Engineering, Structures and Innovations

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Nursery Mechanization – Letting the Process Drive the Design

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Index Words: Nursery, Mechanization, Automation, Process Improvement, Design

Significance to Industry: The single most important factor that determines the level of success in a nursery operation is labor management. Issues that must be considered when managing this resource include availability, skill level, training, productivity and technical aptitude. Many nursery growers have invested significant amounts of time and money into equipment and procedural changes that can enhance the overall effectiveness of labor by increasing productivity and reducing the potential for injury. This investment trend is likely to continue as availability of qualified skilled laborers remains a concern for growers as the nursery and greenhouse industry continues as the fastest growing segment of U.S. agriculture (1). Adopting design and process improvement techniques proven over many years supporting manufacturing and related business environments will better ensure that equipment designed and/or selected to support nursery operations will offer the best overall improvement and cost savings opportunities.

Nature of Work: This project is part of a research effort currently being supported by the United States Department of Labor and the Mississippi Agricultural and Forestry Experiment Station entitled ‘Enhancing Labor Performance of the Green Industry in the Gulf South’ (2). Through completion of a detailed Systems Analysis of the nursery industry, this project will identify areas for improvement and process factors that will influence the future design and selection of nursery equipment. In addition, a nursery baseline process model will be completed that can be used to support process improvements and forecast potential cycle time savings through simulation. The Integrated Definition (IDEF) process modeling technique was chosen to support this effort (3). This paper will focus on systems analysis techniques/results and how they can be used to influence design and support process improvements.

Results and Discussion: The Systems Analysis includes data from four nursery types – large container, small container, ball & burlap and bare root production. This data includes process models developed as a result of various engineering observation visits. Nurseries from six states were visited and all significant
processes were evaluated. Process models include, but are not limited to, propagation, transplanting, spraying, fertilizing, pruning, and shipping. A systems analyses of these processes included repeated observations of the work being performed with the following areas identified: areas for improvement, tools and equipment used, safety concerns, process cycle time, distances traveled, and physical dimensions of products and supplies.

Process models included details sufficient to identify three major components influencing the outcome of each nursery operation step in accordance with IDEF guidelines.

![Diagram showing Inputs, Nursery Processes, Mechanisms, Controls, and Output]

Process Inputs can include outputs from prior operations, management direction, regulations, etc. Mechanisms are made up of the tools, equipment, supplies and labor used to perform a task. Process Controls include all of the constraints that might influence process output such as environmental conditions, financial restrictions, and technical limitations. Together; these three components will define the qualities of the Output (cycle time, product quality, labor efficiency, customer satisfaction) of each process step in a nursery operation. In addition to focusing on these process factors when designing/selected equipment to offer improvement in a specific area, one should also be aware of how a single process factor can directly or indirectly influence other areas in the operation. For example, changing the container style (width: height) used will impact areas such as transplanting/upsizing, container spacing, fertilizing, blow-over protection, spraying and shipping among others. These inter-relationships are most often overlooked but can have significant impact on the overall success of a mechanization strategy.

While process uniqueness defines the differences between container and field production, it was found that all container nurseries do share similar processes to the point of a safe one-man lift which, simplified, is approximately thirty-five pounds (4, 5) or essentially a seven gallon container. Similar processes were
defined as processes sharing a majority of the three process factors described above. This information could prove valuable to the design of common or modular mechanization. In addition, other common areas identified across all nurseries included hand pruning, application of time-released fertilizer into containerized product, and manual spraying of various chemicals.

This research has shown that using IDEF modeling and related ‘high-tech manufacturing developed’ process improvement techniques can be used effectively within the green industry offering valuable insight into the nursery/greenhouse ‘system’ including process requirements and inter-relationships. These results are currently being employed to support existing mechanization equipment evaluations with results to follow. In addition, common safety concerns have been identified and have prompted the development of a series of nursery/greenhouse worker safety training videos. These safety concerns have been grouped into three categories; ‘The 3-E’s of Nursery & Greenhouse Safety’ (Ergonomics, Equipment and Environment). The systems analysis observations have shown that operations with inherent safety concerns generally result in reduced worker productivity regardless of the recorded injury rate. This observation will be evaluated further and quantified using developed process models.

**Literature Cited:**

A Wireless Sensor Network for the Nursery and Greenhouse Industry

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Index Words: real-time, cost-effective, environmental, data, irrigation, environmental, management,

Significance to the Industry: We have successfully developed a wireless sensor network comprised of third generation wireless nodes developed by Carnegie Mellon Robotics Institute that integrate a variety of sensors which can measure substrate water, temperature, electrical conductivity, daily photosynthetic radiation and leaf wetness (ECH2o series; Decagon Devices, Pullman WA) in real-time. Control of irrigation solenoids is also possible using these rugged low-power sensor nodes, based on the measurement of real-time substrate moisture data. With this system, growers can deploy sensors within their growing operation to provide three of the most important environmental data streams for monitoring plant growth and productivity. A web-based graphical reporting system has the capability of monitoring real-time data from their production areas, from anywhere in the world with an internet connection. Growers should reap an immediate financial payback through improved plant growth, more efficient water and fertilizer applications, together with a reduction in disease problems related to over-watering.

Nature of Work: A number of researchers have published information on the potential of sensors that have the ability to directly sense the water status of soils in the field (4, 5). Relatively sophisticated systems are being used at similar scales in vineyards (4), forestry nurseries (3) and golf courses (1) for similar purposes and while the sensors perform well, these systems are extremely expensive, and have limitations for many fruit and field growers including power and communications in remote areas. Higher-tech greenhouse irrigation systems (5, 10) have been in use for some years now, but most of these systems do not provide a control system to manage irrigation scheduling. Affordable systems that can transmit data for long distances from low-power nodes are essential – since real-time information will greatly improve the quality of the management decisions made using that data.
In previous research, Murray (6) and others (2,7) found that multiple time-domain reflectometry (TDR) sensors must be used in organic substrates, to provide an accurate and repeatable measure of water content (2, 6, 7). Various container sizes will probably require specific sensor lengths and/or configurations. In addition, Murray (6) provided practical information on placement of sensors with overhead (sprinkler) and drip irrigation systems, together with the minimum number of probes that should be used in varying situations. A TDR network was deployed for three years to monitor and control irrigation scheduling in a container-nursery environment (8). This research network significantly reduced water consumption by 50% over cyclic timed overhead irrigation, and significantly reduced nitrogen and phosphorus leaching from container nursery production systems (8, 9).

The Carnegie Mellon University (CMU) sensor network (11) is composed of battery-powered sensor nodes, each consisting of a rugged waterproof box that measures approximately 3" x 5" x 7" (Fig. 1). Each node contains a microprocessor, a radio for wireless communication, and an interface board that provides for multiple sensor interfaces. When the nodes are deployed in the field, they use built-in radios to automatically find one another and form a wireless network. This network can then be used to relay real-time data from sensors attached to the nodes to a central computer. The network achieves a six to 12-month battery life through a synchronized, low-duty-cycle, geographical forwarding routing scheme.

The CMU sensor network has three unique features that distinguish it from other wireless data collection systems: (1) the communications are multi-hop; (2) the network is self-configuring, and (3) the nodes can be used to actuate a solenoid valve, which will allow for automated monitoring and control, should the grower wish to utilize this control capability. The first feature allows transmission of data over distance longer than the range of a single radio i.e., if a node is not within range of the central computer, it automatically finds another node to act as a relay (Fig 1). The second feature means that the network is easy to install and that it can be reconfigured by simply moving the nodes around. It also means that the system is can withstand single-point failures – i.e., if a node should fail, the network automatically finds an alternate path for the data transmission. The third feature makes it possible to go beyond sensing and use the nodes to monitor and control devices automatically or from remote locations.

We have developed a short list of what we consider are essential features for any technology system which uses sensors for environmental monitoring and control. The sensors must be mobile for efficient movement to critical areas. Data from sensors should be transmitted wirelessly over large distances with little to no interference and with minimal power requirements. That data should be automatically logged and made available in an interpretable form for the user. Additionally, the data should also be easily integrated into the irrigation system for automatic control. Finally, the sensor/node system should be scaleable to
increase the size or usefulness in the nursery. Additionally the system should be inexpensive (less than $5,000 for a starter network), and user-friendly (plug and play operation) to install and operate.

By hybridizing the CMU system with Decagon and other low-cost commercial sensors, we have taken advantage of the prior research and development that Carnegie-Mellon University has put into developing the wireless network. These nodes have a unique capability to dynamically route any data gathered by the sensors, to the base node. In addition, the nodes are waterproof, lightweight and durable (Fig. 2), and can be quickly moved with the sensors to another location. Most importantly, we have configured the nodes to accept a variety of analog and digital sensors, with the ability to “push” a signal to actuate solenoids for irrigation management and other environmental control functions for ‘plant-driven’ environmental control. The grower can of course fully intervene and control the system at any times in ‘manual’ (monitoring) mode.

The WebSensor software (Fig. 3) is very easy to use, customizable (i.e. can accommodate specific calibration curves for various substrates), and integrates with a web-version that allows for data sharing over the internet. For these reasons, we feel that this hybrid system addresses all the major grower priorities and it will allow us to move forward with implementation of a ‘plant-driven’ irrigation management system into the industry within a short time. However, before that can happen, we have considerable optimization work to do by deploying into real production systems, to ensure that it does in fact perform adequately in a range of commercial operational environments.

**Literature Cited:**

Fig. 1. Schematic of the Operational Sensor Network
Fig 2. An operational second-generation wireless node with various Ech₂O and analog sensors.

Fig 3. Computer screen capture of WebSensor graphic user interface and reporting system.
Effect of Foliar Applied Paint on Growth of \textit{Ficus benjamina} L.

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\textbf{Index Words:} plant height, color, interior plant production, weeping fig

\textbf{Significance to Industry:} Shrubs and ornamental trees are traditionally produced in above-ground container, pot-in-pot, or field nurseries. In order to achieve good quality and marketable crops, growers are searching for methods to maximize plant growth in the shortest time. Different color shades, already used in the greenhouse to adjust light quality to promote growth (3) are difficult to use in production outdoors. This study investigated the influence of different color paints on height, growth, and leaf number of weeping fig (\textit{Ficus benjamina} L.). The results revealed significant plant height increase in light blue paint-treated plants compared to non-painted plants (control). Painted-plants had less leaf numbers versus the control, while growth indices had no difference except plants in the blue paint group.

\textbf{Nature of Work:} Plant height is the main component of plant architecture. Many methods are commonly used to inhibit stem extension and produce compact plants, but only a few methods are available to increase plant height, such as PGRs (2) and shade (1). For field nurseries, to quick establishment of plant height reduces production cost and time. This study evaluated the influence of foliar applied paint by on plant growth and development.

One gallon \textit{Ficus benjamina} L. were transplanted into 2-gallon containers on February 5, 2005 into a 6:1 (by vol) pine bark : sand substrate, amended with 6.6 kg/m$^3$ (11 lbs/yd$^3$) Polyon 18-6-12 (Pursell Technologies Inc. Sylacauga, Alabama); 0.9 kg/m$^3$ (1.5 lbs/yd$^3$) Micromax (The Scotts Co., Marysville, OH) and 3.0 kg/m$^3$ (5lbs/yd$^3$ ) dolomite limestone. Each pot received 600 ml water twice per day using drip emitters. One week later, 48 plants were assigned randomly to each of six paint (Prang Washable Paint 16 oz., Dixon Ticonderoga Company, Heathrow, FL) treatments: no paint (control), red (1 : 1 = red paint : water), light red (0.5 : 1 = red : water), blue (1 : 1 = blue : water), light blue (0.5 : 1 = blue : water), and orange (1 : 1 = orange : water). Paints were sprayed on to the upper leaf surface with a hand sprayer. Plants were randomly arranged and grown in a double layer polyethylene-covered greenhouse at the Paterson Greenhouse Complex, Auburn University, AL for three months. Painting was repeated every two weeks for new growing leaves. Plant growth indices (GI)[(height + width at widest point + width perpendicular to width at widest point)/3] were measured every 7 days until May 28, 2005.
Results and Discussion: At 43 days after planting (DAP), plants with light blue paint showed significantly higher growth than the control and were the highest group at 71 DAP (Figure 1; Table 1). Weeping figs with light blue paint were 124%, 113%, and 123.5% taller at 43 DAP, 71 DAP and 92 DAP, respectively, than the control. At 78 DAP, plants in light blue paint group become the tallest across all treatments. The results provide strong evidence that light blue paint promotes height growth for weeping figs. The stress of paint, however, caused some leaf abscission. Leaf numbers of all painted groups are lower than those of the control, although leaf numbers of plants treated with orange paint have no significant difference than the control. Of all paint groups only the blue paint group was significantly larger than those of the control. At the end of the experiment, we used high pressured tap water to completely clear the paint from the foliage prior to selling all plants at a campus plant sale.

This study suggests that a foliar application of a thin film of blue paint on the upper leaf surface could increase plant height.

Literature Cited:

Working Conditions and Socioeconomic Impact of Mechanization in Horticulture Firms

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Index Words: Working hours, worker training, worker safety, worker retention

Significance to the Industry: In order to sustain robust growth in the horticulture industry, continuous improvements in the skills of the nursery workforce and their year-round availability are necessary. These nursery workers perform varied functions and are subjected to different working conditions. Many jobs in the nursery industry require large amounts of stooping, lifting of heavy containers, and exposure to chemicals, dust, and plant materials. These tend to be relatively-low paying jobs making it difficult for nursery managers to compete for and retain workers in currently tight domestic labor markets. Many commercial nursery operations have employed immigrant labor to meet their rising labor requirements. In the long-run, there is a need to increase the skill level of these migrant workers in order to improve wage rates, recruitment, and retention of workers.

Nature of Work: A regional socioeconomic survey of nursery automation was conducted in the northern Gulf of Mexico as a part of a research program undertaken by the Mississippi Agricultural and Forestry Experiment Station (MAFES) and the U.S. Department of Labor (DOL) entitled “Enhancing Labor Performance of the Green Industry in the Gulf South.” The socioeconomic survey consisted of eight parts, namely: workers’ demographic characteristics, nursery characteristics, nursery automation, greenhouse automation, labor and capital markets, pesticide and chemicals, working conditions, and respondents’ characteristics. The overall goals of the regional socioeconomic survey were to develop a socioeconomic profile of horticulture workers and to evaluate the impact of automation on their employment, earnings, safety, skill-levels, and retention rates (1, 2, 3, 4). In this paper, the specific objectives were to determine the impact of mechanization and to compare the working conditions, workers’ training, safety and retention among nurseries and greenhouses in the northern Gulf of Mexico region. Working conditions included working hours, access to rest and lounging areas, sanitation facilities and drinking water, housing benefits, dental and medical insurance, and retirement benefits. Workers’ training were measured by the percent of workers (POW) provided with training on basic horticultural skills and length of basic training period for new workers. Workers’ pesticide and chemical training and safety was measured by POW sent for training on chemical and pesticide application, POW who were aware of the
danger associated with exposure to chemicals and pesticides, POW who handled chemicals and pesticides and POW handling chemicals and pesticides who were equipped with personal protective equipment. Workers' safety were measured by the number of work-related injuries reported and manhours lost due to work-related injuries. Workers' retention rate was estimated from the percent of workers who were employed in the same nurseries and greenhouses during the last two years.

Results and Discussion: A total of 87 Nursery Automation Survey Forms (NASF) were completed from personal interviews with operators and managers of nurseries (N=21), greenhouses (N=22) and mixed nurseries and greenhouses (N=44) randomly selected in Mississippi (32), Louisiana (29), and Alabama (26). The participating nurseries and greenhouses were randomly selected from the lists of wholesaler growers from each of the three states included in the survey.

During peak months, working hours averaged 9.14 hr/day or 51.48 hr/wk and 7.09 hr/day or 36.09 hr/wk during slack months (Table 1). The average wage rate reported by nurseries and greenhouses was $7.89/hr. Most of the workers have access to rest and lounging areas (94.44%), and sanitation facilities and drinking water (95.83%, Table 2). Limited housing benefits (15.12%), dental and medical insurance (7.58%), and retirement benefits (10.49) were provided by nurseries and greenhouses to their workers. Nurseries and greenhouses provided basic horticultural training to 37.91% of their new workers averaging 6.83 hr per nursery (Table 3). Majority of their workers (87.13%) were employed in the same nurseries or greenhouses during the last two years. Less than one third (29.96%) of the workers were sent to chemical and pesticide application training while almost all of them (97.33%) were aware of the dangers associated with exposure to chemicals and pesticides (Table 4). Although about a third of the workers (33.28%) were handling chemicals and pesticides, almost nobody (0.33%) was involved in chemical or pesticide related injuries or illness. Almost all of the workers (94.20%) handling chemicals or pesticides were equipped with personal protective equipment. The number of work-related injuries reported by nurseries and greenhouses averaged less than one (0.43) per nursery involving about 11.83 lost manhours.

The general format of the empirical models used to evaluate the socioeconomic impact of automation or mechanization in Mississippi, Louisiana and Alabama on working conditions was as follows:

Eq. 1 WORKCOND C AVELOAM WORKTOTAL SALESYR3 YEAR2 NURONLY GHONLY PERACUSE,
where WORKCOND - dependent variables representing working conditions, benefits or safety (%),
C - constant,
AVELOAM - average level of automation or mechanization (%),
FTE - number full-time equivalent workers,
SALESYR3 - annual gross sales ($),
YEAR2 - number of years in operation (yr),
NURONLY - dummy variable representing nursery only (1 or 0),
GHONLY - dummy variable representing greenhouse only (1 or 0),
PERACUSE - percent of total acreage used in production (%).

The preliminary TOBIT results showed that improvements in automation or mechanization were associated with the following:

1. Higher percent of workers (POW) with dental and medical insurance.
2. Higher POW sent for training on chemical and pesticide application.
3. Higher POW who were employed in the same nurseries and greenhouses during the past two years.
4. Longer working hours for more mechanized nurseries and greenhouses.
5. Neutral effects on other dependent variables representing working conditions, benefits or safety.

Literature Cited
Table 1. Means and standard deviations of the working hours and gross wage rate in nurseries and greenhouses which participated in the socioeconomic survey in the northern Gulf of Mexico

<table>
<thead>
<tr>
<th>Working hours</th>
<th>Nursery only</th>
<th>Greenhouse only</th>
<th>Mixed nursery and greenhouse</th>
<th>All nurseries and greenhouses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak season</td>
<td>8.00 ± 2.93</td>
<td>9.54 ± 1.19</td>
<td>9.36 ± 1.54</td>
<td>9.14 ± 1.87</td>
</tr>
<tr>
<td>Slack season</td>
<td>6.09 ± 2.94</td>
<td>6.92 ± 1.32</td>
<td>7.47 ± 1.50</td>
<td>7.09 ± 1.86</td>
</tr>
<tr>
<td>Hours per week</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak season</td>
<td>51.45 ± 14.44</td>
<td>52.23 ± 9.09</td>
<td>51.21 ± 13.44</td>
<td>51.48 ± 12.61</td>
</tr>
<tr>
<td>Slack season</td>
<td>34.09 ± 15.78</td>
<td>34.92 ± 5.92</td>
<td>37.16 ± 8.46</td>
<td>36.09 ± 9.69</td>
</tr>
<tr>
<td>Gross wage rate ($/hr)</td>
<td>7.91 ± 1.35</td>
<td>8.38 ± 1.36</td>
<td>7.70 ± 1.36</td>
<td>7.89 ± 1.36</td>
</tr>
<tr>
<td>Item</td>
<td>Nursery only</td>
<td>Greenhouse only</td>
<td>Mixed nursery and greenhouse</td>
<td>All nurseries and greenhouses</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------</td>
<td>-----------------</td>
<td>------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>POW with rest and lounging areas</td>
<td>100.00</td>
<td>83.33</td>
<td>97.37</td>
<td>94.44</td>
</tr>
<tr>
<td>POW with housing benefits</td>
<td>7.35</td>
<td>3.33</td>
<td>23.97</td>
<td>15.12</td>
</tr>
<tr>
<td>POW with dental and medical insurance</td>
<td>6.94</td>
<td>5.56</td>
<td>8.82</td>
<td>7.58</td>
</tr>
<tr>
<td>POW with retirement benefits</td>
<td>0.00</td>
<td>5.56</td>
<td>17.24</td>
<td>10.49</td>
</tr>
<tr>
<td>POW with sanitation facilities and drinking water</td>
<td>100.00</td>
<td>94.44</td>
<td>94.74</td>
<td>95.83</td>
</tr>
</tbody>
</table>

Note: POW - percent of workers (%).

<table>
<thead>
<tr>
<th>Item</th>
<th>Nursery only</th>
<th>Greenhouse only</th>
<th>Mixed nursery and greenhouse</th>
<th>All nurseries and greenhouses</th>
</tr>
</thead>
<tbody>
<tr>
<td>POW provided with training on basic horticultural skills</td>
<td>22.69</td>
<td>23.75</td>
<td>50.97</td>
<td>37.91</td>
</tr>
<tr>
<td>Length of basic training period for new workers (day)</td>
<td>3.56</td>
<td>2.88</td>
<td>10.04</td>
<td>6.83</td>
</tr>
<tr>
<td>POW who were employed in the same nursery during the last two years</td>
<td>93.13</td>
<td>85.31</td>
<td>85.28</td>
<td>87.13</td>
</tr>
</tbody>
</table>

Note: POW - percent of workers.
Table 4. Worker’s pesticide and chemical application training and safety among nurseries and greenhouses which participated in the socioeconomic survey in the northern Gulf of Mexico

<table>
<thead>
<tr>
<th>Item</th>
<th>Nursery only</th>
<th>Greenhouse only</th>
<th>Mixed nursery and greenhouse</th>
<th>All nurseries and greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>POW sent for chemical/pesticide application training</td>
<td>27.44</td>
<td>35.63</td>
<td>28.56</td>
<td>29.96</td>
</tr>
<tr>
<td>POW aware of danger associated with</td>
<td>97.06</td>
<td>100.00</td>
<td>96.15</td>
<td>97.33</td>
</tr>
<tr>
<td>POW handling chemical/pesticide</td>
<td>50.25</td>
<td>40.16</td>
<td>22.53</td>
<td>33.28</td>
</tr>
<tr>
<td>POW involved in chemical/pesticide-related injuries/illness</td>
<td>0.00</td>
<td>0.00</td>
<td>0.64</td>
<td>0.33</td>
</tr>
<tr>
<td>POW handling chemical/pesticide with personal protective equipment</td>
<td>94.12</td>
<td>96.84</td>
<td>92.95</td>
<td>94.20</td>
</tr>
<tr>
<td>Number of work-related injuries</td>
<td>0.24</td>
<td>0.16</td>
<td>0.64</td>
<td>0.43</td>
</tr>
<tr>
<td>Man-hours lost due to work-related injuries (hr)</td>
<td>15.06</td>
<td>0.42</td>
<td>15.97</td>
<td>11.83</td>
</tr>
</tbody>
</table>

POW - percent of workers.