8 A

A REVIEW OF CITRUS HARVESTING IN FLORIDA

by
Jodie D. Whitney, Ph.D.
Professor of Agricultural Engineering, P.E.
University of Florida, IFAS
Citrus Research and Education Center, Lake Alfred

ABSTRACT

The removal of Florida citrus from the tree for harvesting is still done by handpickers on ladders and requires a work force of 20,000 to 35,000 persons. Moving fruit from the grove and subsequent fruit handling has been mechanized in the last 40 years. Factors affecting harvesting are fruit type and utilization, grove characteristics, and harvest labor requirements and costs. Although mechanical harvesting research over the past 35 years has not developed a feasible machine to replace the picker, substantial design and field performance information has been developed to mechanize the harvest of a significant portion of the crop if labor becomes unavailable or too costly. Some picking aids have been implemented to increase the productivity of pickers, but their feasibility is questionable under current conditions. Renewed attempts have been made to mechanize the harvest since 1993. A harvesting program administrator was employed by the Florida Department of Citrus in January 1995 to develop a program which will insure the harvest of future crops at a competitive cost. Record crops, low fruit prices, steadily increasing harvest costs, and more regulations are predicted for the next decade.

INTRODUCTION

Florida citrus bearing acreage (trees over 4 years old) and production have increased fairly steadily over the past 75 years except for the effect of major freezes (Figure 1). Bearing acreage peaked at 849,000 acres in 1971, then fell to a low of 508,000 acres in 1986 after the 1985 freeze, and rebounded to 668,000 acres in 1994 (Citrus Summary, 1949-50, 1964-65, 1967-68, 1982-83, 1992-93; Commercial Citrus Tree Inventory, 1994). Production peaked in 1980 at 284 million boxes, then fell to a low of 154 million boxes in 1990 after 5 major freezes during the 1980s, and is predicted to rebound to 266 million boxes in 1995 (USDA Citrus Estimate, 1995). During the past 25 years, oranges have comprised over 70% of Florida's citrus production, and Florida was the world's leading producer of oranges until 1978 when Brazil became the leader.

In the mid-1950s, the Florida citrus industry first expressed a collective concern about labor availability problems associated with harvesting because citrus acreage and production had been steadily increasing at a rapid rate for 2 decades (see Figure 1). A research project was established at the Lake Alfred CREC (then Citrus Experiment Station) in 1957 to search for possible solutions and the first and only paper (Coppock and Jutras, 1959) on harvesting presented at this Conference summarized the initial efforts of the project. The purpose of this paper is to review the developments in Florida citrus harvesting over the past 35 years (Coppock and Hedden, 1977; Whitney and Harrell, 1989), and discuss the current status and possible situations for the future. Harvesting in this discussion relates to the activities required to separate the fruit from the tree, place it in a suitable container, move it roadside, and then to the processing plant or packinghouse. Most of the information, however, will concentrate on the first 2 of these 4 activities.

Organization of the industry. There are approximately 12,000 growers whose holdings range from a few to thousands of acres. Many growers are "absentee" owners because they do not live on or near their grove property and are not involved in day-to-day grove operations. Cooperatives and caretakers are grove management organizations which mange all or part of the grove operations including harvesting for the absentee owners. Grove ownership by large corporations has become more common in the last 2 decades. One of the reasons for this is the southern movement of new citrus plantings during this time into the flatwoods areas to reduce the risk of freeze damage, and the practical development of these flatwoods areas under environmental constraints usually requires that relatively large tracts of land be considered.

The production, harvest, and utilization sectors of the citrus industry are often under different management, and ownership of the fruit can change as it moves from one sector to another. The production and utilization sectors are mechanized while the harvest sector requires fairly large numbers of seasonal hand laborers to remove fruit from the tree and place it in a fruit handling container.

Fruit handling. Fruit handling systems for moving fruit from the field container to roadside have been successfully mechanized since Coppock and Jutras presented their paper in 1959, and have been described in some detail by Hedden and Churchill (1984). Until the late 1950s, fruit was handled in the standard 90-lb field boxes, twowheel trailers, other specialized equipment, and was very labor intensive. Since that time, both the fresh and processed fruit handling systems described below have reduced labor requirements at least two-thirds with container costs also reduced.

For fresh fruit handling in the grove, the current system of pallet bin containers (10 field boxes) and flat-bed trucks with grapple-type loader booms was adopted (Figure 2). At roadside, the pallet bins are usually transferred to a flat-bed, semitrailer for transportation to the packinghouse, unless the packinghouse is a relatively short distance from the grove. The majority of the pallet bins are constructed of wood, but some utilize a steel frame and flexible liner, and in recent years, plastic bins have seen increased use.

For processed fruit, wire baskets (10 field boxes) first replaced field boxes as field containers. The baskets were handled and emptied with loader booms mounted on trucks having high-lift bulk bins with capacities from 60 to 100 field boxes. At roadside, fruit in the bulk bin was dumped, as it is today, into a semitrailer (500 field box capacity) which is pulled to the processing plant. In the early 1970s, the round, molded polyethylene tub (Figure 3) which is in use today began replacing the wire basket. The tub, produced in 8 and 10-field box capacities, is somewhat lighter and much easier to handle.

FACTORS AFFECTING HARVESTING

Fruit type and utilization. Over the past 20 seasons, Florida citrus production has averaged 71% oranges, 23% grapefruit, and 6% specialty fruits (Citrus Summary, 1992-93). Since 1988, 83% of the citrus was processed, 93% of the orange, 55% of the grapefruit and specialty fruit. This left 17% of the citrus utilized as fresh, and with an average packout of 65%, 17/0.65 or 26% of the crop was harvested destined for the fresh market. All fresh market fruit must be handled with care, especially the specialty varieties which have thin and fragile peels. All citrus harvested by hand is separated from the tree with a twisting, snapping motion except for tangerines which are often clipped to reduce peel damage. Productivity of the picker depends on the fruit type (size) and utilization (fresh generally lower than processed). A survey done during the 1967 season showed the productivity of the citrus picker in boxes/h averaged 11 in grapefruit, 7.3 in oranges, 4.9 in murcotts and tangelos, and 2.7 in tangerines (Florida Industrial Commission, 1967).

The harvest season for fresh fruit can last from September to July, whereas the main thrust of the processing season is usually December to May. Valencia or late oranges have historically been slightly less than half the total Florida orange production and is the only cultivar normally harvested after citrus trees bloom in the February-April period. Thus, Valencia has the mature and young (next year's) fruit on the tree at harvest time. Selective harvest of the mature fruit presents no particular problems for hand harvest, but is a significant problem for mechanical removal devices and fruit-loosening abscission chemicals.

The trend in the relative percentage of early/mid-season vs. Valencia orange plantings has changed somewhat over the past 15 years, probably in reaction to the freezes in the 1980s. Tree inventory data in 1994 (Commercial Citrus Tree Inventory,

1994) showed that for orange trees planted prior to 1981, Valencia was 48% of the total orange acreage. From 1981 through 1993, Figure 4 shows the existing acreage planted in early/mid-season vs. Valencia oranges after 1980. More early/mid-season orange acreage existed for most of the years trees were set. The greater acreage of all orange trees planted from 1986 to 1992 was due mostly to new plantings in South Florida in reaction to the freezes in the 1980s, while the downward trend in 1992-1993 was probably a reaction to low fruit prices. Currently, the total acreage in existence for early/mid-season and Valencia oranges are 334,000 and 301,000, respectively.

Also, as a result of the 1980s' freezes, consideration has been given to planting specialty cultivars in the colder Northern and Central production areas (see Figure 5) because these cultivars are harvested as early as October and the trees tend to be more tolerant of cold temperatures than orange and grapefruit trees. This is illustrated by specialty tree acreage increasing from 42,000 to 53,000 from 1988 to 1994 (Commercial Citrus Tree Inventory, 1994), and was mainly due to increases in Northern and Central production areas. However, the market for some specialty fruits tend to be somewhat unpredictable and some cultivars have unique production problems.

Grove characteristics. Most of the trees have been planted in a rectangular pattern. Before the freezes of the 1980s, other patterns such as the diamond existed in the Northern production areas. Along the coasts of the Southern production area, the soil is poorly-drained and is bedded between ditches to control the water level around the tree root system. Trees are planted in rows parallel to the ditches on or near the top of the beds. The number of rows per bed varies from 1 to 8, but the most common is 2. The slope of the beds adjacent to the ditches and the effect of water on soil condition in the vicinity of the ditches pose problems with trafficability for fruit handling trucks and pickers setting their ladders for harvesting. Mechanical harvesting equipment would also encounter problems with this type of terrain. By comparison, the relatively flat, well-drained sandy soils in the Central and Northern production areas also pose flotation problems for equipment.

As a result of the 1980s' freezes, Figure 6 shows a major shift in orange acreage from the Northern to the Southern production areas between 1978 and 1994 (Commercial Citrus Tree Inventory, 1978, 1994). Losses in the Northern production area were about 30,000 acres greater than the gains in the Southern production area. Considering the Western, Indian River, and Southern production areas as principally bedded groves, the percentage of the total orange acreage which was bedded increased from 44% in 1978 to 69% in 1994.

Harvest rate and working safety of pickers are generally inversely related to tree height. Many of the older, taller trees in the Northern and Central production areas were lost in freezes of the 1980s. In recent years, the maximum tree height has been limited to 18 or 20 ft. by regularly scheduled tree topping programs. The need for tree topping has been alleviated somewhat by the increased acreage in bedded groves in which shallow root systems tend to limit tree height. Many factors must be considered in determining the appropriate tree height. Most of the citrus cultivar/rootstock combinations are relatively vigorous in nature and limiting tree height by tree topping can limit fruit yields. Growers tend to maximize tree growth for healthy-looking trees with the latest irrigation and fertilization techniques, and hope this will maximize fruit yields. The trade-off is that growers may be reluctant to limit tree height because fruit yields may be limited, but to allow the tree to grow taller will usually mean higher harvesting costs per box and sometimes greater difficulty in getting pickers to harvest the fruit. Another consideration is that in taller trees, most pickers would rather not use picking bags because of ladder stability or safety concerns, and thus will prefer to drop fruit to the ground. While dropping fruit to the ground has been practiced in processed fruit harvesting for many years, it is being discouraged today because of the increased contamination concerns at the processing plant and potential reductions in pounds solids yields from bruised and damaged fruit. In fresh fruit harvesting, it should not be practiced at all, but it is, and contributes to lower fresh fruit packouts. From this discussion, one can see that the goals of the production, harvesting, and utilization sectors may conflict, and many times communications between the 3 are minimal to nonexistent.

Tree spacings vary considerably between groves. Because of the necessity of grove vehicular traffic, between-row spacings have remained relatively constant at 25 to 30 ft. in older groves, with some reductions to between 20 and 25 ft. since 1960. In-row spacings have been less and reduced with time, but are quite variable. Older groves had in-row spacings of 25 ft. or more, but many have been interset at closer spacings, and the current average ranges between 10 and 15 ft. The move toward closer spacing reflects the grower's attempt to maximize fruit yields with more trees per acre. Figure 7 shows the general trend in increased trees per acre with the later crop year set and the 1994 orange acreage accumulated by crop year set (Commercial Citrus Tree Inventory, 1994). In 1993, the average number of orange trees set per acre was 141, which is equivalent to an in-row spacing of about 12 ft. if the between-row spacing is 25 ft. Figure 7 also shows that over half the orange acreage in 1994 has been planted since 1986 when the number of trees planted per acre averaged 131.

Pruning or hedging between rows is a common practice to maintain an alley way for tractors, trucks, sprayers, etc. Crosshedging or pruning between adjacent trees in-row is sometimes done to provide space during harvesting for placement of fruit containers and the movement of pickers and ladders around the tree. Some growers feel that crosshedging increases fruit yields because of the additional fruit bearing surface area created on the canopy between trees. A 5-year research study (Wheaton et al., 1984) has shown, however, that crosshedging (or tree removal) does not increase fruit yields compared to hedgerows. The trade-off, then, is the cost of crosshedging and fruit yield reductions vs. the convenience of the spaces for fruit container placement and picker movement at harvest. In existing hedgerows, the fruit container must be moved through the tree canopy for placement or retrieval, and if the grove is harvested in a conventional manner with the picker moving across rows, then the ladder must be lowered below the bottom of the tree canopy to move across the row. Fruit containers have been handled with some difficulty in hedgerow conditions. Extra care must be exercised for fresh fruit harvesting, particularly for specialty fruits, to minimize fruit damage from the container and the loader boom colliding with the fruit as they are moved through the canopy. Tree skirting or removal of the lower canopy, which is becoming

One alternative to handling fruit containers underneath the tree canopy is the straddle-type fruit handling equipment. Preliminary field trials with available commercial, straddle-type equipment for fresh fruit handling were conducted by the author in 1987. It was projected that the cost of fruit handling would significantly increase over conventional loader boom equipment because of the lower fruit handling capacity and reduced mobility of straddle-type equipment.

Harvest labor and costs. The picker is an essential part of the citrus harvesting system and is paid on a piece rate basis. The work is seasonal in nature and is often not full-time during the season because of inclement weather and when the capacity of the packinghouse or processing plant is a limiting factor. The makeup of the work force and the number of persons required have changed considerably over the past two decades. For the 1973 season, Fairchild (1975) reported 75% of the work force were residents of Florida while the remaining 25% were out-of-state residents or migrants. Since that time, migrants from Mexico have steadily increased as a percentage of the citrus harvesting work force and at present, it is estimated that two-thirds of the pickers are from Mexico.

The number of pickers required has depended on the size of the crop and the time within the season. A survey for the 1967 season (Florida Industrial Commission, 1967) showed the peak labor requirement was greater than 20,000 pickers between December and April, the peak harvest period for processing oranges. For a total production of 195 million boxes that season, the peak and average rates of harvest were 8 and 5 million boxes per week, respectively. The peak work force for the 284 million box crop in the 1980 season was 35,000 (Citrus Industrial Council, 1980).

Figure 8 shows that harvest costs have risen steadily over the past 3 decades (Hooks, 1986; Polopolus et al., 1993) and delivered-in or gross prices have fluctuated greatly (Florida Citrus Processors Association, 1994) in response to the normal influence of supply and demand. The industry has usually become concerned about harvest costs and interested in mechanical harvesting when the differences between gross returns and harvest costs were minimal. Until the late 1970s, the minimal differences usually coincided with periods of high production such as 1960-62, 1967, 1971, and 1977. During the decade of the 1980s, concerns about harvesting were minimal for several reasons. Florida's production was limited by the freezes, the labor supply was abundant at a reasonable cost, and even though Brazil controlled orange juice prices, they were relatively good. Since the last severe freeze in 1989, orange production has steadily increased to the 196 million boxes predicted for 1994-95, prices dropped sharply to current levels after the 1991-92 season, and the forecasted grapefruit crop for 1994-95 is a record 55.5 million boxes. Early in 1991, some industry people could foresee record crops before the end of the decade coupled with projected depressed prices resulting from an excessive worldwide supply of citrus. Again, anticipated record crops and low fruit prices have developed a renewed concern about harvesting and fostered the current collective effort to ensure the future crops will be harvested at a cost which will keep the industry competitive worldwide.

Much of the citrus harvested for processing is removed from the tree, dropped to the ground, and picked up later. As mentioned above, this practice is being discouraged and is utilized to avoid carrying the bag with fruit on the ladder, particularly in taller trees. Family or picking units have used this technique where the stronger member(s) of the unit remove the fruit from the tree while the other members gather the fruit from the ground. For independent pickers, however, it is doubtful whether this technique can improve their productivity, except perhaps where the bonding strength of the fruit to the tree is relatively low and the fruit removal rate can be significantly increased by shaking the limbs. This may occur naturally, e.g., in Pineapple oranges late in the harvest season.

In the 1970s, abscission chemicals which were developed to loosen fruit and make mechanical harvesting more efficient, were used to a limited extent as an aid to hand harvesting. Although they were found to increase picker productivity by as much as one-third (Coppock and Hedden, 1977), pickers were not usually willing to accept lower piece rate wages to offset the cost of using the chemical. Because the chemicals hastened fruit senescence and scarred the peel, they could be used only for processed fruit. The fruit usually had to be processed within a week or 10 days post spray, or it would deteriorate and not be usable. The scheduling of harvest operations that far in advance was very difficult. In addition, fruit was often stored on trucks at processing plants for several days to provide a supply of fruit when harvesting was interrupted by inclement weather or other factors. Compared to unsprayed fruit, the allowable storage time for chemically-sprayed fruit was considerably less and thus reduced the storage supply of fruit at the plant. Abscission chemicals were also investigated for fresh market fruit to eliminate the need for clipping of some specialty cultivars. Loosening results were inconsistent and the 5 to 7 day delay between application and harvest was not compatible with conventional scheduling procedures of most packinghouses.

MECHANICAL HARVESTING RESEARCH

Over 30 years of research and development efforts have gone into methods to improve and mechanize the harvesting of Florida citrus. Much of the significant work has been described in several publications (Coppock and Hedden, 1977; Wilson et al., 1977; Whitney and Sumner, 1977; Sumner and Churchill, 1977; Hedden and Coppock, 1977; Sarig and Coppock, 1986). Time and motion studies were made of handpicking operations to understand what might be done to improve productivity of pickers. Generally, it was found about 25% of the picker's total time was spent on activities commonly referred to as nonproductive, or other than picking fruit. Various picking aids were evaluated to minimize or eliminate the nonproductive activities of the picker and reduce the arduous nature of the picking task. While some of the aids did improve picker productivity and make the picking task easier, none were found to be feasible for alleviating anticipated harvesting problems. Mechanical methods in the form of contact devices (those which contact the fruit to separate it from the tree, see Figure 9), except the robotic approach, were then investigated in the early 1960s, but showed little potential for acceptance. This led to the initial research and development on machinery for mass removal harvest systems, which appeared to have potential to harvest fruit acceptable for processing at a rate commensurate with cost.

Whitney and Coppock (1984) discussed ... harvesting ...

process. Because fruit loosening by the chemicals usually resulted in considerable preharvest fruit drop, systems were developed to remove fruit to the ground and to pick it up mechanically.

Interest in mechanical harvesting increased during the late 1960s and early 1970s for several reasons. The importation of offshore labor was restricted, non-agricultural industries were competing for available domestic labor, production was increasing rapidly, and profit margins were small. One of the main reasons for the shortage of labor was the construction labor demands in Central Florida in preparation for the opening of Walt Disney World near Orlando in 1971. Also at that time, the bulk of Florida citrus was being produced in the Northern and Central production areas (see Figure 6) and 75% of the pickers were Florida residents (Fairchild, 1975). Some growers experienced difficulty in getting Valencia oranges harvested and the concerns about harvesting problems became severe enough that the Florida Department of Citrus initiated an accelerated research and development program subsidized by a tax on all harvested citrus. Up to 1977, production continued to increase and profit margins continued to be small (see Figures 1 and 8). In 1973, an abscission chemical (Acti-Aid by the Upjohn Co.) was approved for use on processed oranges, but it was only suitable for use on only early and midseason oranges. The volume of mechanically harvested oranges (mostly early and midseason) on a semi-commercial basis reached a peak in 1974-75 at 220,000 boxes, or slightly more than 0.1% of the orange crop. Most of the harvesting systems utilized abscission chemicals with limb, air, or trunk shakers (Figures 10-13) to remove the oranges to the ground and machinery to gather, pickup, and load them (Figures 14 and 15). Limbshaker-catch frame systems (Figure 16) were used on old, highly-skirted trees (mainly seedlings) where visibility was good for limb shaker operation and catch frames minimized fruit damage on oranges falling from trees over 20 ft. high.

Numerous problems were encountered with these systems. Because of non-uniforr and inconsistent fruit loosening by the abscission chemicals and losses in fruit collec- tion, harvest efficiencies were frequently less than 95%. The cost of the chemical plus application ranged from $0.10 to $0.25 per box. High rates of chemical caused exces- sive defoliation. As mentioned above, once the chemical was applied, the fruit usuall had to be processed in a week or 10 days. Because of this, equipment breakdowns and inclement weather could easily create a crisis in meeting the time schedule imposed b the chemical. Mechanical pickup equipment had difficulty handling fruit on unever terrain or when yields were over 600 boxes/acre. Tree damage from the chemical and or fruit removal devices were defoliation, small and large limb breakage, and bar damage.

Mechanical harvesting efficiencies in Valencia oranges were low, mainly becaus the efficiencies of the removal devices were low. Harvesting efficiency as discussed i this paper was defined as the percentage of the crop that could be recovered whe compared to hand harvesting. This mainly involved fruit removal percentages of th mechanical devices and yields. Thus, a fruit removal of 90% and a yield reduction o 10% (90% of hand harvested yield) resulted in a 0.9 x 0.9 or 81% harvesting efficienc

Since the peak in mechanical harvesting activity in 1975, the above problems and other conditions (discussed in the previous section) reduced interest in mechanical harvesting until recently. Other factors also affected industry acceptance of mechanical harvesting. Management of a mechanical harvesting system extended over all sectors of the industry—production, harvesting, and utilization. If the chemical failed to loosen the fruit for whatever reason (cold weather, improper application, rain washing off chemical within a few hours after application, etc.), the entire harvesting schedule was upset. In many instances, mechanically harvested fruit delivered to the processing plants required immediate handling to prevent spoilage because of chemical and/or mechanical damage to the fruit. All in all, considerable management skill was required to effectively utilize the chemicals.

In a 5-year study completed in 1985, Whitney and Wheaton (1987) found the overall harvesting efficiency of abscission chemicals with an air shaker was only 75 to 78% in oranges, while the efficiencies of abscission chemicals with a commercial trunk shaker were 93% in Hamlin and 81% in Valencia oranges. In another 5-year study completed in 1986, Whitney et al. (1986) reported harvest efficiencies of near 100% in Hamlin oranges and 91% in Valencia oranges (prior to a young fruit diameter of about 0.5 inches) using abscission chemicals with low frequency (5 Hz) linear trunk shaking for 7 seconds. The possibility of improving harvest efficiency in Valencia oranges by decreasing the shake time to less than 7 seconds was suggested since most mature fruit was removed in the first few seconds of shaking and the damage to young fruit would be reduced.

ROBOTIC HARVESTING RESEARCH

Research on robotic citrus harvesting began in Florida in 1983. When compared to previously researched mechanical harvesting systems, this approach offered some significant advantages. Abscission chemicals would not be needed. Mature Valencia oranges could be harvested selectively from the younger fruit. Fruit could be harvested for fresh or processed market. Harvesting could be accomplished any time of day or night and during inclement weather, unless handling of fresh fruit under these conditions were detrimental.

Harrell et al. (1985) developed a single arm system with machine vision that picked fruit with simple three-degree-of-freedom arms. A second generation arm (the Florida picking robot arm, Figure 17) designed by Harrell (1987) pivoted in a Hook-joint base about intersecting and perpendicular axes. A prismatic link, mounted on the Hook-joint, provided motion in and out of the citrus canopy. Arm actuation was accomplished with two rotary actuators and a hydraulic motor. A rack and pinion drive was used to obtain linear motion from the hydraulic motor. High performance servo valves, controlling actuator flow, were used to achieve the dynamic performance required for picking fruit.

Attached to the end of the sliding link was a rotating lip picking mechanism. A solid state color camera, ultrasonic range sensor, and incandescent lamp was incorporated into the picking mechanism for fruit identification and location. Color machine vision enabled the picking arm to rapidly distinguish between the various hues present in a citrus canopy.

When a fruit was detected by the vision system at the start of a pick cycle, angular velocities of the two rotational joints were regulated, maintaining the targeted fruit's projection in the center of the image plane. The sliding link was actuated, extending the picking mechanism towards the targeted fruit until it was close enough to detach the fruit from the canopy. Once detached, the sliding link was retracted from the canopy and the fruit was dropped (intended for a fruit collection system), and the next pick cycle was started. The picking arm was designed to complete a worst case pick cycle (i.e., a targeted fruit at the extreme edge of the arm workplace) in 1 second. Florida field tests on young orange trees demonstrated continuous harvest rates of 3 to 4 seconds per fruit.

Harrell (1987) made an economic analysis of citrus harvesting assuming 10 robotic arms mounted on a self-guided gantry vehicle. Some of the other assumptions made were: delivered-in fruit price = $6.70/box; harvest efficiency = 85%; average pick cycle time = 3 seconds. The harvest cost (pick, roadside, and haul, and including the cost of 15% of the fruit not harvested) was $2.30/box or about 35% greater than the orange harvesting cost at the time. Robot harvest cost was most sensitive to harvest efficiency and an efficiency of 93 to 99% was required for the robotic harvester to break even with hand harvesting costs.

Sarig (1993) had made a state-of-the-art review of robotics in fruit harvesting. He states there is no consensus on the viability of the robotic harvesting system as an alternative method for the current manual picking operation. While major progress has been made in systems to identify and locate fruit on the tree, only about 75% of the oranges have been properly identified. Further, not all of the identified oranges can actually be picked because the tree structure hinders free movement of the picking arm. Thus, to increase the efficiency of picking, the tree structure should be modified and an obstacle-avoidance algorithm incorporated in the picking arm movement. Finally, the proper end effector on the end of the picking arm must be developed to grasp, remove, and handle the oranges. While the commercial implementation of a fruit-picking robot may be years away, the increasing costs of labor and decreasing costs of computers, vision systems, and robotic equipment hold out hope for robotic harvesting with a favorable cost/benefit ratio. As mentioned above, the success of robotic fruit harvesting will depend greatly on tree structure modifications which will minimize the fruiting depth from the outer canopy edge and the number of fruit which are inaccessible from the outer canopy edge because of the canopy structure.

CURRENT STATUS

Picking aids. There are approximately 50 man-positioner boom machines (Harvesting Systems, Ltd., U.S. Patent No. 3,878,957; Figure 18) being operated as a group to harvest Florida oranges for processing in bedded groves near Fellsmere. This machine has been under development in Florida since the late 1960s. Each machine is self-propelled and operated by one picker in a bucket at the end of a boom. The picker has complete control of the machine and positions himself/herself around the tree canopy with leg and foot controls in the bucket. Oranges harvested by the picker are placed in a collector on the bucket and are pneumatically conveyed through a round tube to a storage bin at the rear of the machine by pulling a vacuum in the bin. The picker is paid for each harvested orange which is counted as it moves through the tube. The storage bin is emptied periodically into a conventional fruit handling truck (goat) without its loader boom. Lights on the machine make night harvesting possible. Down-the-row picking rates of 2400 oranges per hour have been observed and the manufacturer has claimed higher rates. The machine can be used in most any type of grove picked in a conventional manner but is best suited for tall trees with all oranges at least 6 ft. above ground level. In bedded groves, the picker does not have to work on the often treacherous ground conditions found in the ditches. Conventional pickers with fruit bags are sometimes needed where oranges on the tree are on or near ground level. The machine has been used for other grove jobs such as selective hand pruning of freeze-damaged trees and is considerably safer than conventional means of performing this task. The industry has resisted acceptance of the machine because of concerns about its cost and lack of mobility.

In the last 2 or 3 seasons, 2 other machines have been introduced mainly to assist with harvesting processed oranges from the many young, low-yielding trees in bedded groves which have been planted in recent years. They are the New Way Loader (built by James Andrews, Lorida, Florida; Figure 19) and Harvesting Systems, Ltd. pan machine (U.S. Patent No. 5,187,928; Figure 20). Both machines essentially provide a moving storage bin for a group of pickers and minimize the distance pickers have to carry oranges to dump their fruit bags. Using a conventional harvesting system in low-yielding trees, the picker must either carry fruit a long distance between tubs or the fruit handling truck must move partially filled tubs closer to the picker.

The New Way Loader is a fruit handling goat truck, without a loader boom, with a conveyor system added to transfer fruit from a receiving conveyor in front of the truck to the bulk storage bin at the rear of the truck. Usually, 6 to 8 pickers harvest fruit from 2 adjacent rows and dump their fruit onto the receiving conveyor as the driver moves the unit down the row middle. The driver has access to the conveyor system and can grade out undesirable fruit if needed. When the storage bin is full, the truck is driven to roadside for dumping. The Harvesting Systems, Ltd. pan machine is mounted on a chassis similar to the boom machine described above and pneumatically conveys fruit from the pan (where pickers dump fruit) at the front of the machine to the storage bin at the rear of the machine. The machine driver and pickers operate similar to that described for the New Way Loader, except the driver does not have access to the conveying system for fruit grading purposes. As with the boom machine, fruit in the storage bin is usually dumped into a conventional fruit handling truck (goat) for transport to roadside. These machines should ease the fruit-carrying burden on pickers in young, low-yielding trees and have seem limited use in taller, more productive trees. With both the New Way Loader and pan machine, pickers and driver must work as a team and be paid as a team since no feasible methods has been devised to account for the productivity of individual team members and pay them by the conventional piece rate. Except for families working as a team, many pickers (particularly those with high productivities) prefer not to work in a team because they are not independent and cannot get reimbursed for their individual efforts. Time and motion studies in field tests with these machines during the 1992-93 season indicated pickers spent at least 90% of their time picking oranges in young low-yielding trees which did not require ladders (Florida Department of Citrus, 1993). No direct time and motion comparisons under similar grove conditions were made with the machines and conventional harvesting operations, but conventional pickers spent about 80% of their time picking oranges in