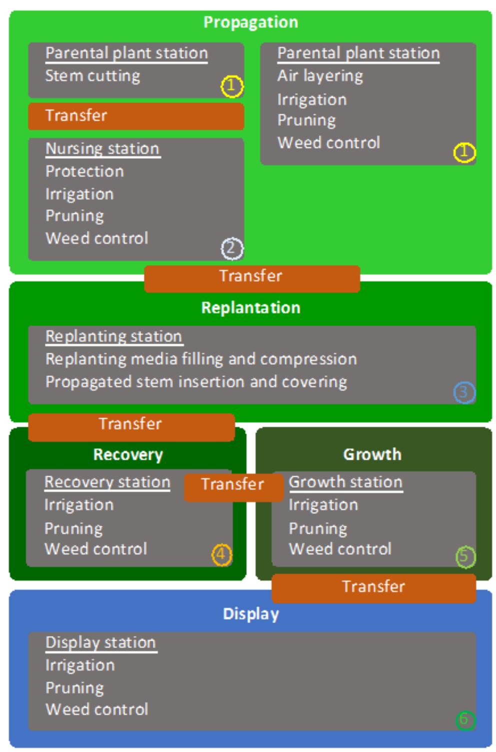


Figure 1 Operations and activities in original plant nursery process

Every dry day, two workers spent two hours on irrigating, and four hours on pruning and weeding. Many transportations were involved in the nursing process. Single-wheel carts were used for inter-station plant transferring; they had to move through ever changing pathways that had never been properly paved. Plants and materials were transferred to the carts by hands without the aid of trays or pallets. All nursing activities were done manually by the assistance of only basic hand tools such as scissors, wooden sticks, scoops, shovels and forks. There was no standard operating procedure. The work quality was always varied.

2.3 Approaches and framework

The procedure of implementing solutions was primarily divided, based on USA strategy (Kapp, 1997), into three stages: (1) understanding and (2) simplifying the existing process; (3) automating after it had been simplified. Tools were employed to drive and fulfil the strategy. They are discussed below and summarized into the framework shown in Figure 2.

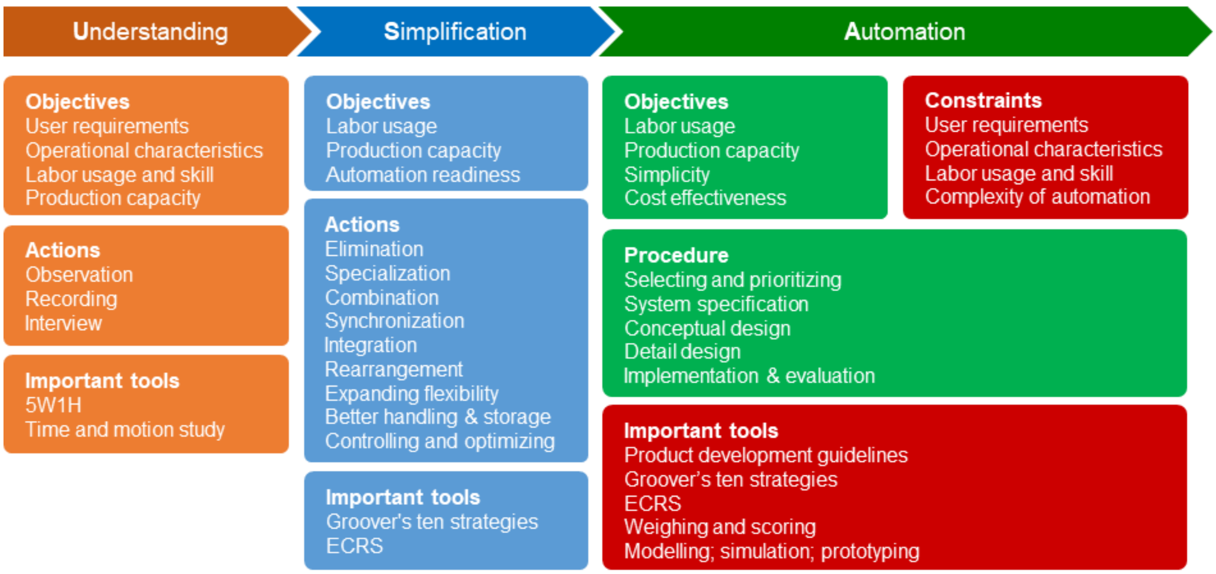


Figure 2 Framework for implementing solution

The procedure started with gathering information, and this was generally done by observation and video recording. In critical cases, for example, the replanting operation, the study went deep into analyzing the seating position and the body movement, and these were found useful later in formulating possible solutions. Questions based on the concept of 5W1H (Weng et al., 2014) were used during interview and discussion with the owner and the workers, and for asking oneself, during gathering and analyzing information, formulating ideas, and identifying solutions.

In the stage of simplification, potential solutions for process improvement were determined, with both ten strategies proposed by (Groover, 2007) and the concept of eliminate, combine, rearrange, and simplify (ECRS) (Kato and Smalley, 2011) as the underlying principles. The activities having no contribution to the value of end products were eliminated; those that remained were improved by combining/integrating, synchronizing, simplifying, tooling, and so on. The reasoning method was primarily used in the decision making. When it was found to be unreliable as there was not a distinctive choice, a weighting and scoring method (Xiao et al., 2007) was then used. Criteria and constraints were drawn from relevant aspects of user requirements, operational characteristics, complications and potential gains.

For the third stage, the procedure started from selecting the operation to be automated, followed by establishing system definitions and specifications, developing and selecting concepts, design and evaluation, and ending at the point when automatic systems operated as intended. The guidelines for product development proposed by Dieter and Schmidt (2013) were followed. The involvement of the owner and the workers remained essential in ensuring that the automatic systems would be readily adopted and would justify the requirements. The ten strategies and ECRS remained the essential tools in seeking the potential solutions and in formulating the conceptual designs. At this stage, selecting the solutions that were suitable to be incorporated and developed further into the final design involved more complicated combinations of criteria and constraints than at the previous stage. Thus, the weighing and scoring method was generally used.

In general, automatic systems having the operational characteristics easily adapted by workers and capable of integrating with the manual parts of operation were the most favorable. The solution, however, had to make a tradeoff between its operational complexity and labor reduction, since it was aimed to be executed by workers with limited skill. Although, a training could be done to help, high turnover rate amongst skilled workers was another problem that the owner was facing. With regard to the potential gains, selecting a solution took into account not only labor-time reduction, but also benefits including cost effectiveness, increased production capacity, reduced rework, and improved quality.

2.4 Solution implementation and evaluation

As the implementation was advancing through the stages, possible solutions, once available, were brought to the owner and the relevant workers for discussion, some were subjected to trials, on the aspects of applicability and working condition, as well as further improvement. After agreed by all relevant parties, the final solutions, except, those associated with the replantation, were initially tried in small sections of the farm to ensure that issues had not been missed; those associated with the replantation were tested alongside the original operation. The workers were trained to work with these new solutions, and the owner and related workers were trained for maintaining the solutions. Training was done by explaining, demonstrating, and extensive hand-on practicing under the supervision of either a specialist or the owner. After which the operations were monitored for difficulties; if needed, assistance was given, to ensure that the workers could eventually work without mistake and accident. The relevant people were interviewed for feedbacks.

After the workers had been familiar with the solution, the labor times spent on the improved activity were measured and compared to that measured on the original version at the beginning of implementation. The time measurements on the improved activities were conducted between two and six months after the introductory period depending on the actual periods and frequencies of occurrences. There was not an attempt to establish the standard operating procedure (SOP); slight variations in the working methods were allowed as much as the new solutions could still retain their purposes. This was to relax the working atmosphere.

The labor times for both original and improved activities were measured on all fulltime workers who were normally assigned for the activities. These workers had direct experiences on the relevant activities between 2 and 9 years. Their performances were given an equal weight in the measurement because of the low-skill requiring nature of the activities. The times of sampling were randomly picked within the actual working period and the numbers of measurements were varied to give the relative accuracies within 10%, at 95% confident level (Sauro and Lewis, 2016). The plant varieties and variations were ignored in the measurements, since both original and improved activities were subjected to these in the same way. In addition, all plants, regardless of varieties, were intentionally cut and propagated to approximately the same size which made the whole process almost identical. Initial time assessment also showed no significant influence of the plant varieties. Idle times or interruptions that commonly occurred, for example, waiting for the ongoing traffic, were considered as parts of the measuring results. Only the measurements that were interrupted by unusual events, such as power interruption, were discarded. If it is not otherwise stated, the above procedure was used for the labor-time measurements reported here and the values presented were the average values.

3 Implementation

3.1 Process improvement

The improvements in the operations which all relevant activities were kept operating manually are discussed below, and those associated with automatic systems are discussed in the following sections. The implemented solutions are summarized in Table 1.

Table 1 Problems and improvements in plant nursery process

Operations	Related problems	Solutions
Stem cutting/ Air layering	Variation in stem cutting size Imprecise bark and cambium cutting Variation in coconut fiber cover Plant damage	Specifically made gauges Use of slotted trays
Replantation	Space required for growing media Variation in filling quantity and density Varied and long operating time Working condition Number of workers varied with production rate Scattering of replanted pots Space required for plant relocation	Semi-automatic replanting system Storing media in the overhead hopper Control of filling level and compressing pressure Repeatable operation Constant operating time Operating with one worker Concurrent operations Workstation redesign Use of pallet boxes
Transportation	Frequency	Use of slotted trays and pallet boxes Combined recovery and growth station Use of foldable shades
	Variations in distance and time from ever changing pathways	Paved, dedicated pathways
	Fatigue caused by single-wheel carts and unpaved ground	Four-wheel trolleys Paved, dedicated pathways
Irrigation	Time consuming Waste of water Plant damage	Fully-automatic irrigating system Control of irrigating time Fixed piping
Weed control	Time consuming	Covering ground with weed control fabric

The activities risking of plant damage were decided to remain manually operated. Although automatic systems capable of performing precise and delicate actions were now viable (Gao et al., 2016; Han et al., 2019), they would not be economically feasible here. The activities that remained entirely original included the weeding and the pruning of individual plants, since there was no other solution found to provide sufficient improvement to these activities. For the stem, bark, and cambium cutting activities, gauging tools were adopted to create the size consistency of cut stems, which should allow for a simpler and cheaper automatic system to be implemented in later stages of the plant nursery process. These tools shared the same design principle, but they were different in the overall dimensions to match the activities and the plant varieties. An example is shown in Figure 3. A type of locally available pallet boxes was employed for the plants that had been potted to prevent damage, to keep them from scattering around, and to facilitate the lifting and transferring. For the same reasons, a type of locally available slotted trays was used with the stems that had been cut from the parental plants. They were also used for containing the cut stems during propagating to gauge the dimension of covering media (coconut husk), and to control the direction of root growth, which would help reduce the variation that the automatic system would have to deal with.

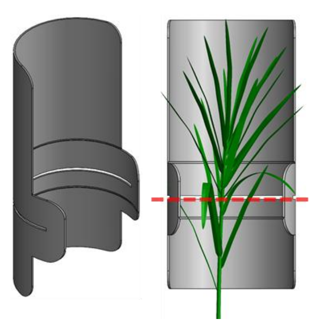
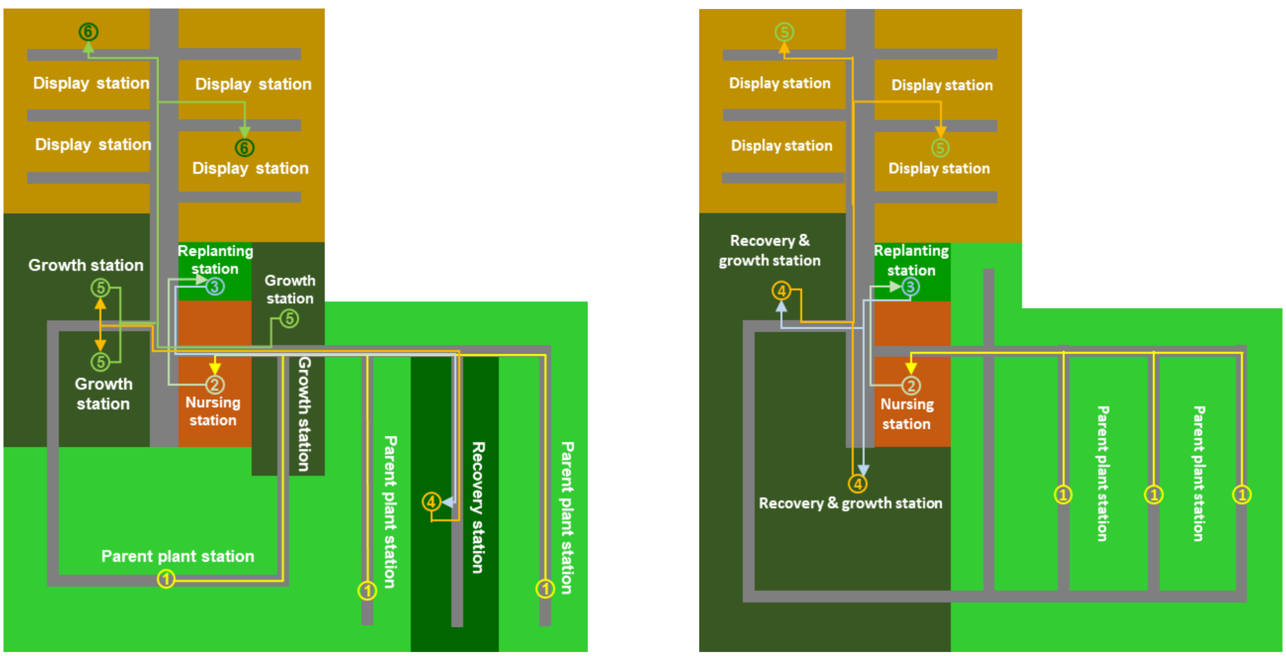


Figure 3 Gauge for stem cutting

Three possible solutions including machine weeding, spraying with herbicide, and covering with a fabric were considered for controlling the weed on the ground. However, the machine weeding could damage the plastic bag pots and the herbicide could cause yellow spots on the plant leaves. The weed control fabric was therefore the preferred choice, because it had no apparent impact on the product quality and was just slightly more expensive.

Transportation between stations could be almost entirely removed by replanting the cut stems directly into the pots without prior nursing and left in the same place until reaching the saleable sizes. However, the solution would have required large investment for all utilities necessary and increased the production time by 22%. A compromising solution was implemented and that was combining only recovery and growth into one area. This required only installing manually operated, foldable shades.

For the transportation between stations, the first improvement involved the proper allocation of spaces for pathways and paving them with hard packing materials. The existing single-wheel carts were replaced by a type of locally available four-wheel trolleys capable of securing the slotted trays and the pallet boxes in double stacks. The farm layout was also re-arranged to bring the same activity into one large area. The use of land was reorganized and empty spaces scattering across the farm, especially in the parental plant station, were relocated together into areas large enough to be utilized (Figure 4).



(a) Original (b) After rearrangement

Figure 4 Plant nursery farm layout

3.2 Fully-automatic irrigating system

The irrigating operation was labor-intensive; it consumed four labor-hour every day. Considering the cost and the availability of necessary equipment and the fact that no high skill requiring activity was involved, the automatic solution was so simple and cheap. The implemented system adopted the existing main plumbing and pumps to minimize the investment cost. Only extra piping, sprinklers, water pressure regulators, timers, and solenoid valves were required to become fully automated. Schematic diagram of the system is shown in Figure 5.

The system was primarily aimed to replace labor. However, it also needed to produce the water droplet that was sufficiently coarse and carried adequate energy so that the wind would not significantly alter its trajectory, and at the same time did not cause any damage to the plants. In addition, the sprinkler nozzle openings needed to be adequately large, otherwise they would be clogged regularly by mineral deposit and algae growth. After several trials with different sprinklers, positioning, and water pressures, a type of rotary impact sprinklers with a fixed nozzle opening of 3 mm was selected and installed at 1.5 m above the ground and 6 m apart (Figure 6). The amount of water delivered could be adjusted through setting the watering time on the timer. The system allowed the separated zones to be irrigated independently and outside the working hours.

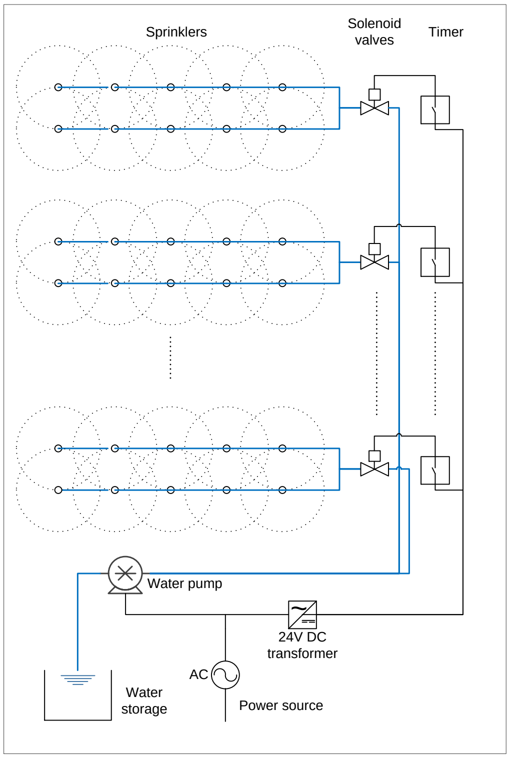


Figure 5 Schematic design of fully-automatic irrigation system

Figure 6 Automatically controlled sprinklers installed at parental plant station

3.3 Semi-automatic replanting system

The replanting operation was more complex than the irrigating operation. It was a combination of delicate and simple activities. The first information essential to designing was the results of motion and time study (Kanawaty, 1992) conducted on the individual activities. For the reliability of the results, only the performances of experienced workers were used. Their performances were given an equal weight.

The original replanting operation was divided into four groups of activities: filling, compression, insertion and relocation. At full production, two workers were required at this station. The propagated plants were piled around the workers. The growing media came in 25 kg sacks. At the beginning of a replantation period, they were transported and poured on the ground to create a pile large enough to last several days of replanting. The replanting activity began with the workers scooping and filling the growing media into the plastic bag pots, and lightly pressing the media to a required density (see also Figure 7a). The same workers then inserted the plant stems into the pots, and covered the top of the pots with more media (Figure 7b). Finally, the finished plant pots were relocated to free the working tables for the next replantation; they laid scattering in the area and later had to be individually picked to the cart. The activities were only assisted by basic tools such as scoops and wooden sticks. The workers seated low near the ground in order to reach the growing media, and they needed to move often as the growing media in the surrounding was exhausting.

The average times spending on the four activities (see more detail in “Assessment of semi-automatic replanting system” section) were presented in the time descending order on Pareto diagram (Grosfeld-Nir et al., 2007) to assist the decision making. The cumulative line in the diagram (Figure 8) showed that more than 80% of the total replanting time was spent on filling and compressing. These activity groups, thus, were strong candidates for implementing an automatic solution. Since the activities did not have direct engagement with plants and the variations in size, shape and form of the plants could be kept at minimum through the measures implemented in the earlier stages, the solutions were relatively simple. On the other hand, automating the insertion would not be simple; proposed solutions would have to effectively deal with precision and delicacy. Nevertheless, the insertion together with the relocation accounted for less than 20% of the total operating time; automating them was estimated to be more costly than the benefit it offered.

(a) media filling and compression (b) plant insertion

Figure 7 Main parts of original replanting operation

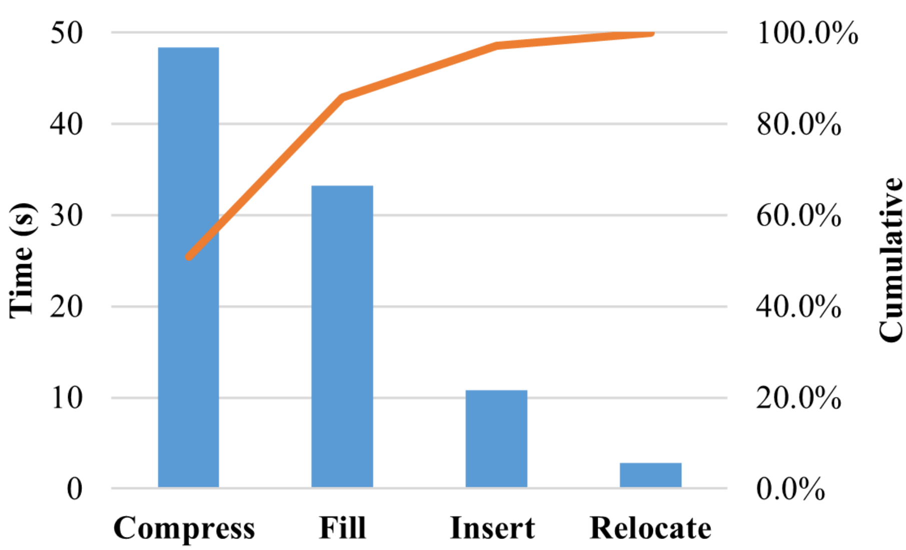


Figure 8 Pareto diagram showing the time spending on original replanting activities

Design was, therefore, strategized for a semi-automatic system that automated the compressing and the filling activities, but kept the inserting and the relocating activities operating manually. The system's specifications were primarily drawn from user's requirements and operating characteristics. In addition, aspects including working condition, ease of operating and maintenance, and energy efficiency were also taken into account. Possible solutions were conceptualized to be as simple as possible, with the aids of certain elements in the design for everything (DFX) approach (Benabdellah et al., 2019), notably, minimizing the numbers and varieties of parts and materials, using locally available parts, and adopting designs that could be made locally. Due to the complexity of the design's criteria and constraints, selecting solutions were relied on the weighing and scoring method.

Table 2 is given as an example on the selection process. It involved the applicator for the compressing action. Thirteen criteria were created based on the information obtained from observation and interview; they were also used in the selection of other components. The priority scores for the individual criteria were formulated based on their importance by the farm owner and the specialists. A score mutually agreed by both parties was given to each criterion according to its compliance. The range of scores was between 5 and 1: scores of five and one were given for the most and the least compliances, respectively. The individual scores were then multiplied by the corresponding priority scores, and the results were then summarized into the total score. The solution having the highest total score was the strongest candidate. In this case, it was the pneumatic piston.

Table 2 Selection of applicator for compressing action

Potential solution	UR1[a]	UR2[b]	OC1[c]	CX1[d]	PG1[e]	CX2[f]	PG2[g]	UR3[h]	UR4[i]	UR5[j]	OC2[k]	CX3[l]	PG3[m]	Total score
Priority	5	5	5	5	5	4	4	3	3	3	3	2	2	
Hydraulic piston	4	4	3	3	3	4	4	5	5	5	5	3	5	193
Pneumatic piston	5	3	4	4	4	5	5	5	5	4	5	4	4	213
Screw press	3	2	5	2	2	2	3	3	3	3	4	2	3	139
Die press	2	5	2	5	5	3	2	4	2	2	2	5	2	159

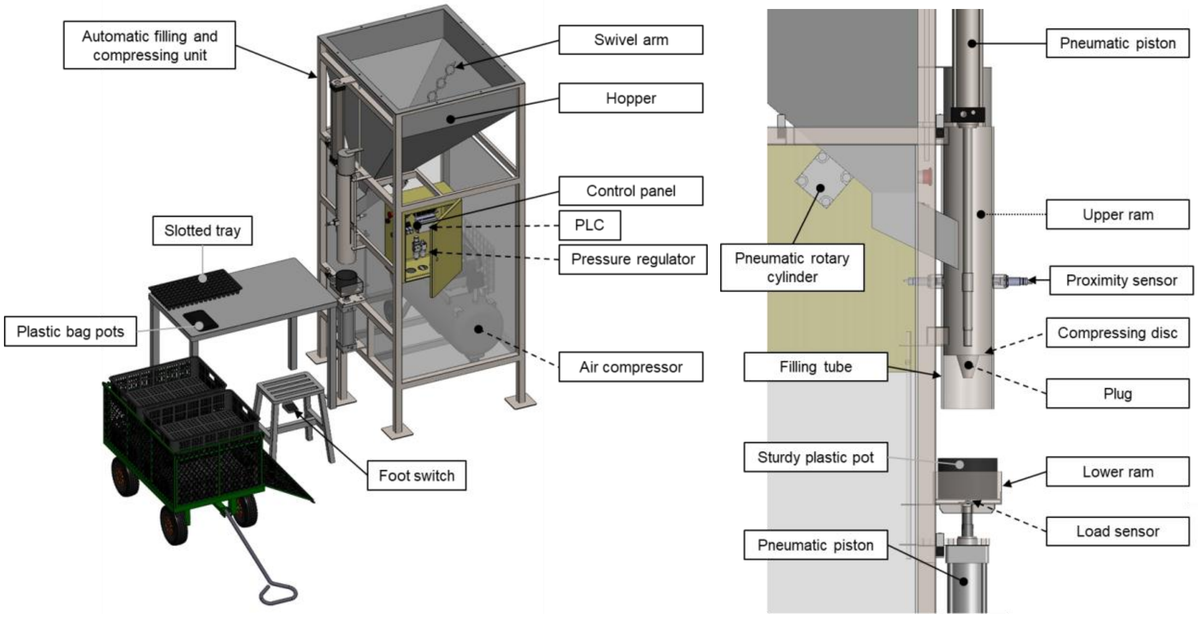
Note: URX: user requirement; OCX: operational characteristic; CXX: complexity; PGX: potential gain; [a]UR1: cost of components; [b]UR2: durability; [c]OC1: safety; [d]CX1: component complexity; [e]PG1: production capacity; [f]CX2: required skill of worker; [g]PG2: required number of workers; [h]UR3: suitability for media handling; [i]UR4: integrating with other activities; [j]UR5: working condition; [k]OC2: design conformance; [l]CX3: ease of maintenance; [m]PG3: energy usage.

The selected design solutions were combined into a single integrated system and evaluated for the integrity and potential errors such as conflicting movement, entanglement, collision, and mismatch. The overall design was presented to the owner and workers for assessing the functionality. Structural stresses and strains of the critical components, especially, those around the filling tube, were analyzed by finite element simulations for integrity and safety. After passing all changes and assessments, the detail drawings were issued to a local workshop for manufacturing.

In the final design, most of filling and compressing activities were taken over by automation. As a result, the replanting cycle was reorganized for the synchronization of the automatic and the manual activities; To minimize the risk of accident, the activities that involved the interaction between workers and the system were arranged to only take place either before or after the engagement of the automatic cycle. Figure 9 compares the workflows in the original and the improved replanting operations. The working station was designed around the automatic filling and compressing unit as shown in Figure 10a. The worker now seated in an upright position on the chair to operate. The table was the space where the manual activities were executed, and for placing the slotted tray and the plastic bag pots. The pallet boxes were placed on the trolley located on the left-hand side of the worker. The container for the growing media used for covering would be securely attached to the unit on the right-hand side of the worker, just below the control panel.

(a) original (b) improved replanting operations

Figure 9 Work flow



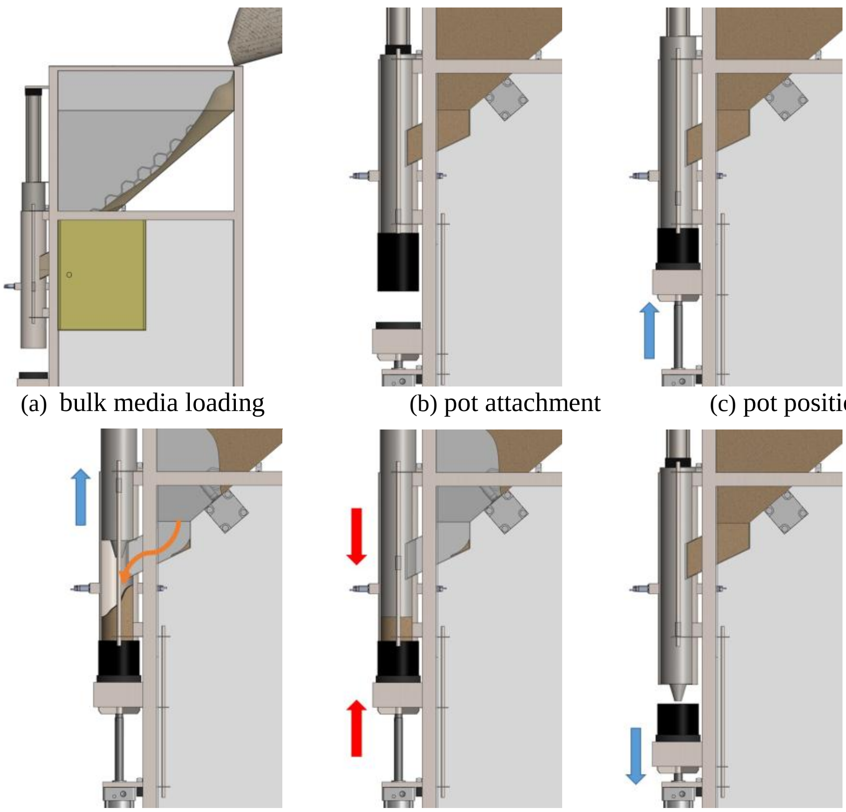
(a) isometric (b) side views

Figure 10 Configurations of replanting station and compressing and filling unit

The unit was basically a pneumatic-driven system with a built-in air compressor. The compressing and filling actions were primarily the combined results of the movements of the upper ram in the filling tube and the lower ram at the base. (See also Figure 10) The lower end of the upper ram was attached with a compressing disc. The plug shape at the center of the disc was used to create a hole impression on the compressed media for plant insertion. The top of the lower ram was fitted with a bag mold – currently used a sturdy plastic pot with the dimension to match the bag pot – used for securing the plastic bag pot during the filling and compressing activities. The rams were separately driven by pneumatic pistons. The automatic cycle was managed by a programmable logic controller (PLC) installed inside the control panel. Two buttons were located on the control panel: one for resetting, which returned the system to the starting position after a faulty incident, and the other for emergency, which immediately cut off the power supply. A complete cycle required a single tap on the foot switch to activate; the cycle would start only if both rams had been rested in the starting positions. The pressures of compressed air supplying to the pistons were maintained at pre-settable values by pressure regulators. The levels of pressure used in compressing the growing media to the required density only produced the net force similar to that exerted by hand in the original process. No risk of serious injury if a body part entangling between the rams was found in the trials. However, to avoid an unauthorized or accidental adjustment which could lead to a serious injury, the pressure regulators were installed inside the control panel. In addition, a load sensor was attached to the lower ram for preventing the overloading.

The growing media was loaded directly from the sack into the hopper situated at the top. The filling of media into a pot was then done automatically through the filling tube by the gravitational force and with the assistance of a swivel arm: the filling level was exacted by the proximity sensor and could be changed by relocating it; the swivel arm was continuously driven by a pneumatic rotary cylinder controlled by the same PLC. The hopper was able to contain up to one sack of growing media, which would make about 100 replants before a refill. The limited volume of the hopper was intended by the owner to shorten the time that the growing media was exposed to the environments. Since the height of the unit needed to match the upright seating position, filling the hopper involved a meter climb from the ground. An earth ramp built next to the unit was the solution preferred to a staircase by both owner and workers in terms of convenience and safety.

Once a worker filled up the hopper (Figure 11a), the system was ready to operate. A cycle of replanting started with the worker manually attaching a plastic bag pot to the bottom of the filling tube (Figure 11b). The worker then tapped the foot switch to activate the automatic cycle, which then continued by itself to the end without the need to keep the foot on the switch. It began with the lower ram raising to lock the pot in position (Figure 11c). The next step involved the upper ram moving up to let the media flown into the filling tube (Figure 11d). The media was then compressed by both rams (Figure 11e). In the last step, the lower ram retracted, and when it reached the bottom (Figure 11f) the automatic cycle was ended. Once the pot was removed, the system was ready for another replanting. During the engagement of automatic cycle, the same worker used this period to insert a plant into the pot that had just been finished from the previous automatic cycle (Figure 12), covered it with more media taken from the nearby container, and placed it in the pallet box.



(a) bulk media loading (b) pot attachment (c) pot positioning

(d) media filling and metering (e) media compression (f) pot retraction

Figure 11 Working sequence of semi-automatic replanting system

Figure 12 Worker manually inserting plant into pot in parallel to automatic replanting cycle.

4 Results and discussion

This section discussed on the key elements and the assessment results of the implementing solutions. The process of plant nursery after the implementation is summarized in Figure 13. The labor times spent on the original and the improved activities are compared in Table 3. Training and adapting times are shown in Table 4.

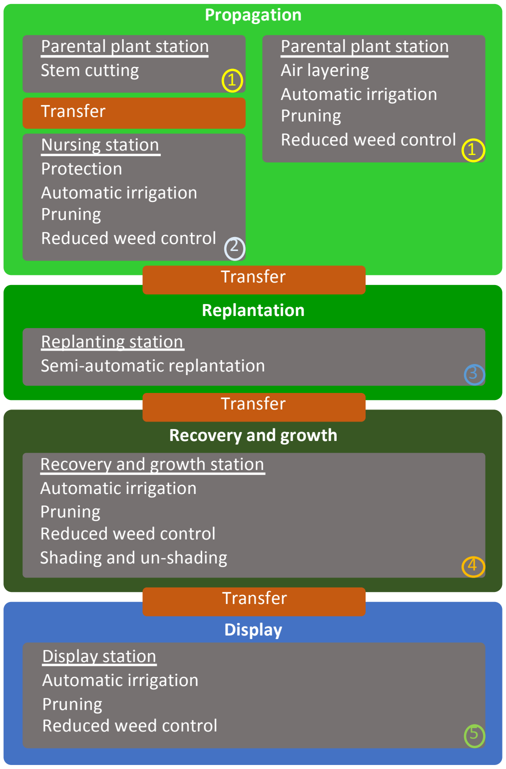


Figure 13 Operations and activities in plant nursery process after improvements

Table 3 Labor time measuring results for original and improved activities

Operations	Average labor-times per unit[a]		Annual quantity[b]		Labor-times per year[c]	
	Original	Improved	Original	Improved	Original	Improved
Stem cutting	54 s	30 s	24,500 plants	24,500 plants	368 h	204 h
Air layering	300 s	180 s	10,500 plants	10,500 plants	875 h	525 h
Growing media preparation	18 s	18 s	400 times	400 times	2 h	2 h
Replantation	107 s	32 s	35,000 plants	35,000 plants	1,040 h	333 h
Actual replantation					1,040 h	311 h
Setup	-	1 h	-	3 times	-	3 h
Daily inspection	-	5 min	-	50 times	-	4 h
Weekly cleaning	-	1 h	-	15 times	-	15 h
Transportation					217 h	151 h
To nursing station	1.9 s	1.9 s	24,500 plants	24,500 plants	13 h	13 h
To replanting station	1.7 s	1.7 s	35,000 plants	35,000 plants	17 h	17 h
To recovery station	5.6 s	5.1 s	35,000 plants	35,000 plants	54 h	50 h
To growth station	5.5 s	0 s	35,000 plants	-	53 h	-
To display area	8.2 s	7.4 s	35,000 plants	35,000 plants	80 h	72 h
Irrigation	2 h	5 min	252 days[d]	252 days[d]	1,007 h	21 h
Ground weeding	112 h	58 h	5 times	2 times	560 h	116 h
Shade folding and unfolding	-	1 h 30 min	-	3 zones x 4 times	-	18 h
Total annual labor time					4,069 h	1,370 h
Total reduction in annual labor time						2,699 h

Note: [a] From actual measurements; [b] estimated from past figures; [c] average labor time per unit multiplied by annual quantity, and change to hour unit; [d] the average of dry days given by various weather information sites.

Table 4 Training and adapting durations for implemented solutions

Solutions	Training duration[a]	Adapting duration[b]
Gauging tools	30 min	2 h 30 min
Four-wheel trolleys	15 min	30 min
Slotted trays	20 min	30 min
Pallet boxes	15 min	30 min
Foldable shade	1 h	5 h
Weed control fabric	1 h	3 h
Combined station and layout rearrangement	-[c]	-[c]
Fully-automatic irrigation	15 min	12 days
Semi-automatic replantation	2 h	40 h

Note: [a] Longest time required for operation training, or installation training in cases of foldable shade and weed control fabric; [b] longest time required to work correctly and seamlessly; [c] no training, but brief explanation given.

4.1 Assessment of weed control fabric

Weeding the entire farm originally required 112 labor-hours at a time and was done 5 times a year, taking 560 labor-hours a year. Observations done after installing the weed control fabric showed that the weeding frequency could be reduced to 2 times a year. That the weeding interval was extended long enough for it to be done after plants had been relocated to another station. Thus, plant rearranging activities originally taking place during weeding were eliminated, and that further reduced the labor time by 48%. In total, the use of weed control fabric removed 444 hours or 79% off the labor time. However, every 5 years, a part of this reduction would be offset by 75 labor-hours required for replacing the fabric. An additional benefit was that the ground drainage pattern no longer needed regular repairs, because the fabric protected it from erosion produced by irrigation and rain, but information was insufficient to estimate the labor time saving.

It took a person up to 1 hour to train and 3 hours to be familiar with the important aspects in the use of the fabric which included proper ground weeding to prevent damage to the installing fabric, arranging the fabric to avert waterlogging, and walking with suitable shoes over the fabric. No maintenance was required. Small damages could be left unrepaired, while damages large enough for weed to grow could be easily fixed by patching with the same fabric.

4.2 Assessment of transportation-related improvement

Transportation was improved in several ways including modification of pathways, uses of slotted trays, pallet boxes and four-wheel trolleys, combination of recovery and growth stations, and rearrangement of farm layout. The use of single-wheel carts in the original inter-station transportation was found to be the activity mostly complained. The carts were very tiresome to operate as they had to be lifted, held, pushed and navigated all at the same time through poorly-packed, uneven pathways. The new pathways opened the possibility of using four-wheel trolleys which were more secured and easier to maneuver. By using the trolleys together with the slotted trays and the pallet boxes, plants were securely transported with less risk of falling off the cart and squashing each other. Random inspection during the introductory period uncovered that plant damages were reduced by 30%. Although most damages did not make the plants rejected, the damage reduction potentially improved the consistency of plant propagation and growth, and reduced the number of reworks.

For each travel, the trolley was capable of transporting up to 160 propagated plants or 30 potted plants, which was similar to what the single-wheel cart was capable. The trolleys' capacity could have been used to carry more plants but they were limited by the weight that the workers felt comfortable with. They also facilitated lifting and the transferring within stations where the pathways were too narrow and uneven to operate the trolleys. There were no more plants scattering around which workers had to bend over several times a day to pick up. The containers did not require maintenance, while the trolleys' wheels needed regular cleaning and re-greasing in the same way as those of the single-wheel carts did. Broken containers and wheels could be easily replaced since they were commercially available and relatively cheap.

Combining the recovery and the growth stations eliminated the transportation of plants between them. However, new activities occurred as a result, and that included unfolding the shade for the recovery period and folding for the growth period. The annual labor-time used for these was 18 labor-hours, which was a third of the labor time saving contributed by the combination. It was used for manual rolling and unrolling the shade along the roof frame. The shading had no moving mechanism, and did not require maintenance. Damage could be avoided by taking precaution during installation, folding and unfolding; if occurred, it could be treated in the same way as that on the weed control fabric. The shading needed to be replaced every 5 years, and the time required was 4 labor-hours.

The rearrangement of the farm layout appeared to have little effect on the transportation time. However, the farm layout became more organized and less confusing. A suggestion of adding necessary signs to all areas was given as a further improvement on this matter. Grouping the empty spaces gave 20% extra space to the combined recovery and growth station, which was the area crucially determining the farm's production capacity.

With all related improvements combined, the annual labor time in transportation was reduced by 30%, i.e., from 217 to 151 labor-hours a year. The majority of the reduction was contributed by the combination of the recovery and the growth stations. The contribution from others was little probably due to the fact that they did not significantly change the transporting capacities, distances or speeds.

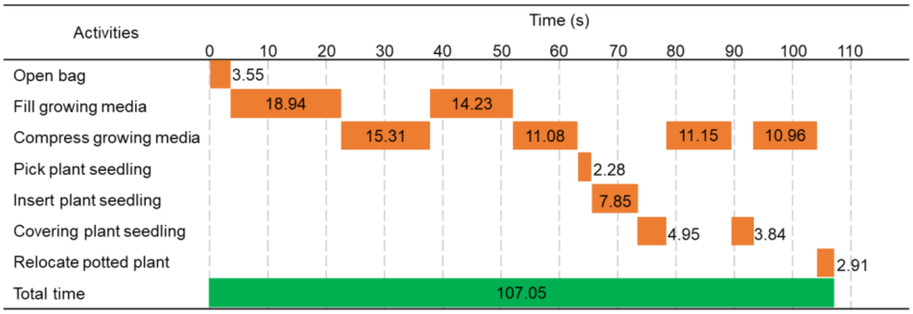
4.3 Assessment of fully-automatic irrigating system

The fully-automatic irrigating system almost entirely substituted 1,007 annual labor-hours of the manual irrigation. The worker only spent about 5 minutes a day – totally, 21 labor-hours a year – to inspect the system, to clean nozzles as a precaution, and to deactivate the system if there had been enough rain during the day. The system gave an annual saving of 986 labor-hours, the highest saving amongst all solutions. Plants were found to be irrigated more thoroughly and evenly, and without the risk of damage from water hose movements. Other activities in the farm were able to start right away, as the irrigation could be scheduled to take place before the working hour began. The irrigating duration could be set for the correct amount of water, providing that all plants in the same zone required the same amount of water. The irrigating durations were set based on the volumes of water that had been delivered by manual irrigating.

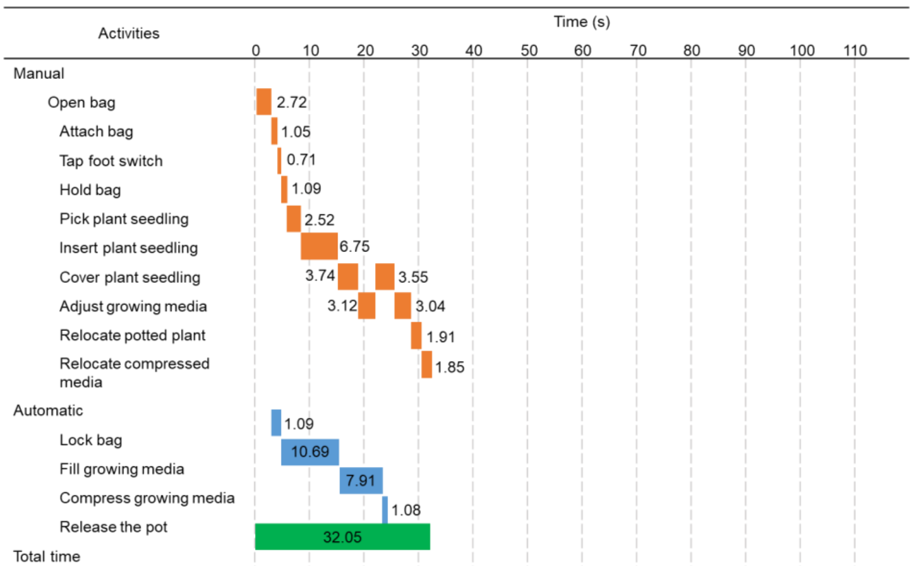
Training to operate the system required 15 min at most. The adapting period was however the longest amongst all solutions, because the actual irrigation only occurred once a day. All repairs could be done in-house, and with spare parts available locally.

4.4 Assessment of semi-automatic replanting system

The semi-automatic replanting system was a combination of, the semi-automatic filling and compressing machine, and the rearrangement of working cycle and station. The activities in the replanting operation were originally executed in a sequential manner (Figure 14a). In the new replantation, they were divided into two groups including those associated with automation and those remained entirely manual. The two groups of activities were executed alongside, and the new working cycle became that shown in Figure 14b. The results from the motion and time study (also in Figure 14) showed that the time required for completing a replanting cycle was significantly reduced, and that was from approximately 107 to 32 seconds or by 70%. The automatic cycle apparently took less time than the manual cycle, resulting in a machine idle time of 11 seconds within a single cycle. However, there was virtually no idle time between replanting cycle, and the next replanting cycle was able to start straightaway after the previous cycle finished. It is also important to note that, although the repeatability, as indicated by the standard deviations in the labor-times measured, for the other operations was not significantly different between those before and after implementing the new solutions, the standard deviations of the labor-times for the replantation was found to be clearly reduced after the introduction of the semi-automatic system; they were reduced from 7.6 to 1.4 seconds. These was probably contributed by not only the application of the automatic sequence itself but also the improved consistency of the inputs and the rearrangement of the working station.



(a) Original



(b) improved

Figure 14 Replanting cycles and times

The training and adapting periods were much longer than those for other solutions because the workers had to adapt themselves to the working arrangement and the automation, which they had never been experienced. Only the owner was trained and allowed to do the setup. The automatic unit required 1 labor-hour in average for full setting up included installing/replacing the compressing disc, plug and bag mold, and optimizing the growing media filling. The setup was estimated to be done for no more than 3 times a year for the current plant varieties and the production schedule. Every day at the beginning of replanting session, 5 minutes were spent for general inspection. The filling tube assembly and the hopper needed once a week with 1 labor-hour for cleaning. This was considered essential to prevent their mechanisms from clogging and seizing. The maintenance of other critical components was outsourced to a contractor, and it was scheduled to be done outside the replanting periods.

An annual production of 35,000 plants would be completed in about a third of the labor time used by the original replanting; i.e., 333 labor-hours compared to 1042 labor-hours. As a result, only one worker was needed at the station even for high demand periods. In addition, the automatic filling and compressing gave every pot with the correct densities of growing media, independent from skill, strength, tiredness and emotion of workers. The working condition was improved by the upright seating position (compare Figure 12 with Figure 7a) and the new workstation arrangement, where all necessary equipment and materials were within hand reaches.

Direct feeding of growing media through the hopper helped overcome problems originated in piling the growing media on the ground. The space required for replantation was reduced by 45%. The time that the growing media stayed outside the sack exposing to the environments was shorten from 5 days at the longest to no more than two hours. The worker relocations which had originally occurred hundreds of times a day were entirely eliminated.

Time required for transporting and loading the growing media into the hopper was, however, found to be virtually unchanged: in average, it was 18 seconds per sack. These were thought to be contributed by two major factors with opposing impacts. Firstly, although the worker needed to travel the same horizontal distance as in the original replantation, here they had to travel up for 1 meter in order to load the hopper. This gave a negative impact for the time and the work load. Secondly, the worker filled the hopper with no more than one sack at a time, and the fillings were more than one hour apart. This had the positive impacts considering the original method which the worker had to carry up to fifteen sacks consecutively.

All propagated plants prepared by stem cutting and about half of those prepared by air layering, i.e., 85% of the total production, were replanted by the system using the setup and the operating cycle described earlier. This was partly achieved by the assistance of the gauging tools and the slotted trays, and the decrease in cut stem damages which improved the size consistency of root spread to some extent. For the other part, this system's setup was capable of coping with sizes up to 120% of the sizes of the hole impression on the compressed media. For plants with wider root spreads, if turned up intermittently during the production, the worker could manage by manually enlarging the hole before inserting the plant. The replanting cycle time would increase from 32 to 38 seconds and with a little larger standard deviation (1.4 seconds versus 2.0 seconds). To replant them in large quantity, the automatic unit would be re-setup to automatic filling only half the pot and manual filling the rest after plant insertion. This was used for the remaining 15% of the total production. The latter solution was found to take slightly longer (39 seconds) than that of the previous solution, but with the levels of standard deviation (1.5 seconds) similar to those of the normal operation. Another possible solution was suggested and that involved changing the plug on the compressing disc to a larger size. It had yet to be subjected to trial.

The system was designed to work with the plastic bag pots used for the main production which were always in the same size. Pots in larger sizes were used in the farm only for replanting the plants that had been left unsold for longer than a year. Due to their quantity and replanting schedule, it was found to be uneconomical to automatically replant these unsold plants. Anyway, the system could be modified to work with other pot sizes, which may be required in the future. It would require replacing the bag mold, the filling tube, and the compressing disc with sizes to match the pot. The cost of a new set was estimated to be 175 USD.

4.5 Overall assessment

Information on Table 3 shows that the total annual labor time required for the original production capacity was reduced by 2,699 labor-hours, and this was equal to 66% reduction. Nearly 65% of the reduction was contributed in some ways by the use of automatic systems. One worker could possibly be removed from the farm – estimated based on 7.5 working hours a day and 220 working days a year. However, it was agreed from the beginning and considered as a betrayal if anyone was to be discharged, after all their contributions and commitments given to the project. Nevertheless, the farm still gained benefits from the labor time reduction. The workers had time to pay more attention on other responsibilities, especially, precise and delicate tasks such as pruning, pot weeding, and plant propagation. Work overload and part time employment which had always occurred ahead of the high demand periods, and could last up to 4 weeks at a time, was not happened any longer. The 20% extra area that was given to the recovery and growth station eventually became fully utilized. As a result, the overall production capacity was found to increase by 47% – the same spot of land could be repeatedly used to grow 2 to 4 plants a year. The owner and the workers even had the spare time to make further improvements.

In terms of labor turnover problem, since the operations and the maintenances of the solutions were kept simple and they were able to manage by low-skilled workers, training of new employees and their adaptations should not become issues more significant than before. Initial interviews with the owners of several farms revealed that work load and payment appeared to be the primarily reasons for the frequent labor turnover, which were in agreement with Hobbs et al. (2020) and Juliarti et al. (2018). If they were the cases, the improved working conditions should give people more reasons to come and the existing workers less reasons to go.

It is worth mentioning that the replanting system had the potential to produce approximately 130,000 plants a year – an estimation based on 7.5 daily working hours, 220 days, and 75% of theoretical maximum capacity. Although the farm was able to partially utilized it due to the limited land available for plant recovery and growth, it opened a new business opportunity. That was making the excess capacity available for hire by neighboring farms.

4.6 Implementation cost and payback period

This implementation costed the owner 3,000 USD in total, in which 800, 950 and 1,250 USD were accounted for process improvement, fully-automatic irrigation system, and semi-automatic replantation system (see the details in Table 5). It was spent on parts, components, manufacturing, and labors that were used for in-house work. The static method commonly used for calculating the payback period of investment (Götze et al., 2008) was adopted for calculating the payback period of these expenses.

Table 5 Estimation of payback period for implementing cost

Cost and saving	Process improvement	Fully-automatic irrigation system	Semi-automatic replantation system	Total
Cost of implementation	800	950	1,250	3,000
Parts and components	754	842	859	2455
Manufacturing	-	-	380	380
In-house labor	46	108	11	165
Annual saving from labor reduction[a]	452	444	318	1,214
Annual cost of operating	10	30	110	150
Utility (electricity)[b] and consumables	0	7	60	67
Maintenance[c]	10	23	50	83
Net positive saving[d]	442	414	208	838
Payback period[e]	1 year 10 months	2 years 4 months	6 years	2 years 9 months

Note: If it is not stated otherwise, figures are in USD. [a] Corresponding labor time savings multiplied by 0.45 USD labor cost per hour; [b] extrapolated from the differences between the previous and the current electricity bills of the same month for 3 months; [c] 5% of the cost of movable components; [d] annual saving from labor reduction minus annual cost of operating; [e] cost of implementation divided by net positive saving.

For the calculation, the annual savings estimated from the reductions in labor time used for the original production capacity were the only benefits taken into account. The other financially-quantifiable benefits, such as that from the plant damage reductions and the increased production capacity, were excluded due to the lack of information necessarily required for the calculation, such as the farming's actual cost and overhead. The costs incurred by operating the implementing solutions were from the extra electricity, which was the only extra utility expense, required to operate the automatic systems and for consumables and maintenance. Those already existed before the implementation were not parts of the calculation.

The calculation showed that the investment made by the owner on the implementation would be repaid in full within approximately two years and nine months. This was well before the equipment would reach the end of life. The calculation was, although, hypothetical since not a single worker was actually discharged from the farm, and it was partially based on certain assumptions and exclusions. It represented the bottom line, and was intended as the view into the financial feasibility of the implementation, which the solutions would pay back over a reasonable period of time from their benefits.

4.7 Key elements in implementing automatic systems

Implementing automatic systems into small-scaled farming is challenging in its own way. Small farms, like the case study, have to face the combination of cost and labor constraints different from those faced by large-scaled farms. They have limitations in the benefits they can offer to attract high-skilled workers and in the scale of budget to match a large investment. As of the agricultural nature, the systems have to deal with materials that are delicate and very much varied. The paradox is that delicacy and variation usually require a complex and expensive system that is not economically justified by most small farms. Even more so, implementing an off-the-shelf or a generic automation did not always give the optimum benefit, because it sometimes came with issues such as work and terrain incompatibilities, engineering difficulties, unreachable technical supports, unavailable repair services or replacement parts, and maintenance costs (Mrema et al., 2014).

Finding the operation where a simple and economic system can make significant impact is thought to be the first key element in the case like this. Benefits on production capacity, productivity, quality and economic justification, for examples, can be realized by automating the simple repeating parts of the operation such that the workers are relieved and allowed more time to focus on more delicate activities. The degrees of simplicity and economy may be subjective. However, a sufficient understanding of the underlying reasons was found very crucial in finding the practical and feasible solution. It takes time, effort, and several visits, especially, on the kind of farming that is unfamiliar. Strong commitments of all parties, especially, the owner, workers and specialists, throughout the project are needed. Since the details of operating procedures are usually not documented, well-organized observation, recording, and interview are necessary. The interviews and the discussions with the owner and the workers were proven critical in understanding the process nature, constraints and requirements; discussions with workers should be constantly conducted throughout the implementation. They also reduce the number of changes necessary for the system after it is built and introduced into the field, which is usually more costly than the changes done in the earlier stages, and makes the period of adaptation become uneventful.

Systems that were simple to understand, operated with only a few buttons, and came with a minimal information display were found to be strong candidates in the eyes of workers. This type of system also helped relieve the owner from troubles involving labor turnover, training, and skill. It is also necessary that the variations in the dimensions of raw materials that are critical to the automatic operation are minimized to enable the use of a simpler and cheaper system.

The implementation of automation, whether it is state-of-the-art or simple, is still a complex procedure and demands a proper methodology to guide through the whole process and to ensure that the important issues are not to be missed. There are concepts, approaches, guidelines, and tools in literatures that can be selected and combined to create the frameworks practical for any particular cases. However, there is no single universal framework for every case, and it must be ensured that the specific framework created can effectively handle all important aspects and key issues. For the framework used here, the implementation procedure was divided in such a way that each step became simple enough to tackle. The framework was also composed of tools for specialist to effectively work with the users. It is worth mentioning that the framework here do have an obvious limitation as a result of the strong requirement on workers' involvement. That it would not be applicable for the case having an intention of discharging some people at the end because it will very negatively affect the morals and the performances of those who still remain. The existing process must be improved prior to applying an automation, otherwise wastes and inefficiencies will continue their existences into the automated process and exaggerate if the capacity is expanding.

Implementing automatic systems, nevertheless, requires a set of knowledge, skills, and experiences which are not commonly possessed by most small farms. If the case were not a part of a research project, a group of specialists would have to be hired and the owner would have to pay for the hiring cost. The cost of implementation would have been doubled or tripled those reported in the previous section. This economic barrier would have rendered the project even more challenging or not feasible entirely. This kind of burden can be lightened through a collaboration with other farms, especially in the case requiring a more complicated system. The “sharing” concept, as demonstrated by Sims et al. (2011), would help on the issues such as investment, ownership cost, and land availability. The local authorities, universities and such also needs to get involved in organizing the collaboration, making necessary expertise available, and even better funding the project. They can help even further by organizing short courses targeting on developing skills such as working with automation and designing basic automations. Site visits and workshops are also helpful in lessening all the barriers and encouraging the involvement and the collaboration of all parties. This kind of projects can also be considered as a mean for students to develop skills and experiences by actual practicing, which may in-turn change the perspective of younger generations toward agriculture.

5 Conclusion

Process improvement and automatic systems were successfully implemented to the case-studied farm for making its operation less dependent on labor’s skill, cost and turnover. The success would not be possible if it was not assisted by the framework and several product developing tools. The key aspects would not be addressed effectively without the strong involvement of people in the farm. The implemented solutions not only reduced the labor time in the process, but also improved the production capacity, the product quality, and the land utilization. The automatic systems did not contribute to these benefits because it reduced or removed workers, but it allowed them to work in more relaxing and effective ways and to be assigned to more important activities. The uses of automatic systems also opened up opportunities for business expansion and collaboration. The work demonstrated that effective solutions for farming could be simple and affordable, at least in this circumstance. However, they are by no means the solutions that can always be applied directly to other similar cases because each farming is unique and may require a more complex solution. Nevertheless, it gave an insight into the important tools to be used and the key points to be addressed in the implementation. It is also important to note that in the case like this difficulty was always hard to overcome without support in many ways from important parties and collaboration amongst themselves.

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