EVALUATING VIDALIA ONION PACKINGHOUSE IMPROVEMENT WITH

DISCRETE EVENT SIMULATION AND NON-DESTRUCTIVE TESTING

by

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(Under the Direction of ERNEST WILLIAM TOLLNER)

ABSTRACT

Sizing and inspection performance of three Vidalia onion packinghouses were assessed and the impact of improving these variables and of incorporating an X-ray inspection technology evaluated using discrete event simulation. Model assumptions were derived from two-year four-cultivar samples and from a three-packinghouse time study. Sizing accuracy of the packinghouses was significantly different ($p<0.05$) while reject incidence in marketable onions was not significantly different ($p>0.05$). Percentage of oversized onions, by weight, found in most of their size categories exceeded US Grade Standards tolerance limit. Technology incorporation reduced the number of internally defective onions per box by 80-94%. Estimated selling prices per box of X-ray inspected onions were within the range of historical shipping point prices in Vidalia district for controlled atmosphere (CA)-stored and non-CA stored onions, suggesting that pricing for these superior quality onions seemed to be economically sustainable. An undergraduate interdisciplinary course on fresh food supply chains was also developed.

INDEX WORDS: Vidalia onion, packinghouse simulation, sizing, X-ray, inspection, postharvest

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Ad Majorem Dei Gloriam

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CHAPTER 1

INTRODUCTION

Two seemingly divergent realities formed the foundation of this project: the huge storage losses of the Vidalia onion industry and inadequate postharvest education in developing countries. The first two sections of this chapter provide a brief background on the Vidalia onion industry and on the postharvest education in developing countries while the final section describes the project rationale and its objectives.

THE VIDALIA ONION INDUSTRY

The Vidalia onion, hailed as America’s favorite sweet onion, is the most valuable vegetable crop in Georgia. It contributes roughly 15% of the state's total vegetable farm gate value in 2004 (Boatright and McKissick, 2005). More specifically, the southeastern region of the state, where the famed Vidalia sweet onions are grown, accounted for 99.7% of the total onion farm gate value in 2003 (Boatright, 2004). In a study on sweet onion consumers, Costa et al. (2003) reported that 63% of the respondents indicated Vidalia onions were their favorite, confirming its reputation as America's favorite sweet onion. These reports highlight both the economic importance of the Vidalia onion industry to the state of Georgia and its significance in the sweet onion market. This industry, however, continues to face a number of serious challenges.

Increased competition from other onion-producing states and South American sources highlights the need for improved varieties for storability and the need for research to identify diseased onions before they enter controlled atmosphere (CA) storage. (Boyhan and Torrance, 2002). Annual onion damage due to diseases, for example, averaged $12.86 million from 1998 to 2003 (Williams-Woodward, 1998-2003). At the postharvest end, Boyhan and Torrance (2002) reported that in some years, growers lose 50-70% of their onions coming out of CA storage due to Botrytis neck rot (*Botrytis allii*). Purvis et al. (2002) also indicated that, even in good years, storage losses due to this fungus can range from 10-20%. Considering that about 56.7 million kilograms (125 million pounds) of onions can be put into CA storage (University of Georgia College of Agricultural and Environmental Sciences, 2001), this fungus can cause considerable loss. While there are no economic estimates available for Vidalia onion losses at the retail level, Sumner et al. (2001) has indicated that bacterial soft rot and various mold rots, indicative of poor postharvest handling practices, could occur at the terminal or retail markets.

The virtually undetectable progression of these diseases within the onion bulbs, as well as the expressed consumer preference for quality and freshness in sweet onion decision purchases (Costa et al., 2003), underscore the importance of adopting a more stringent inspection method in packinghouses. Human visual inspection, the method presently used in grading operations, is inadequate in segregating onions with internal defects.

Recognizing this inadequacy, several researchers at the University of Georgia have investigated the potential use of X-ray imaging in detecting the internal defects of sweet onions. Technological innovation, after all, is a key to gaining and retaining competitive advantage because of its potential to lift revenues by adding value, enhancing market access or reducing losses (Banks et al., 2000). While their studies indicated the technology's capability to detect internal damage, commercial adoption, however, remains nonexistent. Kays and Paull (2004) noted that equipment costs, operating costs and safety considerations are, generally, the primary deficits preventing the wider use of X-ray instruments in assessing internal quality attributes of horticultural products.

There is, however, very limited information related to the assessment of the economic and operational impact of this technology on the packinghouse. In fact, there are very few studies that focused on Vidalia onion packinghouses. Since this technology offers an excellent opportunity for grower-packers to gain better control of their product quality, the availability of such information or the creation of related decision-making tools could contribute toward fostering a more positive atmosphere for the technology's adoption and consequent diffusion across the industry. More importantly, this information and the development of related management tools offer packers an opportunity to examine and understand their operations better.

POSTHARVEST EDUCATION IN DEVELOPING COUNTRIES

High postharvest losses and inadequate agricultural education continue to plague many developing countries. In the Philippines, for example, average postharvest losses for vegetables and fruits remains unacceptably high at 42% and 28%, respectively (Castro, 2003). These losses were attributed to constraints which remained seemingly unchanged over the years: low adoption of improved postharvest facilities, lack of linkage between producers and the market, insufficient training and extension activities, a weak information system and technical inefficiencies, among others.

Calls for more relevant agricultural education programs (FAO, 1997; Lindley, 1998) and the need for an interdisciplinary systems approach (Goletti, 2003; Yahia, 2005) to reduce postharvest losses in these countries have been proposed According to the FAO report (1997), agriculture education and training failed to adapt and respond to the realities of rural societies and that curricular content is not sufficiently geared towards locally important problems. The agricultural supply chain, whether in the context of rural development or commercial enterprises, depends on, and is controlled by, a mix of disciplines. Yet, agricultural curriculum, as seen from the student's home institution at least, fails to adequately reflect this integration among disciplines. While the academic programs incorporate a course or two from some of the relevant disciplines, students in a discipline are usually trained almost in isolation from other disciplines as there is no formal venue to engage in interdisciplinary undertakings. Students do not have enough opportunity to bring together the principles learned and skills acquired in the technical and management courses to a comprehensive whole.

Similar observations were also made in a profile study (Borja, 2003) involving the 1958-2001 alumni of Xavier University College of Agriculture (XUCA), Philippines, the student's home institution. The alumni-respondents highlighted three areas that need to be looked at by the College with respect to its curricular programs: (1) student engagement in more praxis and field work, (2) training of students as generalists since prospective employers often provide the necessary specialized trainings, and (3) strengthening of the research component. The importance and challenge of incorporating faculty and student research, as well as strengthening linkages with government, local communities and other sectors of society, into the day-to-day realm of a traditionally teaching university has also been articulated lately.

PROJECT RATIONALE AND OBJECTIVES

This project, then, proposed two integrative vehicles that would help key stakeholders both in the Vidalia onion industry and the Philippine agricultural education sector to develop more appropriate responses to seemingly divergent concerns.

The first vehicle, which involved the development of an onion packinghouse simulation model, primarily aimed to respond to the current paucity of information about Vidalia onion packinghouses and about the economic and operational implications of adopting the X-ray inspection technology in their facilities. It can be used as an illustrative case in classroom instruction to underscore the importance of both technical and managerial components in understanding the operations of a packinghouse and in considering potential improvements.

The second vehicle involved the development of an interdisciplinary course on improving fresh produce supply chains. Future producers, packinghouse managers, processors, distributors, and other professionals engaged in food and agriculture need to develop a more comprehensive understanding of, and exposure to, both technical and managerial issues confronting the various business links if they are to become more effective contributors to the improvement of the food supply chain. Viewing the Vidalia onion industry as links of a chain, for example, is imperative in understanding the full impact of introducing an improvement in one of these links.

The project, then, has three general objectives: (1) to provide information about the performance of Vidalia onion packinghouses, (2) to assess the economic and operational impact of incorporating an x-ray inspection system into the operations of a Vidalia onion packinghouse using a simulation model, and (3) to develop a means of enhancing the agriculture and food curriculum of XUCA. Specifically, it aims to:

1. Gather baseline information about the operations of a Vidalia onion packinghouse and evaluate its performance in terms of sizing and inspection accuracy;
2. Develop a computer model simulating the flow of Vidalia onions through the grading-packing line with and without X-ray inspection;

3. Evaluate the economic and operational implication of this technology in the packinghouse; and
4. Develop an interdisciplinary course focusing on improving postharvest supply chains.

CHAPTER 2

REVIEW OF LITERATURE

This literature review draws its presentation from four major research streams. The first stream focuses on studies relating to onions in general and to Vidalia onions in particular. It presents the investigations relating to the anatomy and physiology of the harvested onion bulbs, the field and packinghouse operations, losses at the storage and market levels and the economic aspect of Vidalia onion production and packing. The second stream of this review looks at the X-ray imaging inspection technology and its applications in the internal quality evaluation of horticultural products. The third stream delves on the postharvest education in developing countries and on the importance of the interdisciplinary systems approach in improving local postharvest chains. The final stream focuses on the application of simulation models in instruction and in evaluating the economic impact of technology adoption in agricultural enterprises.

THE COMMODITY

The Bulb Anatomy

Komochi (1990), DeMason (1990) and Brewster (1994) provided extensive background on the anatomy of onion bulbs and their formation. An onion bulb essentially consists of six parts (Figure 2.1): (1) the dry outer protective skin, (2) the outer fleshy swollen sheaths derived from bladed leaf bases, (3) the inner swollen bulb scales without leaf blades, (4) innermost sprout leaves, termed as such because they may protrude as sprouts under favorable conditions, (5) the compressed and flattened stem, and (6) the roots. The dry protective skins, which are actually the outer scales that have lost water and dried during maturation, are important to appearance, preventing water loss, and inhibiting infection (Brewster, 1994). These very thin dry scales, particularly those of the Grano and Granex cultivars, are easily lost in harvesting and handling, leaving the fleshy scales unprotected from pathogen invasion and mechanical injuries (Corgan and Kedar, 1990)

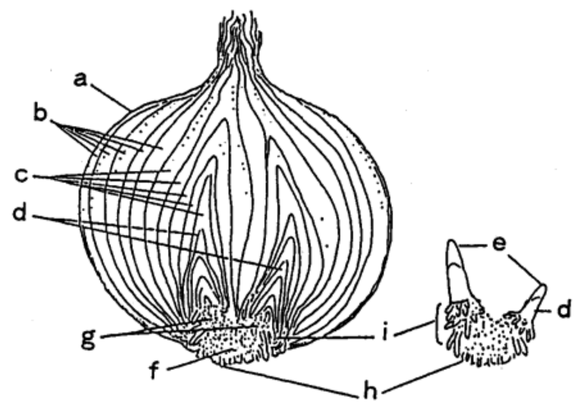


Figure 2.1 Diagrammatic illustration of an onion bulb. Letters denote: a. skin, b: scales with leaf blades, c: scales without leaf blade, d: young sprout leaves, e: sprouting leaves, f: old stem plate, g: new stem, h: outer roots, i: inner roots. (Source: Komochi, 1990 p96).

Onions are frequently classified into three classes, according to the minimum day length requirement to initiate bulb formation: (1) short-day onions, which require approximately 12 hours or less to initiate bulbing; (2) intermediate onions, which need 13-14 hours; and the (3) long-day onions which require above 16 hours (Brewster, 1994).

The Vidalia onion is a short-day onion (Boyhan and Torrance, 2002) and is defined to be any onion of the hybrid granex, granex parentage or other similar varieties that is produced in the Vidalia onion production area (Georgia Department of Agriculture, 2005). There are currently 24 varieties that are planted and marketed as Vidalia onions and are loosely grouped into three broad maturity categories: early, mid-season or late (Boyhan & Torrance, 2002). Maw et al. (1989; 1996) and Maw and Mullinix (2001) presented a profile of some of the physical and mechanical properties, as well as the grade distribution, of selected Vidalia onion cultivars.

According to Corgan and Kedar (1990), most short-day onions are relatively succulent, low in pungency and lack the tough dry scales typical of the storage type cultivars. The mild flavor of Vidalia onions is attributed to the high moisture content and the relatively low level of *S-alk(en)yl cysteine sulfoxide* in the bulbs. However, these characteristics also make these onions highly susceptible to damage as they, unlike their more pungent counterparts, do not possess a natural protection from some diseases (Maw et al., 1998a).

Postharvest Field Operations and Mechanical Damage

The following investigations clearly established the effect of handling procedures on bruise damage incidence from harvesting to packing. Maw et al. (1989) described how bulb bruising could provide a suitable growth environment for pathogenic organisms. They described the onion bulb as made up of concentric rings that adhere to one another. When impact or pressure is applied, the adjacent rings slide over one another at or near the area of impact. This differential movement breaks the seal between the two adjacent rings and provides a space for cell juices to accumulate, thereby creating the appropriate environment for pathogens to grow and multiply. Figure 2.2 shows the various unit operations performed in harvesting onions.

Figure 2.2 Major Unit Postharvest Operations Performed on the Vidalia Onions in the Field

Undercutting of bulbs involves severing the onion roots in the ground through the use of a rotating bar or fixed blade, which may cut, bruise, or displace the onions (Sumner et al., 2001).

In a study comparing the performance of two undercutters (powercutter and rotobar), Maw & Smittle (1986) reported that bulb damage ranged from 5-18%.

Clipping, or the cutting of onion tops and roots to recommended lengths, could also increase the likelihood of injury and/or disease infection of the bulbs. This could arise due to less careful use of shears, the use of contaminated shears (Hurst, 2001) and the presence of onions with extra short necks (Sumner et al., 2001).

While harvesting of Vidalia onions is primarily done by hand, mechanical harvesting has become more prevalent over the past years (Boyhan et al., 2003). Maw et al. (1998a) reported that damage to mechanically harvested onions amounted to 10.3% at moderate speed (2.3 kph) and 5.5% at maximum speed (3.4 kph). However, differing results in the studies of Maw et al. (1998a, 1998b, 1999) comparing the storability of mechanically harvested and hand-harvested onions could also be explained by cultivar differences. Their studies indicated that the shelf life of machine-harvested 'Granex 33' and 'Savannah Sweet' onions was as good as, if not better than, those harvested by hand. They evaluated onion moisture loss and onion decay twice: (1) after 24 weeks of cold and CA storage and (2) after air conditioned storage two weeks later. They also reported that, regardless of harvesting method, 'Sweet Vidalia' onions have greater storability over 'Nikita' onions and that machine harvesting proved to be a more viable option for 'Sweet Vidalia' than for 'Nikita' onions (Maw et al., 1999). Comparing 'Savannah Sweet' and 'Sweet Vidalia' in their 1998 study, the researchers indicated that the former cultivar had greater storability, regardless of harvesting method (Maw et al., 1998b). In that study, storability of 'Sweet Vidalia' onions that were hand-harvested was significantly better than those that were machine-harvested.

Purvis and Torrance (1998) also assessed the impact sustained by onions during harvest and in packinghouse operations using an instrumented sphere. Results of their study indicated high acceleration levels through the mechanical harvester (130G, G = 9.8 m/s^2) and during loading of onions into the trailer (113G). During hand harvesting, the following average acceleration levels were reported: 123G when dropping onions into plastic harvesting buckets at 36 in. high, 161G during loading of field bags onto the truck, and 219G from the truck bed to the stacks of bags. Higher acceleration levels translate to higher bruising probability.

Packinghouse Studies

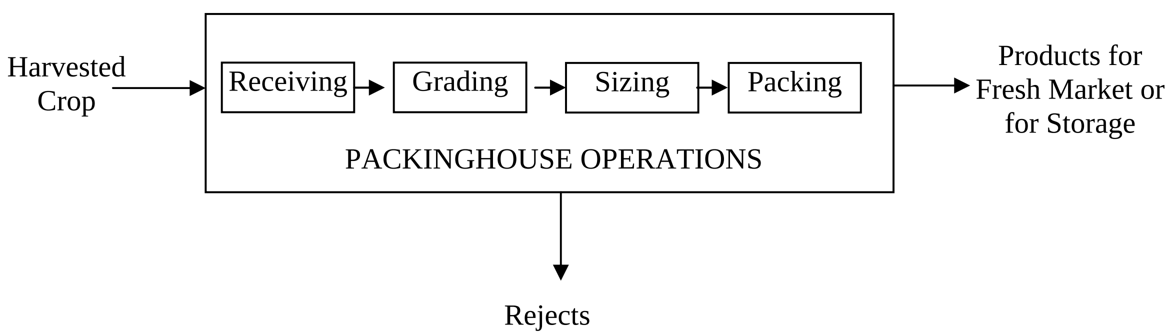


Figure 2.3 Simplified view of Vidalia onion packinghouse operations, showing input and output flows

A packinghouse for fruits or vegetables transforms a highly variable input into a more uniform quality product that meets customer requirements (Figure 2.3). The harvested commodities pass through a series of unit operations where those not meeting the standards are rejected while the rest are stored and/or shipped to various destinations. A survey of literature on the Vidalia onion industry indicated that while there are a number of investigations about the operations of harvested onions en route to, and immediately after, the packinghouse (i.e.

storage), there is a paucity of information originating on Vidalia onion packinghouses. There is limited information, for example, on packing shed performance in removing defective commodities and on the associated economic consequences of any related improvement action, such as the incorporation of a more rigorous inspection system.

Due to this sparsity of information, this subsection also draws on studies of other onion varieties in the United States to help bridge the information gap on Vidalia onions in packinghouse operations until the onions are prepared for subsequent storage or distribution. Related packinghouse studies found in the literature can generally be categorized into: (1) bruise damage incidence and detection, and (2) packinghouse performance or efficiency.

Mechanical Damage Bruise damage investigations at the packinghouse are primarily focused on the mechanical loads sustained by the onions during drops or transfers from one component to another. Common methods of bruise damage assessment at the packinghouse include (1) visual inspection for onion damage before and after each of the identified transfer points in the packing line; (2) use of an instrumented sphere, either impact-recording or pressure-measuring; and (3) laboratory drop tests.

The study of Peterson et al. (1984), which covered several commercial packinghouses, involved the collection of yellow sweet Spanish onion samples before and after each of the five drop or transfer points in the packing lines and storage of packed samples in high humidity environments to accelerate rot incidence. This two year-study reported that there was an overall trend of increasing rot after storage with increased handling of yellow sweet Spanish onions in packinghouses. The same trend was observed whether packing stored or freshly harvested onions. Rot incidence ranged from 7.5-29.9% at the first sampling location and 33.3-54.5% at the end of the packing line.

Timm et al. (1991) and Bajema & Hyde (1995) studied onion packinghouses using instrumented spheres, which mimic the onion as it moves through the packing line. Several transfer points in the packing lines that caused high acceleration impacts were identified. These points generally have large changes in elevation, bare steel ramps and chutes and uncontrolled onion flows. Bajema and Hyde (1995) reported dramatic reduction in the number of impacts experienced in a 'Walla Walla' onion packinghouse after modifications, such as the introduction of lining materials, on the identified transfer points.

The effect of these transfers between successive machinery components on the onions is simulated through the laboratory drop tests. Studies showed that the extent of bruise development is influenced by drop height, by the impact surface and by the condition of the onions (whether freshly harvested or stored) prior to packing. Timm et al. (1991) showed that onions that were cured and stored for two months were more susceptible to damage than those that were freshly harvested. Bruise initiation occurred at lower drop heights (at 6mm and 10mm for cured and freshly harvested onions, respectively) on steel surfaces compared to the Poron 15250 surface (400mm and 450mm for cured and freshly harvested onions, respectively). At the greatest drop height on each surface, the researchers reported that bruise diameter averaged 50% larger for cured onions compared to the freshly harvested ones. Bruise depth was also greater for the cured onions. They also showed that for all surfaces studied, the probability of bruise occurrence increased as the drop height was increased.

Studies also established the relationship between drop height and storage losses in onions. Purvis and Hakim (1998) reported that half of the Vidalia bulbs that were subjected to bruising and stored at 20ºC for five months exhibited decay and were unmarketable. Weight loss during the five-month storage also increased as the drop height was increased. Bruises were introduced by dropping the cured onions from various heights (0, 12, 24, 36 inches) to a steel surface. Herold et al. (1998) also indicated that total mass loss, as well as rotting loss, increased strongly as drop height onto a steel surface was increased. They further showed that multiple mechanical loads, illustrated in the study through repeated drops of onions at the same height, significantly affected respiration rate and caused additional mass losses. For Vidalia onions, Hurst (2001) identified eight potential sites in packinghouses that were likely to inflict bruises on onions. These included (1) unloading conveyor, (2) loading drying bin, (3) wire transfer belt, (4) incline to scale brusher, (5) incline to pre-grader, (6) incline to sizing rings, (7) incline chute to labeler, and (8) labeler to mesh bag.

Packinghouse Efficiency Bollen et al. (1993) presented a comprehensive discussion of the various parameters that affect the design and operation of sorting equipment, as well as outlined the various approaches used by researchers in analyzing the sorting operation. As previously indicated, there is a current paucity of information about the performance of Vidalia onion packinghouses in removing defective commodities and the associated economic consequences of any related improvement action, such as the incorporation of a more rigorous inspection system. Apart from Tollner (1993), for example, there are very limited studies that focus on packing Vidalia onions. Considering the significant market and the value of Vidalia onions in the sweet onion market (Costa et al., 2003), such information would be important in investigating opportunities that optimize, not only the performance of the packinghouse, but also that of the entire onion postharvest chain as well.

Tollner (1993) evaluated the efficacy and economics of incorporating a commercial X-ray inspection machine in an onion packinghouse using an MS Excel spreadsheet. In the study, he tracked 1000 onions from the farmer’s field to retail, using four scenarios: (1) control (no nondestructive testing (NDT) technology at the packinghouse and no repack at the distribution center; (2) no NDT with repack; (3) with NDT and no repack; and (4) with NDT and repack. He has shown that machine accuracy and false positive statistics were within acceptable ranges, and that the "NDT with repack" treatment increased the product value at the retail level. He also showed that such a technology addition would not be profitable to the packinghouse unless vertical integration of supply chain operations was in place. However, the subjective assumptions used in the simulation model, such as the price multipliers, costs, product yields at each business level, as well as the Gaussian distribution assumption of onion sizes, need to be further examined.

Other Georgia-based studies on packing fruits or vegetables were also sparse. Studies found focused on loss assessment and simulation of operations prior to the grading process. Campbell et al. (1986) evaluated the postharvest losses of tomatoes from a single farm, starting at harvesting until the commodity was displayed in a retail outlet. He found that of the harvested tomatoes entering the packinghouse, about 42.7% were discarded. This is broken down into defective (25.4%), damaged (16.3%) and uninjured tomatoes (1%). Only 35% of the total harvested tomatoes reached the retail market. From this study, a simulation model was constructed and seven sample scenarios were analyzed to illustrate the breadth of use of the model in evaluating a postharvest system. Because this study focused on the entire fresh tomato supply chain, it did not provide information on the efficiency of each business link, particularly that of packinghouses and on possible process improvement areas. A simulation model for peach postharvest operations was also created by Thai and Wilson (1988). However, the grading and boxing operations were not dealt with in great detail as the study focused its analysis on the interaction effect of three factors (speed of peach pickers, speed of hydrocoolers and distance between the orchard and packinghouse) on the overall product flow, using 27 sample scenarios.

Other studies focused on simulated defect detection of horticultural produce and on the improvement of visual sorting performance. These studies, however, did not deal with any specific commodity. More data from actual packing lines are necessary to make these studies more meaningful to the intended packinghouse operators. Thai et al. (1986) developed a computer model that simulated the incidence and detection of latent damages in horticultural products. Each entity in the model was assigned a shelf life using a probability distribution, and this shelf life was reduced whenever it went through a packinghouse operation that produced latent damage on the commodity. Whenever the current shelf-life is less than the actual time elapsed since harvest, the entity is considered defective or unacceptable. This simulation model used ten packinghouse steps, two of which were assumed to inflict latent damage on the commodity. This study demonstrated that latent damage incidence and detection in packinghouses and in the entire postharvest chain can be feasibly represented using a discrete event model. While the simulation model helped in visualizing the impact of latent damage on shelf life, it was still too general to be of substantial assistance to the supply chain stakeholders for a particular commodity. The work of Prussia (1985) and Meyers (1988) provided a glimpse of possible areas that could be investigated to improve visual inspection performance of packinghouses. However, additional information about packing specific commodities would help in making these studies more meaningful to concerned packinghouse operators. Finally, a study investigating the efficiency of five onion packinghouses in Argentina (Lopez Camelo et al., 2003) reported that all the studied packinghouses failed to meet the established limits for ‘slight’ defects and only one of them was able to comply with the standards for ‘basic’ requirements when preparing Extra class onions. The study also reported that the sequence of sizing before sorting and running speed of sorting tables are the most important factors in improving overall efficiency of the packinghouse.

Storage Losses

Although the literature on Vidalia onion packinghouse performance has been sparse, reports on storage losses highlight the limitations of the current inspection system employed at the packing sheds. Vidalia onions are stored in a variety of ways, depending on the market windows (Tollner et al., 1994). These include: (1) the fresh market window, where onions are sold directly from the packinghouses; (2) early market window, where onions are stored in a well-ventilated space; (3) mid-season market, where onions are kept in an air-conditioned environment; (4) late market window, where the onions are stored in a cold room; and (4) CA market window, where onions are stored under CA storage conditions (3% oxygen, 5% carbon dioxide, 92% nitrogen). The introduction of the CA storage technology extended the availability of Vidalia onions into late summer and fall, subsequently increasing the production acreage (Boyhan et al., 2003), as well as the risk of storage losses due to Botrytis neck rot. Approximately half of the production volume each season are put in CA storage to extend the marketing period (Purvis et al., 2002).

Maude (1990), who gave a comprehensive overview on storage diseases of onions, devoted a whole section on Botrytis neck rot, the most economically important of all the storage diseases. The fungus occurred more frequently on mild onion cultivars, such as Vidalia onions, than on the more pungent varieties. Maude (1990) attributed this to differences in the content of volatile sulfides in the fleshy storage scales and to the phenols in the dry outer skins between the mild and the more pungent cultivars. This disease carries no visible symptoms when internally infected bulbs are placed in storage but eight to ten weeks later, necks of affected bulbs soften and beneath the onion skin, a mass of black sclerotia develop. The incidence of neck rot in stored bulbs is increased by bruising during harvesting and subsequent handling.

Onions with internal diseases, such as neck rot caused by *Botrytis allii*, were not eliminated by visual sorting before the graded bulk were placed in various storage conditions. This was shown in studies of Boyhan et al. (2003) and Maw et al. (2005). Boyhan et al. (2003) evaluated the storability of onions during the 2001-2002 Vidalia onion variety trials using CA storage. About 22.68 kg (50lb) of previously graded onions from each plot were placed in CA storage. After 4.75 months in storage, onions were graded and the remaining marketable onions, kept at ambient room temperature, were re-evaluated after 14 days. They reported that the percentage of marketable onions that were obtained after CA storage ranged from 61-94% of the pre-storage weight. After the 14 day-ambient temperature storage, marketable onions were only 32.4-83.2% of the pre-storage weight. Marketable onions after CA storage from the previous year's variety trials ranged 18-63% of the pre-storage weight. The researchers attributed the high cull rates to Botrytis neck rot, accounting for 77% of all culls from storage.

Maw et al. (2005) reported that under warm temperature, low humidity storage conditions, internal diseases, such as that caused by *Botrytis allii*, developed while surface diseases, such as sour skin, are eliminated. Under cold and CA storage conditions, internal diseases were less likely to develop compared to low humidity, warm air storage, but the microorganisms nonetheless survived. Graded onions in this study were stored in the aforementioned conditions for 15-22 weeks.

Purvis et al. (2002) studied the spread of *Botrytis allii* in the mechanically harvested, cured and graded jumbo 'Savannah Sweet' onions during refrigerated and CA storage. The onions were carefully examined to insure that only blemish-free marketable onions were stored. These onions were then subjected to the following six treatments: (1) untreated onions (control); (2) onions + five onions inoculated with *B.allii*; (3) bruised onions (dropped onto a concrete floor from a height of 76.20 cm); (4) bruised onions + five onions inoculated with *B.allii*; (5) cut onions (3.81cm, 0.64cm deep gashes on the opposite sides along the equator); and (6) cut onions + five onions inoculated with *B. allii*. The researchers reported that the fungus grew in inoculated onions both in CA and refrigerated air storage. *Botrytis allii*-inoculated onions stored with sound onions did not infect the marketable onions, but the inoculated onions did infect bruised onions stored in air and onions with cuts in CA and air.

Losses at the Shipping and Retail Levels

Ceponis et al. (1981) and Ceponis and Butterfield (1981) reported the dry onion losses during shipment to, and at the retail and consumer levels in, New York. Although these studies did not focus on Vidalia onions, their work nonetheless provided a glimpse at the extent of losses incurred on the downstream side of packinghouses. Eleven of the 24 disorders found in the shipments were caused by pathogens. The most prevalent were bacterial soft rot and gray mold rot/Botrytis neck rot. At the retail and consumer levels, leading loss contributors were gray mold rot caused by the *Botrytis spp.*, bacterial rots and black mold. Mechanical and freezing injuries were the leading causes of non-pathogenic losses.

Vidalia Onion Economics

There is very limited information about the economic aspects relating to Vidalia onion production and packinghouse operation. Boyhan and Torrance (2003) estimated a total budgeted cost of $3,431.25 per acre. This value is comprised of variable costs (preharvest, harvest and marketing costs) and fixed costs (machinery and irrigation, land, overhead and management). On a 22.7 kg (50 lb) bag basis, this budgeted cost is about \$8.58. The researchers also presented estimated revenues at the pessimistic, optimistic and expected scenarios. Prices and yields in the 'expected' scenario are defined as those that a particular grower would anticipate half of the time, while the 'optimistic' scenario is based from prices and yields that a grower would expect to reach or exceed one year in six and the 'pessimistic' scenario on poor prices and yields that would be expected one year in six.

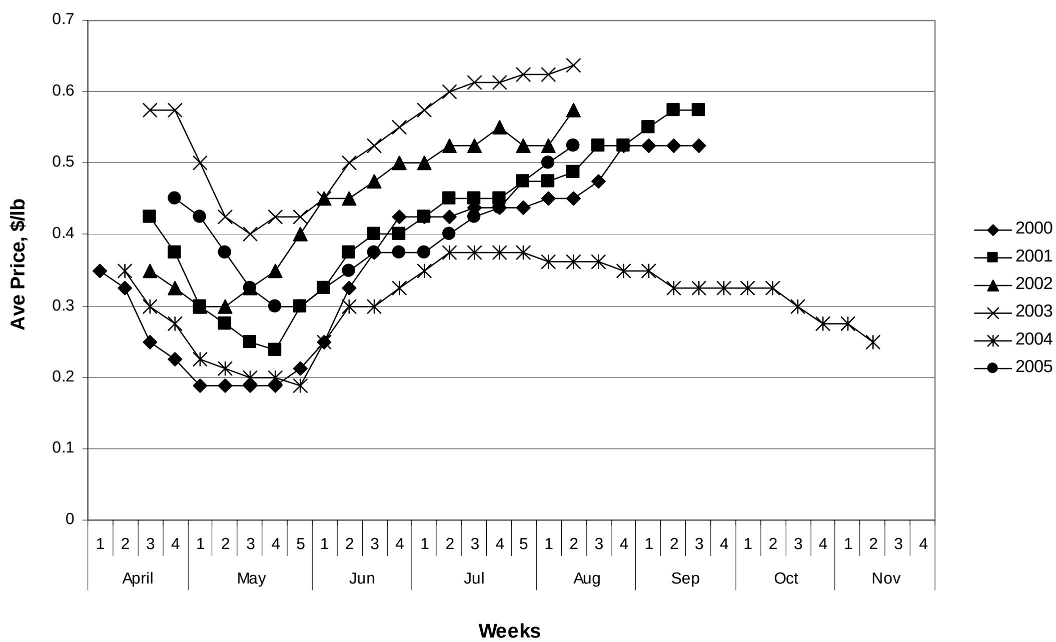


Figure 2.4 Average price per pound of jumbo onion, based on the Vidalia district, GA weekly shipping point prices for 40lb packages (USDA Agricultural Marketing Service, 2006)

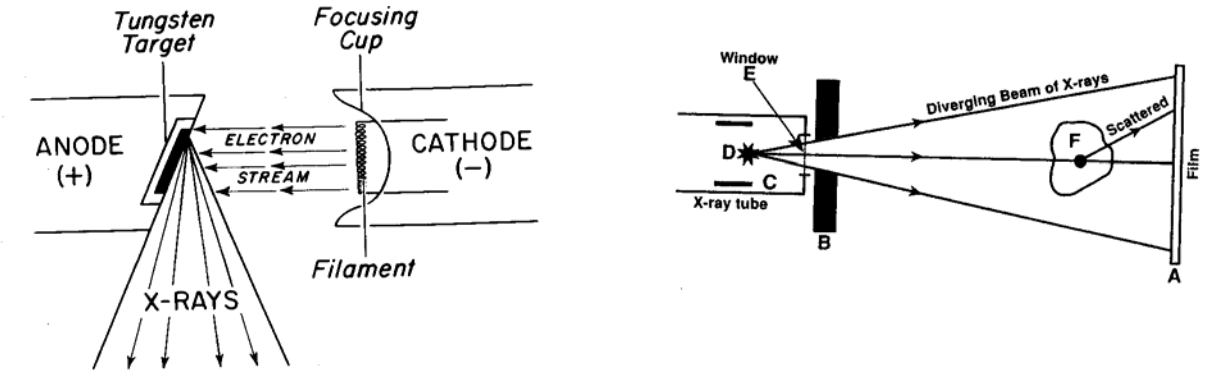
Figure 2.4 shows the average shipping point prices of jumbo onions from the Vidalia district during the past six years. These prices were computed from the weekly shipping point high and low prices reported by the USDA Agricultural Marketing Service (2006) for 18.14 kg bag of jumbo onions.

X-RAY IMAGING-BASED INSPECTION TECHNOLOGY

The application of x-ray imaging in the internal quality evaluation of agricultural produce has been investigated for many years. Internal quality evaluation is enabled because physiological changes during plant development as well as internal damage due to infestation, mechanical injury or disease progression are all associated with tissue density variation. Some of these studies include (1) detection of insect infestation, bruise or internal defects in sorghum (Stermer, 1976), almonds (Kim and Schatzki, 2001), apples(Diener et al., 1976; Schatzki et al., 1997; Tollner, 1993), mangoes (Thomas et al., 1995; Thomas et al., 1993), mangosteen (Yantarasri et al., 1998) and pears (Lammertyn et al., 2001); (2) determination of physiological maturity of lettuce (Garrett and Lenker, 1976), tomato (Brecht et al., 1991), durian (Yantarasri et al., 1998) and peach (Barcelon et al., 1999b); and (3) evaluation of internal quality changes during postharvest storage of peaches (Barcelon et al., 1999a) and mangoes (Barcelon et al., 1999c).

Basic Principles of X-ray Imaging

X rays are electromagnetic radiations of very short wavelengths and are commonly generated when a solid metallic target is bombarded by a high-speed stream of electrons (Bray and McBride, 1992; Cartz, 1995; Curry III et al., 1990). The basic elements involved in X ray generation are shown in Figure 2.5a. Electrons, produced by the heated filament, are accelerated across the evacuated tube to hit the tungsten target. As the electrons converge onto the target, their kinetic energy is dissipated through the emission of a broad-band spectrum of X rays (Cartz, 1995; Curry III et al., 1990).



(a) **(b)**

Figure 2.5. Basic principles of x-ray imaging. (a) Elements involved in x-ray generation (Curry III et al., 1990) and (b) Schematic diagram of an x-ray system (Cartz, 1995)

Cartz (1995) showed the schematic diagram of an X-ray system for radiography in Figure 2.5b. As the beam of x-rays leaves the source, which is a spot source or as nearly a point as possible, it passes through the window E and diverges through the collimator (aperture), B, to the detector, A, which may consist of an image intensifier or an X-ray film. The resulting image on the film reflects the differing amounts of absorption that occurs as the rays pass through the object F, as well as the scattering of radiation by the object or by the test environment.

The x-ray absorption process has been described using Beer-Lambert's Law: $I_z = I_O e^{-\mu z}$, where: I_Z = intensity of the beam at a distance z, I_O = intensity of the beam at the surface of the specimen, z = length of the path of travel or thickness of the test object, μ = linear absorption or attenuation coefficient, which is the fractional decrease in intensity on traversing a unit length of path. The degree of attenuation of an x-ray beam as it passes through matter depends on the radiation energy and the composition of the test object (density, atomic number and electrons per grams) (Curry III et al., 1990). The higher the energy of radiation, the larger the percentage of transmitted photons (x-ray transmission increases), thus attenuation decreases. Tissue density is one of the most important factors in x-ray attenuation. Some tissues attenuate more x-rays than others. It is this difference in tissue densities that determines the amount of contrast in the X-ray image. Density determines the number of electrons present in a given thickness, so it determines the tissue's stopping power. The relationship between density and attenuation is linear (Curry III et al., 1990).

Vidalia Onion Defect Detection and Produce Classification

In the case of Vidalia onions, the application of X-ray imaging has been studied by Tollner and his colleagues at the University of Georgia. Their efforts, over the years, can be broadly categorized into two: (a) defect detection studies, and (b) development of a produce classification system. Lately, there is an effort to investigate the economic impact of the technology but the lack of information from the field has hindered a more thorough analysis of its economic implications.

As in previous studies that used X-ray imaging to assess internal quality of horticultural produce, early defect detection studies in onions focused on computed tomography. Maw et al. (1995), for example, identified damage within sweet onions due to physical impact using X-ray CT scans. They noted that the cross-section of damaged onions showed more air spaces between the rings than those which were not internally damaged. The presence of air spaces was manifested on the scanned image as darker grey areas or regions of low density, whereas the denser tissues were represented by lighter shades of grey. Tollner and Shahin (1993) demonstrated the applicability of X-ray line scan imaging in detecting internal onion defects, such as ring decay, ring separation and internal sprouting. Between the two scanning modes (computer tomography and line scan) for generating X-ray images, the line scanning mode is less accurate but is more appropriate for packinghouse operations due to speed considerations

(Tollner, 1993). In this mode, the commodity to be inspected is passed over a linear array of detectors. An image is subsequently created line by line through repeated scanning as the produce advances on the conveyor. Tollner (1993) also described the principles underlying the X-ray linescan system.

In a series of studies in 2001, 2002 and 2004, Tollner et al. (2005) evaluated a commercially available food product X-ray line-scan inspection machine (Heimann EaglePack® of Smith-Heimann Systems Corp., Alcoa, TN), which utilized a combination of a threshold and morphological classification algorithm to sort good from defective products. In these studies, the rejection parameters of the equipment were configured to suit Vidalia onion inspection. Tollner et al. (2005) indicated that the machine rejected onions with severe defects 100% of the time and those without or only slight defects passed nearly 100% of the time. In their 2004 study, the researchers further reported that 80% of the fruits that passed the routine visual inspection were found to have center rot disease.

While the machine has the potential to detect onion defects, as manifested by the acceptable range in its accuracy and false positives rates, the researchers noted the following to achieve a more consistent machine performance: (1) better singulation and consistent orientation of the onions as they move through the inspection machine, and (2) evaluation of the effect of the various types of diseases and their level of progression in the bulbs on machine accuracy. It was estimated that this machine could inspect onions at approximately 25 bags per hour (Tollner et al., 2005).

Aside from defect detection, there is a body of literature that also focused on image analysis to improve produce classification. Tollner et al. (1994)**,** for example, reported that 70% of the good onions and 70% of the bad onions were correctly classified in their study but emphasized the need to understand classification errors and the need for further studies on image analysis techniques. Tollner and Shahin (1993; 1997) explored the use of image analysis techniques to improve defect detection accuracy. Defects were shown as bright lines or arcs in the processed image. In their 1997 study, accuracy of close to 90% was observed. Shahin et al. (2002) developed a neural classifier for sweet onions and compared its performance against the Bayesian classifier using features extracted from line-scanned images. The researchers reported that the neural classifier that was developed in this study performed better in terms of accuracy and false positives. The selected features used in these classifiers were considered good indicators of internal defects and were extracted and processed using computer programs.

Later investigations relating to the use of X-ray imaging on Vidalia onions explored the economic implications of adopting this technology in packinghouses. Tollner (2004) developed an MS Excel-based model that covers the entire postharvest chain to assess the costs and benefits of incorporating this technology. Four conditions were simulated (control; repackaging at distributor; nondestructive technology at packinghouse; and distributor repackaging with nondestructive technology at packinghouse). The simulation results indicated that while the addition of technology adds value to the consumer, it can cause adverse financial implications to the packinghouse operator (Tollner, 2004). The author, however, indicated that the model needs more objective inputs.

POSTHARVEST EDUCATION IN DEVELOPING COUNTRIES

Mrema and Rolle (2002), Goletti (2003) and Yahia (2005) discussed the continued relevance and importance of the postharvest sector in the global economy, and particularly that of developing countries, in the light of emerging global trends, such as urbanization, liberalized international trade systems, increased concern for food quality, food safety, the environment and sustainable development, emergence of global value chains and information technology developments. Yahia (2005) presented the various global efforts since 2001 that were instituted to improve the postharvest sector of these countries, which is characterized by huge postharvest losses, low research activity and inability to apply the technologies developed in other countries despite the obvious need. In the Philippines, for example, average postharvest losses for fruits and vegetables are 28% and 42%, respectively (Castro, 2003) and research productivity during the last 18 years, in terms of contribution to the total number of postharvest publications, was 0.62% (Yahia, 2005) .

Goletti (2003) and Yahia (2005) advocated the use of a multidisciplinary systems approach as one of the strategies in reducing postharvest losses of developing countries. Mrema and Rolle (2002) also emphasized the increasing importance of a closer integration of harvesting, handling, processing, packaging, storage, transportation and marketing in response to current trends.

Development of adequate human capacity through training and education to address high postharvest losses was emphasized by Yahia (2005) and Asiedu (2003). The need for an interdisciplinary, systems approach to agriculture and rural development education was also stressed by Lindley (1998) and the Food and Agriculture Organization (FAO) (1997) in the light of rapid changes in agricultural and food systems. FAO's Sustainable Development Department indicated that training in the systems approach "requires a teaching methodology using case studies, problem solving approaches and practical exercises", emphasizing that in many developing countries, "agriculture education and training failed to adapt and respond to the realities of rural societies" (FAO, 1997). The relevance of the agriculture curriculum to current and emerging realities was a common issue in all eight regional round table workshops conducted by FAO in the early 1990s. These workshops were attended by heads of agriculture university faculties, agricultural colleges and technical education institutions, high schools and the officials of Ministries of Agriculture and Education.

A similar concern was also experienced in the United States when a nationwide project was undertaken in 1982 to strengthen higher education in agricultural, food and natural sciences programs plagued with declining enrollments and criticisms from the agricultural and business communities (Wilson and Morren, 1990). Educational institutions failed to equip graduates with the necessary skills to cope with the range of complexity that would deal with on the job. One of the identified priority areas for curriculum development was systems analysis in food, agriculture and natural sciences, of which Wilson and Moreen’s book (1990) was the product. They advocated the soft systems perspective as a new way of learning about, food, agriculture and natural resources situations. This was to be part of a broad range of inquiry methodologies in responding to the challenges and opportunities in food and agriculture. Details of this methodology are presented later in this section.

Interdisciplinary Systems Approach in Undergraduate Programs

While there were still no reports found in the literature on the use of an interdisciplinary systems approach in postharvest courses, there are already several cases that illustrate the successful incorporation of the interdisciplinary perspective and systems approach to problem-solving in undergraduate programs of agriculture and natural sciences in the United States. These ranged from an intensive eight-day travel course (Wiedenhoeft et al., 2003) to semester-long courses. These semester-long courses were based on a single campus (Arthur and Thompson, 1999; Karsten and O'Connor, 2002; Murphy et al., 1990; Salvador et al., 1994; Schelhas and

Lassoie, 2001; Schmidt et al., 2001) or on several campuses (Dooley and Neill, 1999). A brief description of the various methods employed is presented below.

An intensive field course in agroecosystems analysis was developed wherein interdisciplinary student teams, engaged in farm visits, group work activities, consultations with faculty members and oral presentations over an eight day period, evaluating and analyzing the productivity, economics, environmental impacts, and social viability of several farms in the Midwest (Wiedenhoeft et al., 2003). This course involved undergraduate and graduate students and faculty members from Iowa State University, University of Minnesota and University of Nebraska Lincoln in 1998 and 1999 and has attracted students from various disciplines: agronomy, general agriculture, horticulture, natural resources, environmental science, agricultural economics and anthropology.

Interdisciplinary teaching characterized the site-specific agriculture (Schmidt et al., 2001) and sustainable agriculture science and policy (Karsten and O'Connor, 2002) courses offered at Kansas and Pennsylvania State Universities, respectively. The site-specific agriculture course was team taught by faculty members from the agronomy, biological and agricultural engineering and geography departments. The course was open to juniors, seniors and graduate students, with the majority (77%) coming from agronomy and agricultural technology and management areas while the remaining came from agriculture business, agricultural economics, animal science and industry, biological and agricultural engineering, chemical engineering and geography. The sustainable agriculture science and policy course, on the other hand, was taught by an agroecologist and a political scientist with invited guest lecturers in soil conservation, nutrient management and agricultural economics. Enrolled students are from agriculture, political science, business and liberal arts.

The capstone course for the natural resources conservation and management majors at the University of Kentucky employed the problem-based learning approach (Arthur and Thompson, 1999). Immersed in a natural resource issue, student teams identified and assessed the interests of key stakeholders through various data collection methods and present alternative courses of action. The issue was chosen by the instructor. A team of faculty members representing relevant fields served as advisors. This problem-based learning approach was also seen in the forestry capstone course at Iowa State University. In this case, however, student teams choose the problem they would like to work on from a list of actual problems submitted by foresters and other interested parties throughout the state (Salvador et al., 1994).

A seminar course, which was first offered in the 1989 spring semester at the University of Illinois, utilized the soft systems approach to solving problem situations in agriculture. Unlike the other previously described courses, this seminar course focused on freshmen and sophomore students. Other cases illustrating the application of multidisciplinary, systems-level approach to learning in universities are also presented by Schneider et al. (2005).

Soft Systems Approach

Soft systems methodology (SSM) was developed by Peter Checkland and his colleagues at the Lancaster University, UK (Checkland, 1981; Wilson and Morren, 1990). In this approach, the focus is on problematic situations and the modeling involves human activity systems. Differences from the hard systems thinking and other inquiry modes is discussed in Wilson and Moreen (1990). SSM is comprised of seven stages, of which stages 1,2,5,6, and 7 are considered the real-world activities while stages 3 and 4 are the systems-thinking activities. Stages 1 and 2 involve identification and synthesis of information about the problematic situation, rather than looking for the problem. Basic facts are gathered from documentary sources and from the accounts and opinions of people involved in the situation. The objective is to display the problem situation from a diverse range of viewpoints and to synthesize what has been gathered into useful alternative conceptualizations. Once the present situation is understood, a vision of the future state should look like is defined. Stages 3 and 4 are aimed at using systems thinking to design and describe proposed future improvements. These stages involve defining relevant human activity systems using the CATWOE[1] mnemonic for each transformation statement and formulating conceptual models of each human activity system. Stage 5 compares the conceptual models with the situation summary developed during stages 1 and 2. This comparison could provide new insights about the problem situation and could introduce specific proposals for change. Stage 6 is focused on debating desirable and feasible change among the people concerned. For a change to be feasible, it must be implemented with the resources and capabilities at hand and should be environmentally appropriate, avoiding unacceptable costs and factors over which people have no control. Stage 7, the implementation stage, is focused on planning for and taking the necessary steps to implement the agreed changes to improve the situation.

The work of Rohs et al. (2002) and Prussia (1999) illustrate cases of how this methodology can be applied in the postharvest sector. Other cases illustrating its use in agriculture and agricultural education are seen in Macadam and Packham (1989), Macadam et al. (1990) and in the sample cases used by Wilson and Moreen (1990).

[1] CATWOE stands for Customers, Actors, Transformation, Weltanschauung (world view or mental framework), Owners and Environmental constraints

SIMULATION MODELS

Models are simplified, yet sufficiently detailed, representations of a system under study. They can be mathematical or physical, static or dynamic, deterministic or stochastic, and discrete or continuous. Banks and Carson (1984) gave a comprehensive discussion of the various steps toward building a thorough and sound discrete event simulation model.

Simulation modeling is one of the many tools available to managers of agricultural businesses to learn more about their business environments and to improve their decision making. These models, for example, can provide a safe environment for these managers to investigate the economic benefit of a new technology for a variety of field and market conditions before actually testing or investing in the technology. Because models provide an opportunity for reflection and experimentation without the attendant costs, they enable managers to more fully understand the complex environment in which they work (Fisher et al., 2000), reducing uncertainty when making decisions. A simulation model is also a powerful teaching and learning tool for teachers and students. The following subsections present two of the uses of simulation models.

As a Tool for Economic Analysis

While a number of economic analyses typically use the static and deterministic partial capital budgeting approaches in evaluating alternatives or evaluating the impact of incorporating new equipment into operations such as those in Ball and Folwell (2004), and Harper et al. (1999), there are studies already that report the use of simulation models in assessing the impact of technology adoption on the financial performance of an agricultural enterprise. Cooper and Parsons (1999), for example, simulated the incorporation of an automatic milking system on a dairy farm by following the activities of zero-grazed and manually fetched cows throughout the year. Results of their simulation model were then incorporated into a financial model and the conventional milking parlor and an automated milking system were then compared in terms of yearly profits. Gempesaw et al. (1992) also used a simulation model to conduct the economic evaluation of a computerized feeding system for three different farm sizes. A similar approach was seen in Miller et al. (1994) in modeling the performance of a bagging machinery for fresh citrus and evaluating its potential economic benefit***s.***

As a Tool for Classroom Instruction

The use of simulation models as an instructional tool in agriculture education and training has been demonstrated in the literature. Some of these include PORKSIM, a pork production simulation, a soybean marketing simulation game, and the crop simulation models, PEACH and Virtualcarrots. PORKSIM, a spreadsheet template simulating the production, marketing and managerial interactions of pork production, has been used in a University of Nebraska-Lincoln animal science senior class for several years to aid students in understanding the interrelationships of production and economics (Massey and Reese, 1995). This tool enabled animal science students to develop a more comprehensive understanding of the pork production system and the existing interrelationships of production, economics and marketing. Popp and Keisling (2001) developed a soybean marketing simulation game at the University of Arkansas primarily to demonstrate the impact of cash sale and storage decisions on profitability to a lay audience. The game required minimal time from participants and could be presented during “field days” and classroom sessions. The education value of crop simulation models was also demonstrated in PEACH and Virtualcarrots simulation models. PEACH demonstrated the interactions between environmental factors, physiological processes and management practices on size and yield of peach fruit (DeJong, 1999). Originally intended as a research tool, the simulation model has been modified into the Windows environment for use in undergraduate pomology classes at the University of California-Davis. Virtualcarrots, on the other hand, is an online carrot simulation model designed to improve instruction on yield-density relationships of field crops at Massey University in New Zealand (MacKay et al., 2005). Aside from understanding yield-density relationships, the tool enabled students to evaluate the impact of seasonality and growing region on yield. Originally, this lesson was taught by the time consuming method of students generating actual crop data, by growing and harvesting carrots in small experimental plots, and analyzing and reporting the results. The loss of first-hand experience by growing and harvesting carrots was handled by a field trip to a commercial grower.

Van Schaick Zillesen (1994) also explored the potential of educational simulations in teaching a food and bioprocess engineering program in the Netherlands and cited the various benefits that can be obtained from such techniques. The researcher also indicated that the number of educational simulations developed remained limited due to high costs. However, as shown by DeJong (1999), simulations could stem from research efforts and could be modified for classroom instruction.

In the postharvest fresh produce sector, there is limited information about the use of simulation models as instructional tools. Aggarwal et al. (2003; 2004), noting this lack amid the proliferation of simulation games and models in other areas, developed a simulation game for peach retail ordering using Stella 7, a systems dynamics simulation software. The peach game focused on the importance of produce ordering to meet consumer demand for peaches, considering fruit perishability, delivery delays, and financial performance.

SUMMARY

Studies in four major research streams were drawn for this literature review: the anatomy and postharvest handling of onions, X-ray imaging based inspection technology, postharvest education in developing countries, and the use of simulation models in research and instruction. Paucity of information about the performance of Vidalia onion packinghouses is highlighted vis-à-vis the current huge CA storage losses that continue to plague the industry. Studies illustrating the potential of X-ray imaging technology in evaluating the internal quality of horticultural produce as well as efforts to investigate the applicability of the technology to detecting internal defects in Vidalia onions were discussed. Literature on agriculture education highlighted the need for an interdisciplinary systems approach to make academic programs in developing countries more relevant to the needs of the local communities. Studies illustrating the utility of the soft systems approach in postharvest supply chains were also presented. Studies utilizing simulation models for understanding a system, evaluating the economic implications of technology adoption as well as its importance in classroom instruction were also reviewed. While simulation models seem to proliferate in many areas in agriculture, the literature is sparse with respect to its use in education and training in the postharvest fresh produce sector.

CHAPTER 3

VIDALIA ONION PACKINGHOUSE EVALUATION AND PRODUCT FLOW SIMULATION[1]

[1] Maria Rosario P. Mosqueda, E.W. Tollner, G.E. Boyhan and R.W. McClendon. To be submitted to the *Applied Engineering in Agriculture*.

ABSTRACT

Lack of information on Vidalia onion packinghouse performance hinders exploration and assessment of improvement opportunities. This study evaluated the sizing and inspection performance of three Vidalia onion packinghouses and developed a simulation model to demonstrate the impact of improving these two performance variables on potential sales revenue generation. A total of 550 Vidalia onions were obtained from three packinghouses for the two-performance variable evaluation. Results indicated significant difference ($p<0.05$) among the three packinghouses in terms of sizing error rate. The major departure from homogeneity was caused by a relatively higher fraction of incorrectly sized onions in one packinghouse. There was no significant difference ($p>0.05$) between the packinghouses in terms of percentage rejects in the sorted Grade 1 onions. One packinghouse failed to meet the tolerance limit for defects, as specified by the US Grade Standards. The simulation model, developed from the onion attributes of the 2005 and 2006 four-cultivar samples and from the 2006 three-packinghouse time study, demonstrated the potential sales revenue differentials that can be realized in packinghouses by improving sizing accuracy and human grader performance.

***Keywords*:** Vidalia onion, packinghouse simulation, sizing, inspection, Allium cepa, short-day onions, postharvest

INTRODUCTION

While there have been a considerable number of studies on the production, curing and storage and marketing of Vidalia onions, there is little information about the performance of the packinghouse. No study was found, for example, that assessed the efficiency of these packinghouses in removing defective onions and the associated economic consequences of any related improvements. Considering the importance of Vidalia onions in the national sweet onion market (Costa et al., 2003), the huge storage losses due to Botrytis neck rot (Boyhan and Torrance, 2002; Purvis et al., 2002) as well as the potential losses due to the manifestation of bacterial and mold rots at the retail and terminal markets (Sumner et al., 2001), more information about packinghouse efficiency could benefit the entire Vidalia onion postharvest supply chain.

Previous studies related to Vidalia onion packinghouses focused on bruise damage evaluation using instrumented spheres or through laboratory drop tests. Purvis and Torrance (1998) assessed the impact sustained by onions from harvest through the packinghouse using an instrumented sphere. Purvis and Hakim (1998) studied the relationship between drop height and storage losses in cured onions. They simulated the loads sustained by onions during drops or transfers from one packinghouse operation to another through laboratory drop tests. Hurst (2001) pointed out eight potential sites in packinghouses that were likely to inflict bruises on onions.

The work of Prussia (1985) and Meyers (1988) presented an in-depth investigation into the sorting process and suggested several methods to improve visual inspection performance at packinghouses. These studies, however, did not focus on specific commodities and were conducted under controlled conditions. Additional investigations into the packing of specific commodities in actual packinghouses may be necessary to make these studies more realistic and meaningful to packinghouse operators.

Simulation models of tomato and peach postharvest operations allowed the evaluation of potential scenarios confronting the key stakeholders of these supply chains. Campbell et al. (1986) constructed a simulation model for the tomato postharvest supply chain and analyzed seven potential scenarios to illustrate the breadth of its application. The model was based on actual postharvest losses measured by Campbell et al. (1986) while following a shipment of tomatoes from harvest to retail. Because this study focused on quantifying the postharvest losses of the entire fresh tomato supply chain, it did not provide information on the efficiency of each business link, particularly that of packinghouses and possible process improvement areas. A simulation model for peach postharvest operations was also created by Thai and Wilson (1988). However, the grading and boxing operations were not studied in detail as the work focused on the interaction of the three factors (speed of peach pickers, speed of hydrocoolers, and orchard-packinghouse distance) on overall product flow. These simulation models allowed users to investigate various scenarios and to quantify the resulting impact on their operations without the attendant experimental costs.

To alleviate the current lack of information about Vidalia onion packinghouses, and considering the suitability of simulation models in evaluating practical postharvest situations, this research has the following objectives: (1) evaluate the sizing and inspection performance of Vidalia onion packinghouses, (2) develop a discrete event simulation model of the grading and packing line operations, and (3) use the simulation model to demonstrate the effects of improving these two performance variables on potential sales revenue generation.

MATERIALS AND METHODS

Evaluation of Sizing and Inspection Performance

Data on the sizing and inspection performance of three packinghouses located in the Vidalia onion production area were obtained during the 2006 harvest season. These sites are subsequently referred to in this report as packinghouse A, B, and C. Fifty onions from each of the packinghouses' size categories were obtained for evaluation. The onions were visually inspected for defects and equatorial diameter measurements were obtained. These measurements were then compared to the size categories used by the respective packinghouses. The chi-square test on equality of several proportions was used to determine variation in sizing and inspection performance among the three packinghouses. Packinghouse performance was also compared to the size and defect tolerance limits specified in the US Grade Standards for Bermuda Grano-Granex Type Onions (USDA Agricultural Marketing Service, 1995).

System Description and Simulation Model Development

Figures 3.1 to 3.3 show the layout of the three packinghouses. These grading-packing lines shared the same four basic processes of receiving, external bulb inspection, size sorting and packing.

Onions enter the grading lines either in bulk bins that are emptied mechanically into the hopper or through a series of conveyors as they are moved from the dryers. The bulbs are then cleaned, pre-sized, and moved through the inspection area through roller conveyors. Workers, who are positioned on either one or both sides of these conveyors, removed the defective onions by hand. The US Grade Standards for Bermuda Grano-Granex Type Onions (USDA Agricultural Marketing Service, 1995) provided the basis for grade classification.

Only those meeting Grade 1 classification are packed as Vidalia onions. Packinghouses A and B considered all rejected onions as culls that have to be disposed of while packinghouse C used Grade 2 jumbos for processing and disposed of all others as culls.

After inspection, a series of hexagonal chain link conveyors sorted the onions into three or four size categories. The bulbs are then moved on belt conveyors to the packing line or into the accumulator bins for storage. Another set of workers are typically positioned on the sides of these belt conveyors for subsequent inspection of the onions. Labeling machines are mounted over a section of these lines so that onions are individually labeled before reaching the box filling area. Grommet roll conveyors are also installed in these lines to facilitate better singulation of onions during labeling.

Onions packed immediately after grading are typically placed in 18.14 kg standard cardboard boxes. The medium grade onions (small mediums, large mediums, or premium mediums) are diverted into accumulator bins for storage or for packing into other package sizes later. Packinghouse A packed jumbo and colossal onions from the observed grading-packing line while packinghouse B placed all size-sorted onions into the bulk bins. Packinghouse C, on the other hand, packed jumbos for about two hours during the visit and later diverted all jumbos into the bulk bins. The boxes are then weight-checked and are stacked and piled onto the pallets for subsequent handling.

The simulation model was developed using ARENA (Rockwell Software, Inc., Milwaukee, WI) and commenced with the onion at the receiving end of the first inclined conveyor immediately after the hopper, shown in Figures 3.1 to 3.3, and terminated when a box of onions is picked up for pallet stacking. Figures A.1 and A.2 of Appendix A in

Mosqueda (2006) showed the simulation model in greater detail. The following subsections discuss some specific details of this model.

1. Arrival of Onions in the Grading Line

To estimate the number of cured onions entering the grading line per unit time, the feed conveyor was video-monitored for about three minutes and the number of onions discharged counted. The number of onions entering the grading line was expressed as an empirical discrete distribution. These onions were assigned four attributes: (1) bulb mass (‘MASS’), (2) average equatorial diameter (‘DIAM’), (3) external defect (‘EXTDEF’) incidence, and (4) internal (‘INTDEF’) defect incidence. If an onion is externally or internally defective, the EXTDEF’ or ‘INTDEF’ attribute is assigned a value of 1. Otherwise, the attributes are assigned a value of 0.

2. External Surface Inspection

Onions are graded according to their ‘EXTDEF’ attributes. False alarm and hit rates, were assumed to be 0% and 100%, respectively. These represent inspection accuracy of the human graders. A decision was classified a ‘hit’ when a defective onion was classified as reject and removed from the grading line while a decision is a false alarm if a good onion was classified as a reject. A ‘miss’ occurs when a defective onion was classified as a good onion.

3. Size sorting

Onions sorted into large medium, premium medium, jumbo and colossal are assigned 1, 2, 3, or 4 for the ‘SIZE’ attribute. If they are sized as small mediums, large mediums and jumbos, their ‘SIZE’ attribute took on the values of 1, 2 or 3, respectively.

4. *Boxing/Packing*

Onions with 'SIZE' attributes of '3' and '4', representing jumbo and colossal onions, respectively, were packed in 18.14kg boxes. Mediums ('SIZE' values of 1 and 2) were not packed but were diverted into accumulator bins for storage or for later bagging using other smaller packing equipment.

5. *Process Times*

The DELAY blocks in the model represent the times spent by an onion to traverse each of the identified packinghouse operations. These were estimated from observation data.

6. *Model Verification and Validation*

To ensure that the model runs according to specifications, the TRACE element of the program was enabled. This feature allowed one to follow or 'trace' the path of the modeled entities as they move from one component of the model to another. The simulated pack yields were also validated from estimates obtained from packinghouse supervisors, actual observations and from estimates given by a representative of a grading-packing line equipment manufacturer.

Data Collection

To represent the stochastic nature of the commodity and of the packinghouse operations, data collection for the simulation model was done in two phases. The first phase was conducted in an X-ray line scan laboratory at the Driftmier Engineering Center, University of Georgia during the 2005 and 2006 harvest seasons. A total of 1,406 Vidalia onions from four cultivars representing early-, mid- and late maturity categories were obtained from the Vidalia Onion and Vegetable Research Center in Lyons, GA. Bulb mass and equatorial diameter measurements were taken. Theoretical probability distributions were fit to the observed equatorial diameter data and statistical tests for goodness-of-fit were conducted. The relationship between bulb mass and diameter was determined through the scatter plots and corresponding correlation coefficients were computed.

The onions were also evaluated for both external and internal quality. Using the US Grade Standards for Bermuda Grano-Granex Type Onions (USDA Agricultural Marketing Service, 1995) as a guide, the onions were classified into Grade 1 and rejects. To determine the occurrence of internal defects, the onions were halved, along the equatorial diameter and further sliced along the neck-root axis. This method, according to Tollner (2004), provided a more stringent evaluation of disease or damage incidence. No distinction was made on the severity of internal defects.

The second data collection phase was done at the three packinghouses during the 2006 harvest season. Process time measurements were obtained by placing ten onions, one at a time at the start of each identified section of the packinghouse and then recording the time when each bulb reached the defined terminus of a particular section. The onions were wrapped in aluminum foil and packing tape to facilitate identification during the time study.

Model Applications

The model was then used to demonstrate the impact of sizing and inspection performance on packinghouse yield and potential revenue generation. Three sizing accuracy scenarios were explored. The specific details of the scenarios are shown in Tables 3.1a to 3.1c. The impact of the human graders' performance on revenue generation was also assessed under four scenarios: (1) 0% false alarm and 0% miss rates, (2) 5% miss and 0% false alarm, (3) 5% false alarm and 0% miss, and (4) 5% miss and 5% false alarm rates.

RESULTS AND DISCUSSION

Sizing Performance

Packinghouse A sorted onion into large medium, premium medium, jumbo and colossal size categories. Figure 3.4 shows the breakdown of the sizes found in the 50-onion sample obtained from each of these size categories at the end of the grading-packing line observed. For the 50-onion sample obtained from the large medium category, packinghouse A was 100% accurate. All 50 onions obtained were actually large mediums. For the premium medium size category, only 44% of the 50-onion sample was correctly sized. Forty-six percent of the onions were jumbos, 2% were colossal and 8% were large mediums. For the 50-unit jumbo sample, only 66% were jumbos as 8% and 26% of the onions belonged to the premium medium and colossal size categories, respectively. Packinghouse A was, however, 86% accurate in the colossal sample, as 14% of the 50 onions were actually jumbos.

Figure 3.5 shows the results for packinghouse B. For the large medium sample, only 54% of the 50 onions were actually large mediums. The rest belonged to the premium medium (40%), jumbo (4%) and small (1%) size category. Percentage of correctly sized onions in the premium medium, jumbo and colossal samples were 68%, 46% and 96%, respectively.

Figure 3.6 shows the sizing performance of packinghouse C. For the small medium sample, 56% of the onions were correctly sized. Accuracy improved in the large medium and jumbo samples, where 78% and 96% of the onions, respectively, were correctly sized.

Results from a chi-square analysis showed a significant difference ($p < 0.05$) among packinghouses in the incidence rate of incorrectly sized onions. An examination of Figure 3.7 clearly shows that the major departure from homogeneity was caused by a relatively higher fraction of incorrectly sized onions in packinghouse B. Analysis also showed no strong evidence that the incidence rate of incorrectly sized onions is different for packinghouses A and C. There is evidence, however, that this rate was significantly different in packinghouses A and B as well as in B and C.

The US Grade Standards for Bermuda Grano-Granex Type Onions indicated that not more than 5% of the onions in a lot, by weight, may be smaller than the minimum diameter specified and not more than 10% may be larger than the maximum diameter specified (USDA Agricultural Marketing Service, 1995). Table 3.2 shows how each of the packinghouses compares with these specified tolerance limits. For packinghouse A, oversized onions comprised 55%, by weight, of the premium medium sample. This translates to potential revenue loss since oversized onions were undervalued as premium mediums. Except for the colossal size category, the high incidence of oversized onions is seen in all categories of packinghouse B as well as in the two medium size categories of packinghouse C.

Incidence of Rejects in Grade 1 (Marketable) Onion Samples

Figure 3.8 shows the average incidence of rejects observed from the samples of supposedly marketable onions from all size categories of the packinghouses. Good onions from the samples averaged at 85%, 87% and 89% for packinghouses A, B, and C, respectively. Statistical analysis, using the chi-square test on equality of several proportions, showed there is no significant difference between the packinghouses in terms of reject incidence. This is also clearly demonstrated in Figure 3.9, which shows the 99% confidence intervals of the proportion of rejects from the onion samples obtained from the packinghouses.

The tolerance limit for individual samples weighing more than 9 kg is one and one half times the specified tolerance of 10 percent or more (USDA Agricultural Marketing Service, 1995). As shown in Table 3.3, the other size categories (except for jumbo) of packinghouse A exceeded the defect tolerance limit of 15% by weight. For packinghouse B, only the colossal sample exceeded the tolerance while all size categories of packinghouse were within the specified tolerance limit for defects.

Simulation Input Data

Table 3.4 show the results obtained from the two-year samples. For easier reference, the 2005 sample is referred to in this report as the "High Defect Incidence Crop' while the 2006 sample as the 'Low Defect Incidence Crop'. The relationship between bulb mass and diameter gave correlation coefficients of 0.94 and 0.88 for the 2005 and 2006 samples, respectively. The p-values of the fitted probability distributions for the equatorial diameter for both samples indicated a good fit.

The process times, shown in Table 3.5, were assumed to follow triangular distributions as there were not enough data points to fit a distribution into the observation data. Table 3.5 also shows the observed input volume of the three packinghouses. These values were adjusted by 20% from the original observation data to reflect the appropriate picture. Onions entering the grading line represented all the harvested onions whereas the onions used in this study were obtained from the research center where small onions, accounting roughly 20% of the harvest volume, were left on the field.

Simulation Results

The simulation results for the three packinghouses using these input data are summarized in Table 3.6. Pack yields derived from the 2005 onion samples were much lower than those based from 2006 samples. The 2006 onions, as seen from Table 3.3, were bigger and had lesser incidence of internal defects. The number of internally defective onions ranged from 1 to 36 per box across the three packinghouses.

The simulated average flow times for colossal onions in packinghouse A were lower compared to those obtained during the time study (Table D.3 in Mosqueda (2006)). During the time study, it took between 46 and 56 seconds to fill a box with colossal onions in the two packing stations whereas in the simulation, the average waiting time to fill a similar box is about 4 and 7 seconds. These time differences could be attributed to the inherent biological variation of the commodity handled. Percentage distribution of mediums, jumbos and colossals used in the simulation is different from those of the packinghouse when the time study was conducted.

The simulated number of pallets produced per hour in each packinghouse was also validated using the estimates obtained from packinghouse supervisors, from actual observations, and from a manufacturer representative of the grading-packing equipment used by two of the packinghouses. For packinghouse A, the simulated yield of 14 - 22 pallets per hour was higher than the 16 pallets per hour estimate provided by the supervisor. However, a representative of the grading-packing equipment manufacturer indicated that the throughput of a system similar to packinghouse A could range between 25 to 31 pallets an hour (J. Fitzgerald, personal communication, 06 June 2006). For packinghouse B, the supervisor indicated that their grading-packing line can produce about 16 pallets per hour. Simulated pack yields were 11 - 17 pallets per hour. Estimated packinghouse C output based on actual observations of the packing rate for jumbo onions was 13 pallets per hour while the simulated yields was 10 – 15 pallets per hour.

Table 3.7 illustrates the impact of sizing errors on potential revenue generation of the packinghouse. If packinghouse A, for example, operates under scenario 2 where 35% of the jumbos were wrongly sized as large mediums and 25% of the colossals were sized as jumbos, pack yield could decrease by 712 boxes and the packinghouse could lose about $10,878 in a day if the packinghouse was capable of operating at 100% sizing accuracy. If the packinghouse operates under scenario 3 where only 10% of the colossals are sized as jumbos and no other undersizing errors are committed, the packinghouse could still lose about $1,850 in day compared to a 100% sizing accuracy scenario.

Table 3.8 summarizes the impact of human graders' performance on potential revenue generation simulated at four levels. If the human graders were quite conservative in rejecting onions (resulting to a 5% miss rate), packinghouse A, for example, would gain about $1,600 in revenues per day (at a $10 unit selling price) than when the graders are performing under the base scenario (0% miss rate). However, such a conservative judgment translates to higher incidence of externally defective onions per box. On the other hand, if the graders were quite liberal in rejecting onions (resulting to a 5% false alarm rate), packinghouse A would lose about $5,700 in terms of potential revenues per day.

CONCLUSIONS

While the results of single visits to the three packinghouses are neither conclusive nor indicative of the general state of the three Vidalia onion packinghouses, these, nonetheless, present a glimpse of some of the improvement opportunities for the grader-packers.

Establishment and implementation of a more formalized quality inspection system may be necessary to facilitate continual process improvement in packinghouses. Such a system, among other benefits, could strengthen regular monitoring of sizing conveyor speeds, random sampling of the bulb diameters after size sorting and of the packed boxes, resulting in improvement of current performance levels.

Chi-square tests indicate a significant difference ($p<0.05$) among packinghouses in the incidence rate of incorrectly sized onions. Further tests indicate packinghouse A and C were not significantly different from each other while packinghouse B was significantly different from A and C with respect to sizing accuracy. High incidence of oversized onions, which exceeded the US Grade Standards tolerance limit in a size category, is common in all packinghouses. While there was no significant difference among packinghouses in terms of incidence of rejects in the sorted Grade 1 onion samples, packinghouse A exceeded the tolerance limit, which was specified in terms of weight.

This paper also demonstrated the feasibility of simulating the onion packinghouse operations using a discrete event simulation software. It quantified the impact of three size accuracy scenarios and of four grader performance levels on pack yield and on potential sales revenue generation. The model can be used to evaluate the impact of other improvement actions, such as the incorporation of a non-destructive technology into the operations of Vidalia onion packinghouses.

ACKNOWLEDGEMENTS

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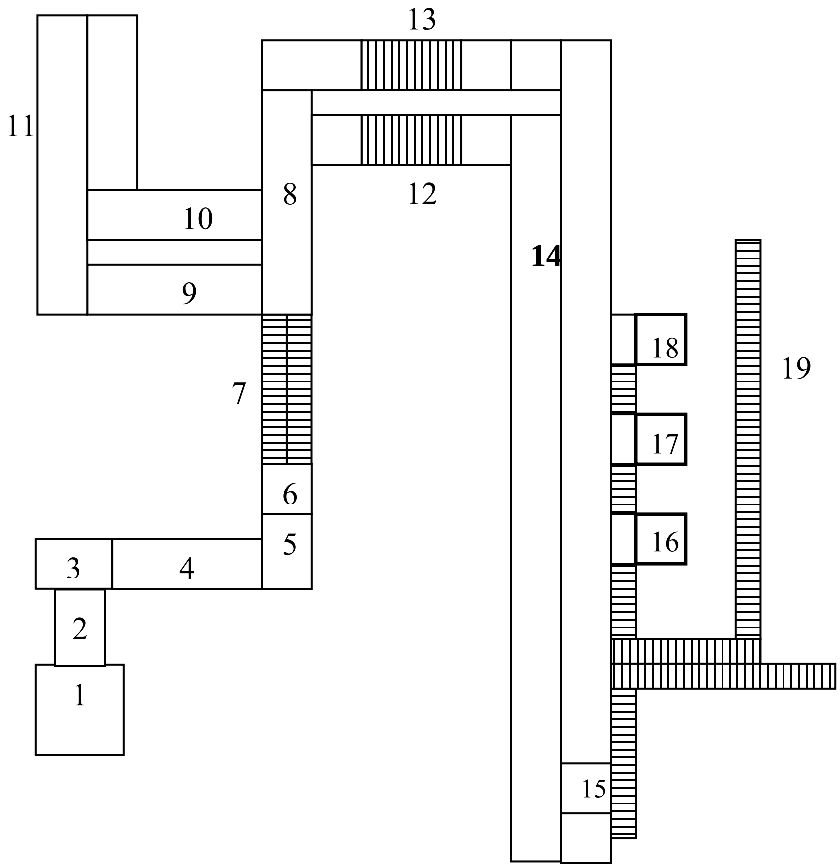
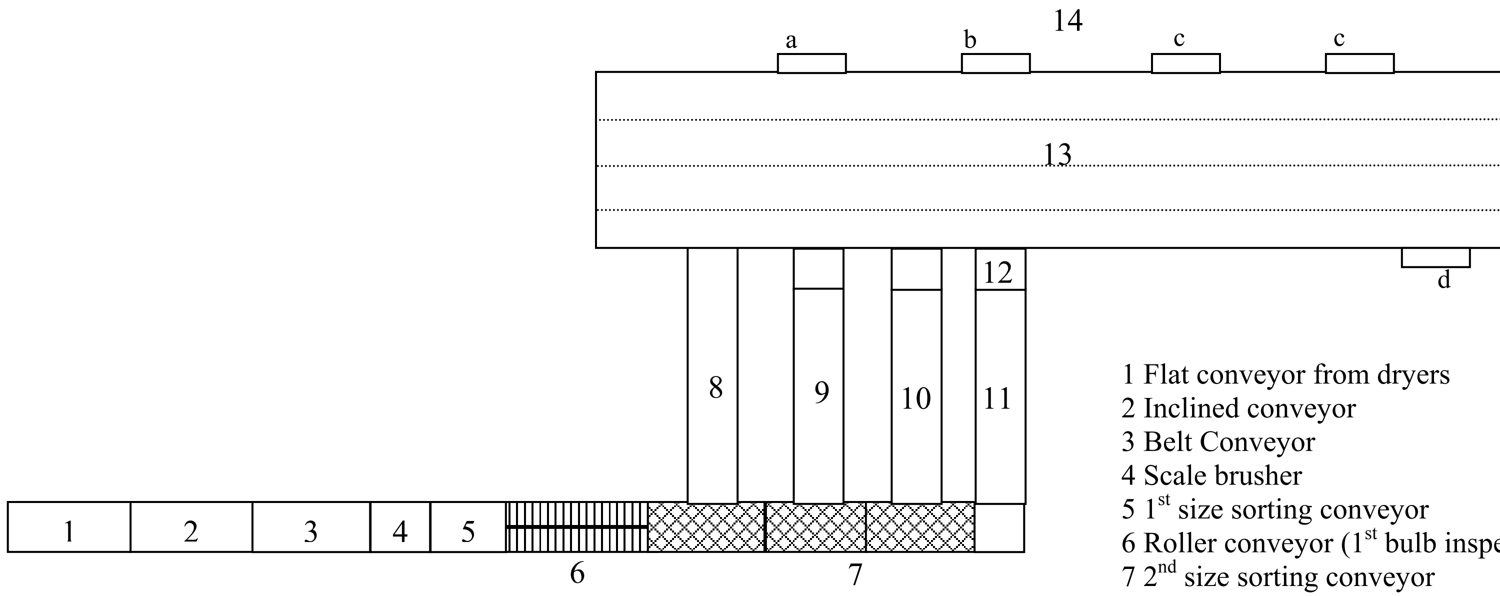


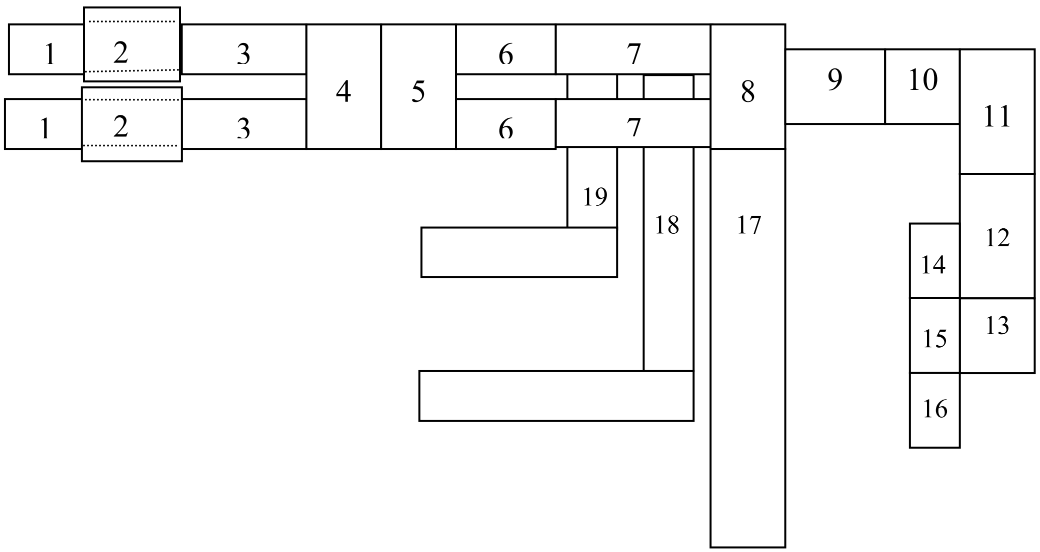
1 Hopper
2 Flat belt conveyor
3 Flat belt conveyor, also connected from dryers
4 Inclined conveyor
5 1st size sorter (small onions)
6 Scale brusher
7 Roller conveyor (1st bulb inspection)
8 2nd size sorting conveyors
9 Belt conveyor for sorted large mediums
10 Belt conveyor for sorted premium mediums
11 Conveyors to discharge medium onions into bins
12 Roller conveyor for jumbo onion inspection
13 Roller conveyor for colossal onion inspection
14 Belt conveyors to convey sorted jumbo and colossal onions for packing
15 Boxing station for Jumbos (Box Station 1)
16 Boxing station for Jumbos (Box Station 2)
17 Boxing station for Colossals (Box Station 3)
18 Boxing station for Colossals (Box Station 4)
19 Roller conveyors for filled boxes

Figure 3.1. Layout of the grading and packing line of Packinghouse A, located within the Vidalia onion production area in southeastern Georgia.



1 Flat conveyor from dryers
2 Inclined conveyor
3 Belt Conveyor
4 Scale brusher
5 1st size sorting conveyor
6 Roller conveyor (1st bulb inspection)
7 2nd size sorting conveyor
8 Belt conveyor for sorted large mediums
9 Belt conveyor for sorted premium mediums
10 Belt conveyor for sorted jumbos
11 Belt conveyor for sorted colossal
12 Labeling conveyors
13 Belt conveyor to convey sized onions to specific exit points
14 Exit points to bins or for packing
a – large mediums
b – premium mediums
c – jumbos
d – colossals

Figure 3.2 Layout of the grading and packing line of Packinghouse B, located within the Vidalia onion production area in southeastern Georgia.



1 Flat conveyor from dryers
2 Hopper
3 Inclined conveyor
4 1st size sorter
5 Scale brusher
6 Roller conveyor (bulb inspection)
7 2nd size sorter
8 Belt conveyor
9 Belt conveyor
10 Conveyor for labeling
11 Belt conveyor
12 Inclined conveyor
13 Packing machine
14 Roller conveyor for assembled boxes
15 Roller conveyor for filling box, part of packing machine
16 Roller conveyor for filled boxes
17 Belt conveyor for jumbo onions to be placed in bins
18 Belt conveyor for large medium onions, discharging into bins
19 Belt conveyor for small medium onions, discharging into bins

Figure 3.3 Layout of the grading and packing line of Packinghouse C, located within the Vidalia onion production area in southeastern Georgia.

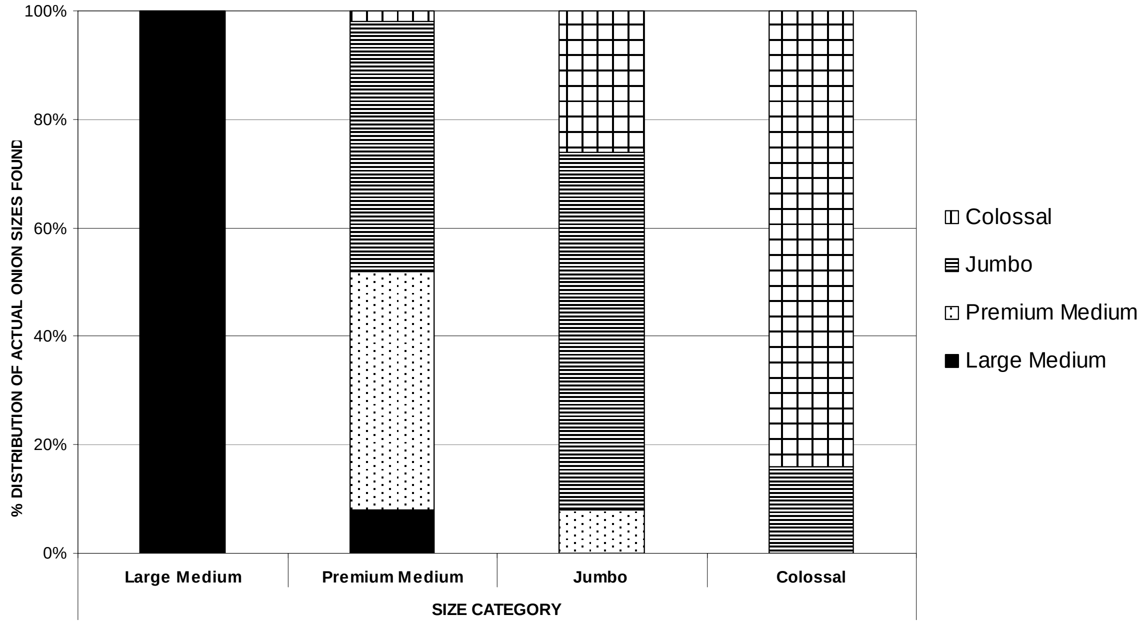


Figure 3.4 Percentage distribution of sizes found in the 50-onion sample obtained at the end of the grading-packing line for each size category of Packinghouse A.

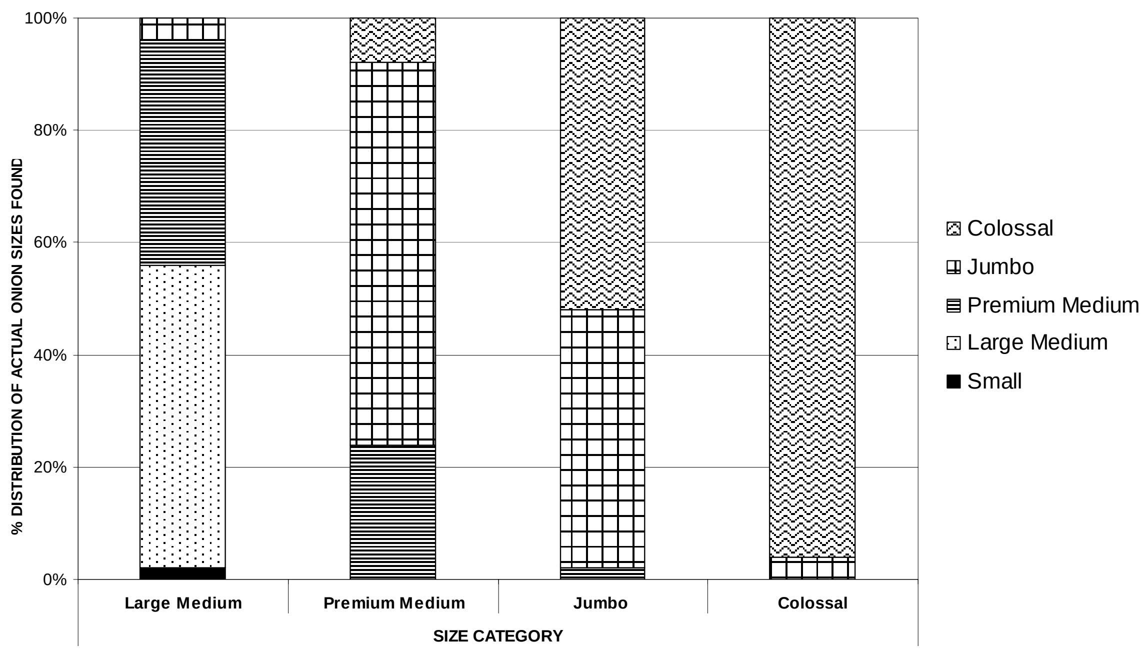


Figure 3.5 Percentage distribution of sizes found in the 50-onion sample obtained at the end of the grading-packing line for each size category of Packinghouse B.

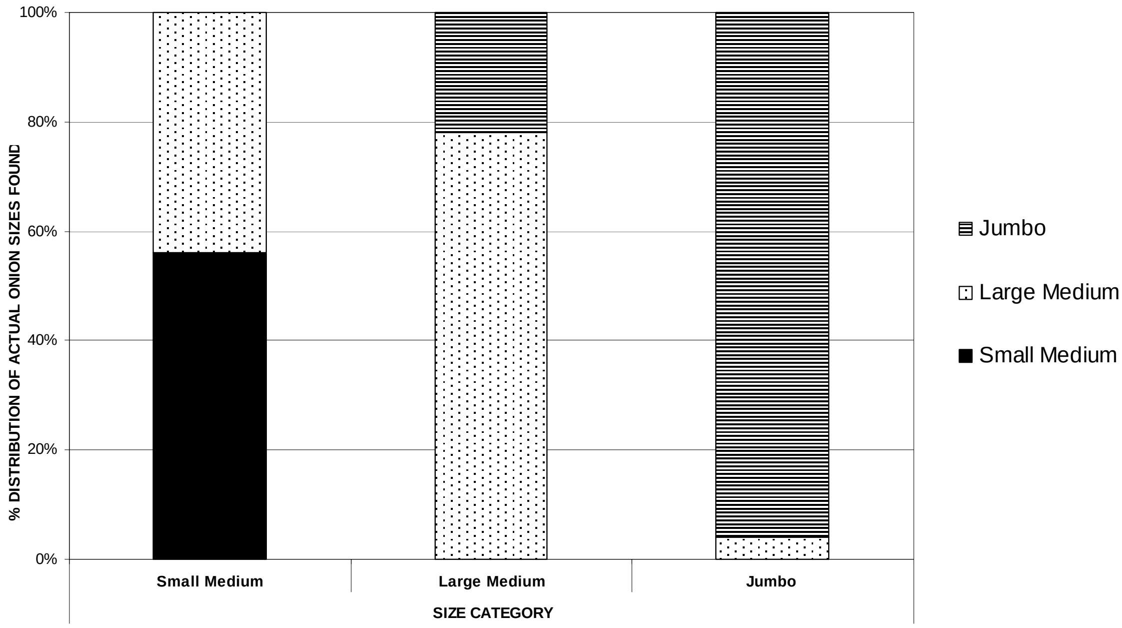


Figure 3.6 Percentage distribution of sizes found in the 50-onion sample obtained at the end of the grading-packing line for each size category of Packinghouse C.

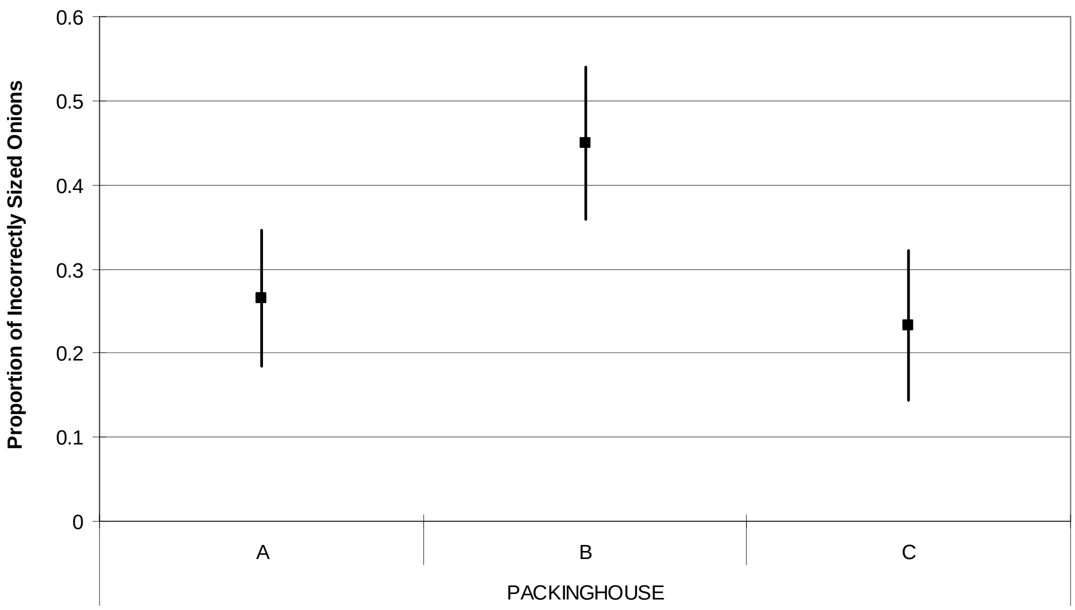


Figure 3.7 Observed proportions of incorrectly sized onions and the corresponding 99% confidence intervals for the three packinghouses.

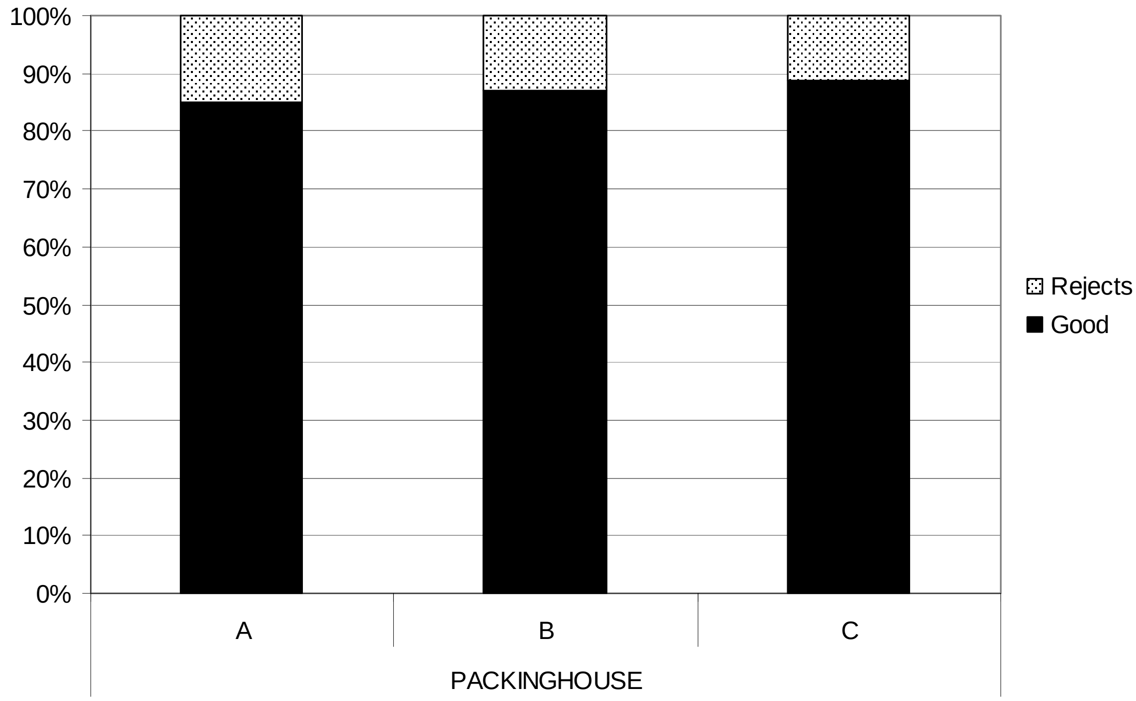


Figure 3.8 Percentage Distribution of 'Good Onions' and 'Rejects' from Grade 1 Vidalia Onion Samples Obtained at the End of the Grading-Packing Line, Summarized for all Size Categories by Packinghouse (May 2006).

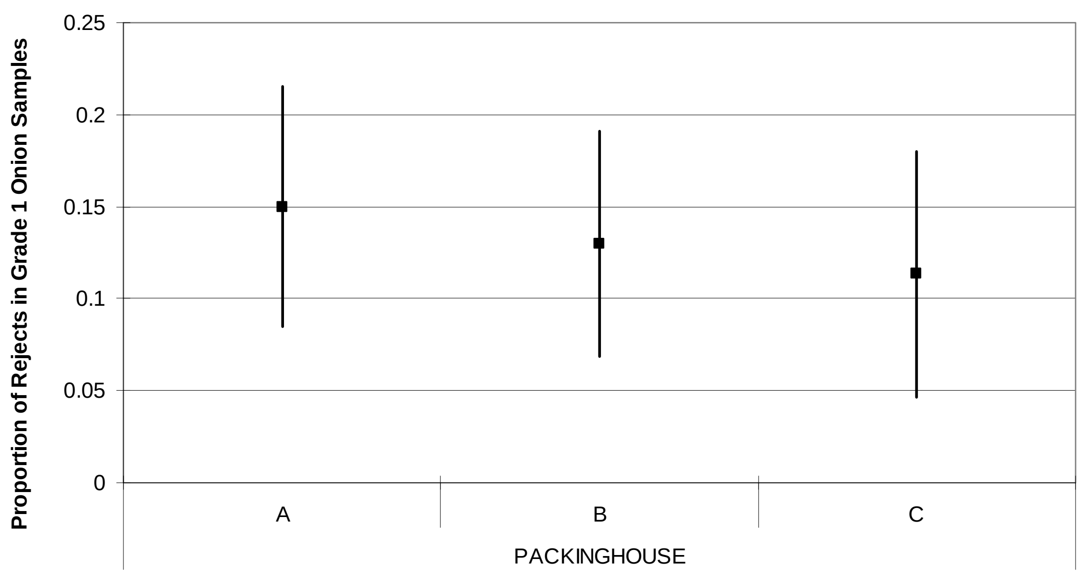


Figure 3.9 Observed proportions of rejects in Grade 1 onion samples and the corresponding 99% confidence intervals for the three packinghouses.

Table 3.1a Size Accuracy Scenario 1 Details for Packinghouses A, B and C

Onion Size	% of Onions Going to the Following Size Categories			
	Large Medium	Premium Medium	Jumbo	Colossal
Large Medium	100	0	0	0
Premium Medium	0	100	0	0
Jumbo	0	0	100	0
Colossal	0	0	0	100

Table 3.1b Details of Size Accuracy Scenarios 2 and 3 for Packinghouses A and B

Onion Size	% of Onions Going to the Following Size Categories							
	SCENARIO 2				SCENARIO 3			
	Large Med	Prem Med	Jumbo	Colossal	Large Med	Prem Med	Jumbo	Colossal
Large Medium	93	7	0	0	93	7	0	0
Premium Medium	0	85	15	0	0	85	15	0
Jumbo	0	35	52	13	0	0	85	15
Colossal	0	0	25	75	0	0	10	90

Table 3.1c Details for Size Accuracy Scenarios 2 and 3 for Packinghouse C

Onion Size	% of Onions Going to the Following Size Categories					
	SCENARIO 2			SCENARIO 3		
	Small Medium	Large Medium	Jumbo	Small Medium	Large Medium	Jumbo
Small Medium	100	0	0	100	0	0
Large Medium	35	62	3	0	85	15
Jumbo	0	19	81	0	10	90

Table 3.2 Percentage of onions, by weight, that are under- and over-sized based on equatorial diameter range specifications for each size category in three packinghouses. One sample of 50 onions was obtained from each size category.

Size Category	US Grade Standard Tolerance Limit, % by weight		PACKINGHOUSE					
			A		B		C[a]	
	% undersized	% oversized	% undersized	% oversized	% undersized	% oversized	% undersized	% oversized
Large Medium	5	10	0	0	1	54	0	51
Premium Medium	5	10	5	55	0	81	0	28
Jumbo	5	10	6	31	1	58	3	0
Colossal	5	10	13	0	2	0		

[a] C sizes: small medium, large medium, jumbo

Table 3.3 Percentage of onions, by weight, that were assessed as rejects from the Grade 1 (marketable) onion samples obtained at the end of the grading-packing line for each size category in three packinghouses. One sample of 50 onions was obtained from each size category.

Size Category	US Grade Standard Tolerance Limit, by weight	PACKINGHOUSE		
		A	B	C[a]
Large Medium	10	23	3	9
Premium Medium	15[b]	25	14	8
Jumbo	15[b]	10	9	13
Colossal	15[b]	28	23	
Average		21	15	11

[a] C sizes: small medium, large medium, jumbo
[b] for individual samples ≥ 9 kg (20 lb)

Table 3.4 Onion Attributes Obtained from the Four-Cultivar 2005 and 2006 Vidalia Onion Samples

Attribute	'High Defect Incidence Crop' 2005 Samples	'Low Defect Incidence Crop' 2006 Samples
Mass of Onion, g	0.004*($DIAM^{2.4631}$)	0.0091*($DIAM^{2.3056}$)
Equatorial Bulb Diameter, mm	TRIA(46,100,133)	51+ 94 * BETA(6.3, 5.22):
% External Defects	DISC(0.7757,0,1.0,1)	DISC(0.778,1.0,1)
% Internal Defects	DISC(0.6964,0,1.0,1)	DISC(0.748,0,1.0,1)

Table 3.5 Process Times Assumptions Used in Simulating the Grading-Packing Operations of three Vidalia Onion Packinghouses

Operation	PACKINGHOUSE		
	A	**B**	**C**
Receiving	TRIA(49,56,79)	TRIA(31, 38, 52)	TRIA(43, 58, 76)
Inspection	TRIA(13,16,19)	TRIA(20, 21, 22)	TRIA(32, 33, 34)
Size Sorting to Bins			
Small Mediums			TRIA(33, 36, 41)
Large Mediums	TRIA(16, 21, 28)	TRIA(26, 32, 36)	TRIA(48, 51, 58)
Premium Mediums	TRIA(19, 22, 29)	TRIA(35, 38, 46)	
Jumbo		TRIA(35, 42, 51)	TRIA(39, 43, 48)
Colossal		TRIA(49, 53, 58)	
Size Sorting to Box/Pack Stations			
Jumbo	TRIA(58, 68, 77)		
Colossal1	TRIA(61, 69, 95)		
Colossal2	TRIA(66, 72, 97)		
From Station Exit to Removal for Pallet Stacking	TRIA(34, 38, 41)		

Table 3.6 Simulation Results for a One-Day Packinghouse Operation (10.5 hour operation, 1.5 hour break) using the Table 3.3 and 3.4 Data

Measure	PACKINGHOUSE A		PACKINGHOUSE B		PACKINGHOUSE C	
	2005 Samples	2006 Samples	2005 Samples	2006 Samples	2005 Samples	2006 Samples
No. of pallets* per hour	14	22	11	17	10	15
Number of Internally Defective Onions/Box						
Jumbo	9 – 36	5 - 29	11 – 34	6 – 28	1 – 29	3 - 26
Colossal	4 – 27	10 - 22	4 – 24	1 – 22		
Average Flow Time, seconds						
Small Mediums (to Bin)					128.82	-
Large Mediums (to Bin)	100.01	99.95	93.06	93.03	145.22	145.24
Premium Mediums (to Bin)	101.51	101.50	100.74	100.72	135.32	136.30
Jumbo (Pack Station or Bin)	193.62	192.83	112.00	112.00		
Colossal (Pack Station or Bin)	198.85**	197.70**	116.36	116.36		

* 1 pallet = 48 -18.14 kg boxes
****** average of 2 stations

Table 3.7 Estimated Revenue Gain/Loss per Size Category due to Inefficient Sizing Based on a Single Day Grading-Packing Operation for the Three Packinghouses with a GOOD CROP

PARAMETER	PACKINGHOUSE A			PACKINGHOUSE B			PACKINGHOUSE C		
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total Number of Boxes Produced in a Day	11,469	10,757	11,314	9,120	8,565	9,014	7,732	7,758	7,770
Potential Revenues**	122,576.00	111,698.00	120,726.00	97,472.00	88,953.00	96,191.00	76,831.00	72,711.00	74,967.00
Estimated Revenue Gain (Loss) due to Inaccurate Sizing		(10,878.00)	(1,850.00)		(8,519.00)	(1,281.00)		(4,120.00)	(1,864.00)

**Based on price per box at $7, 10, 11 for medium, jumbo and colossal sizes

Table 3.8 Impact of Varying the Levels of Human Graders' Performance (% False Alarm and % Miss) on Potential Revenues per Day

PARAMETER	PACKINGHOUSE A				PACKINGHOUSE B				PACKINGHOUSE C			
	0%FA 0% Miss	5%FA 0% Miss	0%FA 5% Miss	5%FA 5% Miss	0%FA 0% Miss	5%FA 0% Miss	0%FA 5% Miss	5%FA 5% Miss	0%FA 0% Miss	5%FA 0% Miss	0%FA 5% Miss	5%FA 5% Miss
Jumbo & Colossal Boxes Produced in a Day	11,034	10,466	11,196	10,635	8,774	8,339	8,931	8,485	7,569	5,847	7,705	7,316
Estimated Revenues Gained (Lost) per Day												
at $10/box		(5,680)	1,620	(3,990)		(4,350)	1,570	(2,890)		(17,220)	1,360	(2,530)
at $14/box		(7,952)	2,268	(5,586)		(6,090)	2,198	(4,046)		(24,108)	1,904	(3,542)
at $18/box		(10,224)	2,916	(7,182)		(7,830)	2,826	(5,202)		(30,996)	2,448	(4,554)

CHAPTER 4

SIMULATING THE INCORPORATION OF X-RAY-IMAGING BASED INSPECTION IN VIDALIA ONION PACKINGHOUSES[1]

[1] Maria Rosario P. Mosqueda, E.W. Tollner, G.E. Boyhan and R.W. McClendon. To be submitted to the *Applied Engineering in Agriculture*

ABSTRACT

A discrete-event simulation model was developed to determine the approximate X-ray machine conveyor belt speed for feasible incorporation of the technology in Vidalia onion packinghouses. The results of the simulation model was also used to estimate the unit cost and selling price per box of inspected onions to ensure a profitable operation. A fundamental assumption of this work is that the increase in quality resulting from the x-ray inspection would justify a higher sales price. Data assumptions were derived from two May 2006 packinghouse time studies, from the four-cultivar 2005 and 2006 onion sample measurements, from the 2006 laboratory X-ray inspection study in onions and from published cost estimates of Vidalia onion production and packing. Results indicate the feasibility of incorporating three and four X-ray inspection units at 0.25 meter per second belt speed under the simulated conditions. Estimated cost of per 18.14 kg box of X-ray inspected onions ranged from $9.00 to $15.00 while the estimated selling price ranged from $11.35 to $25.34, depending on farm yield, quality of incoming crop and on gross profit margin goals.

Keywords**:** Packinghouse simulation, x-ray inspection, short-day onions, Allium cepa

INTRODUCTION

Vidalia onions, grown in the southeastern region of Georgia, are the state's most valuable vegetable crop in terms of farm gate value (Boatright and McKissick, 2005). They are a significant command in the nation's sweet onion market, with a reputation as America's preferred and best known sweet onion (Costa et al., 2003). The Vidalia onion industry, however, faces a number of serious challenges. Increased competition, the need for improved varieties and inadequate segregation of diseased onions prior to controlled atmosphere (CA) storage are among the industry's most pressing concerns (Boyhan and Torrance, 2002). CA storage losses to growers range from 10-20% in good years (Purvis et al., 2002) to as much as 50-70% in bad years (Boyhan and Torrance, 2002) due to Botrytis neck rot (*Botrytis allii*). Considering that about 56.7 million kilograms (125 million pounds) of onions can be put into CA storage annually (University of Georgia College of Agricultural and Environmental Sciences, 2001), this fungal disease spells huge economic losses for grower-packers.

The virtually undetectable progression of this fungal disease within the onion bulbs underscores the importance of adopting a more stringent inspection method in packinghouses. Human visual inspection, the current method used in Vidalia onion grading operations, is inadequate in segregating onions with internal defects. In a recent center rot study, for example, Tollner et al. (2005) reported that 80% of the onions in their study that passed visual inspection were found to have center rot (*Pantoea ananatis*) disease upon halving. Recognizing this inspection inadequacy, several researchers at the University of Georgia have investigated the potential of X-ray imaging in detecting the internal defects of sweet onions (Maw et al., 1995; Shahin et al., 2002; Tollner et al., 1994; Tollner et al., 2006). While their studies indicated the technology's capability to detect internal damage, commercial adoption remained nonexistent in the industry. Kays and Paull (2004) noted that equipment costs, operating costs and safety considerations are, generally, the primary deficits preventing the wider use of X-ray instruments in assessing internal quality attributes of horticultural products.

There is limited literature, however, quantifying the economic and operational implications of incorporating an X-ray inspection at Vidalia onion packinghouses. Tollner (2003; 2004) and Tollner et al. (2006) evaluated the efficacy and economics of incorporating a commercial X-ray inspection machine in an onion packinghouse using an MS Excel spreadsheet model. They tracked 1000 onions from the farmer's field up to the retailing end, in four scenarios: (1) control (no nondestructive testing (NDT) technology at the packinghouse and no repacking at the distribution center; (2) no NDT at packinghouse with repack; (3) with NDT at packinghouse and no repack; and (4) with NDT at packinghouse and repack. They showed that such a technology addition would not be profitable to the packinghouse, in all four scenarios, unless vertical integration of supply chain operations is in place. The subjective assumptions used in the simulation model inputs, such as the price multipliers, costs, product yields at each business level, as well as the Gaussian distribution assumption of onion sizes, however, need to be further examined.

Since this technology offers an excellent opportunity for grower-packers to gain better control of their product quality, the research herein examined in more detail the economic and operational implications of incorporating an X-ray inspection system at the packinghouse. Specifically, it aimed to (1) determine the conveyor belt speed at which this technology could be feasibly incorporated into the operations of Vidalia onion packinghouses, and (2) determine the selling price range at which producing “gourmet quality” X-ray inspected onions could be a profitable undertaking for grower-packers.

MATERIALS AND METHODS

To achieve these, a simulation model was developed using ARENA, a discrete event simulation software of Rockwell Software, Inc. (Milwaukee, WI). Simulation input data were based on a previous three-packinghouse time study as well as from four-cultivar onion samples obtained from the Vidalia Onion and Vegetable Research Center in Lyons, GA during the 2005 and 2006 harvest seasons. X-ray inspection of these onions was conducted at the Driftmier Engineering Center, Athens, GA using an EG & G Astrophysics X-ray line-scan inspection unit. Scenarios were identified and preliminary runs of the simulation models were conducted. The associated cost of incorporating this technology was estimated. The following subsections present these methods in greater detail.

System Description

Figure 4.1 presents a simplified diagram of the unit operations of a Vidalia onion packinghouse. Only a brief overview of the packinghouse operations is presented here as the details were previously presented in Mosqueda et al. (2006).

Onions conveyed from the curing bins into the grading-packing line are pre-sized and cleaned before entering the inspection area. Externally defective onions are removed by graders who are typically positioned on both sides of the roller conveyors. After inspection, onions are sorted into three to four size categories (large medium, premium medium, jumbo and colossal) using a series of hexagonal chain link conveyors. After size sorting, another set of personnel further inspect the bulbs. Only Grade 1 onions are packed as Vidalia onions and lower grade onions are disposed of. One packinghouse used Grade 2 jumbo onions for processing. After the second inspection, Grade 1 jumbo and colossal onions move to the boxing stations and are individually labeled along the way. The medium onions, on the other hand, go to the bulk bins for storage or for later packing. Boxes filled with jumbo or colossal onions are stacked on pallets and are removed by forklift trucks for temporary storage while awaiting shipment.

Simulation Model Development and Data Collection

The simulation model developed by Mosqueda et al (2006) was modified to allow X-ray inspection before and after size sorting. The resulting model diagrams and program codes were presented as Appendix B in Mosqueda (2006). These modified models were run using the same data on onion attributes and packinghouse process times used in the original model (Mosqueda et al., 2006). These data sets are summarized in Tables 4.1 and 4.2.

To enable easy reference in later discussions, the 2006 data set of Table 4.1 is subsequently referred to in this report as the ‘low defect incidence crop’ and the 2005 data set as the ‘high defect incidence crop’. They are designated as such because the 2005 onion samples showed higher percentage of internal defects than the 2006 samples.

Table 4.2 presents the assumed process time distributions and the volume of onions entering a packinghouse. These were based from a previous packinghouse study conducted by Mosqueda et al (2006).

X-ray Inspection of Onion Samples

The internal quality of the four-cultivar onion samples, obtained from the Vidalia onion and Vegetable Research Center during the 2005 and 2006 harvest seasons, was evaluated using an X-ray line-scan inspection machine (EG&G Astrophysics) located in a

Driftmier Engineering Center laboratory at the University of Georgia. This machine was similar to the X-ray inspection equipment used in airports to inspect luggage. To ensure consistent onion orientation during scanning (the x-ray beam was collinear with the onion bulb's root-shoot axis), the onions were placed in an open-top container to constrain their movement. X-ray images generated on the screen were visually evaluated and the onions were classified either as 'good' or 'defective'.

After x-ray inspection, onions were halved and then quartered to verify decision accuracy. A decision was classified a 'hit' when an onion was judged as internally defective based on the X-ray image is actually defective. A false alarm occurred when onion n classified as internally defective when it was not defective. A decision was considered a 'miss' if an internally defective onion was erroneously judged as a good onion. A correct rejection occurred when a sound, healthy onion was judged correctly as such.

The amount of time it takes for a batch of onions to move through a predetermined belt conveyor length of about 104 centimeters during X-ray scanning was measured and recorded during the 2006 phase of the study. The goal was to translate the measured performance data from this slower X-ray inspection machine to the commercial machines with faster belt speeds. Fitting theoretical probability distributions into the observation data and the corresponding goodness-of-fit tests were conducted using ARENA's Input Analyzer tool.

For the simulation model, it was assumed that the machine has a scanning capacity of 12 onions per unit time. This was based on the specified dimensions of a commercial food X-ray inspection machine, the Eagle Pack MK2-IP65 model of Smiths Heimann (Alcoa, TN).

Scenarios and Cost Evaluation

Eight scenarios were initially identified based on these three variables: (1) packinghouse capacity (‘high capacity’ versus ‘low capacity’), (2) quality of incoming crop (high or low defect incidence crops), and (3) installation location of the X-ray inspection system (before or after size sorting).

The cost components making up the total cost of producing “gourmet quality” X-ray inspected onions onion were assumed to include: (1) pre-harvest and harvesting costs, (2) cost of drying, (3) cost of grading and packing, (4) cost of Vidalia onion committee assessment and the (5) X-ray inspection cost.

The first five components were based on the estimates of (Boyhan and Torrance, 2001). These estimates were adjusted so three farm yield levels (400, 500, and 600 bags per acre) can be incorporated in assessing the total approximate cost of producing a box of X-ray inspected onions. Each field bag contains 22.7 kg of onions. The assumed values used in computing these costs are shown in Table 4.4.

The cost of X-ray inspection was estimated based on the financial quotation provided by Smiths Heimann (Alcoa, TN) for the Eagle Pack MK2-IP65 model. The financial quotation did not include any ancillary equipment that would incorporate the machine to the grading-packing line. Thus, this cost estimate is limited solely to equipment and the related installation costs. Table 4.4 shows the cost of operating three and four X-ray inspection machines in a single day.

The selling price per box was estimated using the following formula:

$$\text{Unit Selling Price} - \text{Unit Cost} = \text{Unit Gross Profit}$$

where gross profit is expressed as a fraction of the unit selling price, thereafter referred to here as the gross profit margin. Margins of 20%, 30% and 40% of the selling price were used in calculating the estimated unit selling price.

RESULTS AND DISCUSSION

X-Ray Machine Performance Measures

Table 4.3 show the performance measures in manually classifying onions with or without internal defects based on the X-ray images projected on the computer screen while scanning onions using a EG & G Astrophysics X-ray line-scan inspection unit. For the 2006 samples, 85% of all the internally defective onions and 93% of the healthy onions were correctly classified. Most of the errors associated with identifying the actual internally defective onions were committed when the defects were very slight. For the 2005 samples, the hit rate was almost 97%. This was attributed to the easily distinguishable defects based on the X-ray images, such as rot formation, the presence of fibrous, sometimes hollow, floral stems, and the very yellowish, waxy appearance of inner rings. These results were comparable to those previously reported by Tollner (2004) and Tollner et al.(2005).

Figure 4.2 shows the fitted probability distribution of the amount of time spent in scanning the onions through a 104 cm - long section of the belt conveyor. The resulting p-value indicated a good fit. Approximate belt conveyor speed of the laboratory X-ray equipment, based on these time data, was 0.17 meter per second.

Preliminary Runs

Results of the simulation model preliminary runs indicated that it was not operationally feasible to incorporate even up to six X-ray inspection machines using the original laboratory-derived X-ray inspection time data set. However, when these time data were reduced by 50% of the original levels, which is equivalent to doubling the current 0.17 meter per second, three and four X-ray inspection machines proved feasible in handling the incoming onion volumes of the low and high capacity packinghouses, respectively.

Placing the X-ray inspection machines after the size sorting process showed very low machine utilization rates for the lines processing large and premium medium onions. Thus, subsequent evaluations focused only on placing the machines before size sorting, reducing the number of scenarios to four.

Incidence of Internally Defective Onions per Box

Figure 4.3 shows the breakdown of the number of jumbo and colossal boxes produced during a simulated day under a ‘high capacity packinghouse with a low defect incidence crop’ scenario, with and without technology incorporation. At status quo, all boxes contained internally defective onions while with technology, about 10% of the boxes produced did not contain any defective onion. Ninety percent of the boxes contained defective onions. However, Figure 4.4 shows that the average number of internally defective onions contained in these boxes drastically reduced to just about two to three onions per box. Without technology incorporation, as many as 10 – 15 internally defective onions could be found per box on the average.

Figure 4.5 shows the number of jumbo and colossal boxes produced in a day, with and without technology, under a ‘high capacity with high defect incidence crop’. About 57% of the boxes inspected using the X-ray technology still contained internally defective onions. However, Figure 4.6 shows that under simulated conditions, there could only be one internally defective onion that could be found in these boxes on the average. Technology incorporation decreased the incidence of internally defective onions from 14-22 per box to just about one defective per box.

Unit Cost and Selling Price of X-ray-Inspected Onions

As previously indicated, the average number of internally defective onions could range from 10 to 22 per box under simulated conditions. To produce a box of X-ray inspected onions, where the number of internally defective onions could range from one to three in a box of about 50 to 70 onions, entails attendant costs. Tables 4.4 and 4.5 present the associated costs of producing these onions and estimated selling prices per box under four scenarios: (1) 'high capacity' packinghouse with 'low defect incidence' crop, (2) 'high capacity' packinghouse with 'high defect incidence' crop, (3) 'low capacity' packinghouse with 'low defect incidence' crop, and (4) 'low capacity' packinghouse with 'high defect incidence' crop. Only scenarios 1 and 2 are discussed here as the estimated costs and selling prices of scenarios 3 and 4 did not vary very much from the first two scenarios.

Scenario 1: High Capacity Packinghouse with a 'Low Defect Incidence Crop'

The estimated cost of producing a box of approximately 18.14 kg of X-ray inspected Vidalia onions ranged from $8.94 to $11.83, depending on the farm yield per unit area. This is about 35% higher than the conventional method of grading and packing.

Estimated selling prices assuming 20% and 30% gross margins are still within the range of historical (2000 – 2005) Vidalia district shipping point prices, published by the USDA Agricultural Marketing Service (2006). The estimated price range, at the 40% gross profit margin, however, would approach the price range of CA-stored onions. The shipping point prices for CA-stored onions in 2005, for example, ranged from $16 to $22 per 18.14 kg box.

Scenario 2: High Capacity Packinghouse with a 'High Defect Incidence Crop'

Because pack yield would predictably decrease with a high defect incidence crop, estimated cost of producing the same box under this scenario was 29% higher compared to the first scenario. Thus, to achieve the same profit margins, estimated selling prices were also about 29% higher.

At a farm yield of only 400 bags per acre, the estimated selling prices with 30% and 40% gross margins were within the 2002 and 2003 shipping point price range of CA-stored onions (USDA Agricultural Marketing Service, 2006). At higher farm yields, estimated unit selling prices were still within reasonable range of historical prices of onions graded, inspected and packaged under the existing packinghouse methods. These results suggest that the pricing necessary for the X-ray inspected onions, possessing superior internal quality, seem to be economically sustainable.

A more comprehensive systems analyses by Tollner et al. (2006) suggests that, if one assumes the internally defective onions removed by the addition of the x-ray technology were manifestly defective and removed by the time the produce reached the retail level, the net benefit at the distributor and retail levels would be greater than the loss sustained at the packinghouse level. In other words, vertically integrating the grower, packer, distributor and retail store can produce superior quality onions at a more economical price for the consumer. Vertical integration could offset the loss sustained by the packinghouse resulting from the removal of externally good fruit which would later exhibit defects. Further work is needed to quantify the additional system components and better document the projected savings.

CONCLUSIONS

Four scenarios were simulated to examine the economic and operational implications of incorporating an X-ray inspection system in Vidalia onion packinghouses. The incorporation of three- and four- X-ray inspection machines to handle the simulated packinghouse volumes was feasible at an approximate belt conveyor speed of 0.25 meter per second. The incorporation of this technology reduced the incidence of internally defective onions per box by as much as 80 to 95% compared to the conventional inspection system employed by packinghouses.

Estimated cost of producing an 18.14 kg box of X-ray inspected onions ranged from $9.00 -$12.00 for a 'low defect incidence crop' to $11.50 to $15.20 for a 'high defect incidence' crop, depending on the farm production yield. Estimated selling price per box, at 20% , 30% and 40% gross profit margins, were within the range of historical prices at the Vidalia district shipping point, published by the USDA Agricultural Marketing Service (2006). At the most pessimistic farm yield of 400 bags per acre, the estimated selling prices associated with the 'high defect incidence crop' scenarios approached the 2002 and 2003 price ranges for CA-stored onions.

These results suggest that the pricing necessary for X-ray inspected onions, which could be marketed as "gourmet onions" because of their superior internal quality over the conventionally-inspected onions seem to be economically sustainable.

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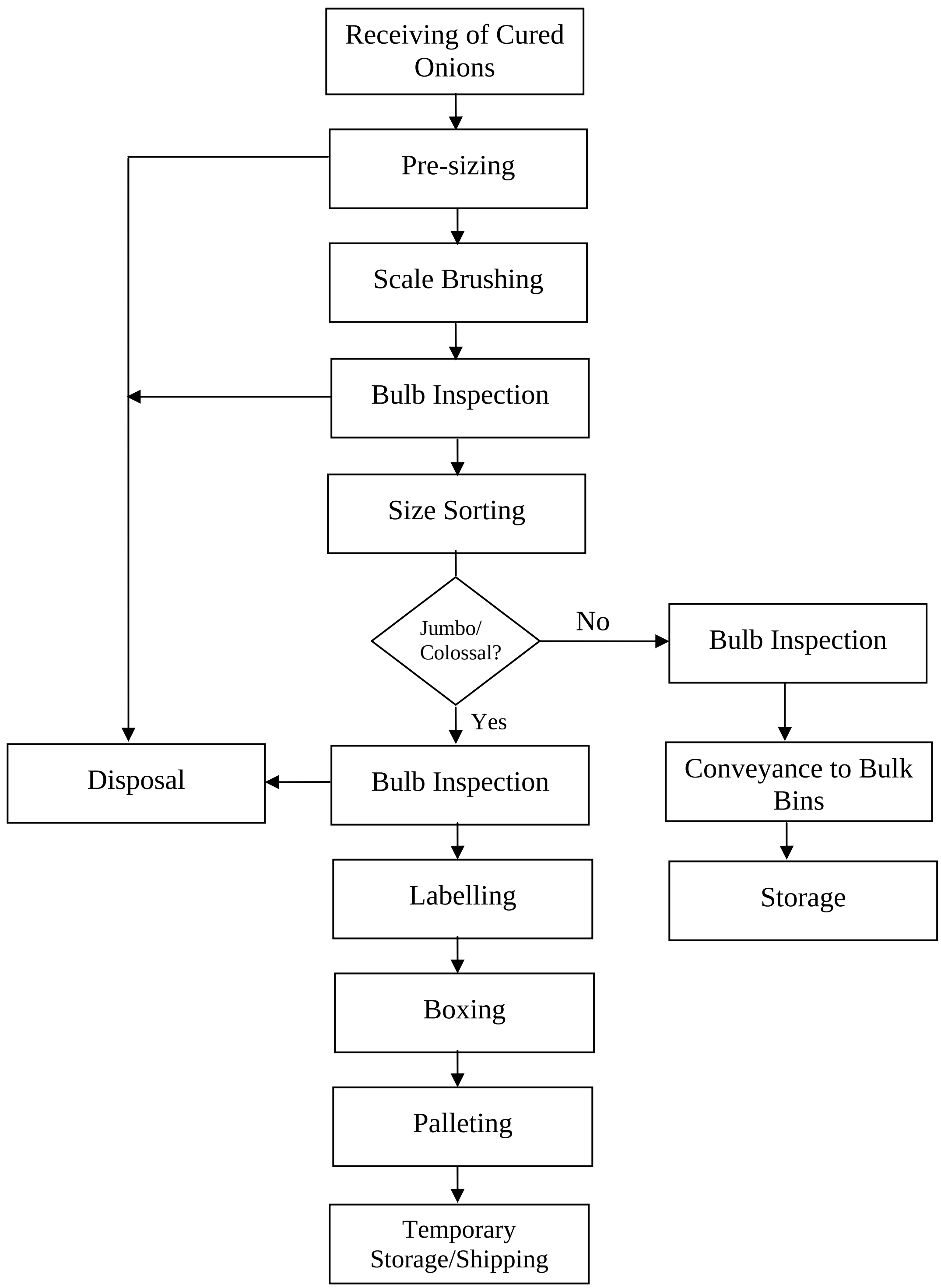

Figure 4.1 Unit Operations of a Vidalia Onion Grading-Packing Line for Jumbo and Colossal Onions

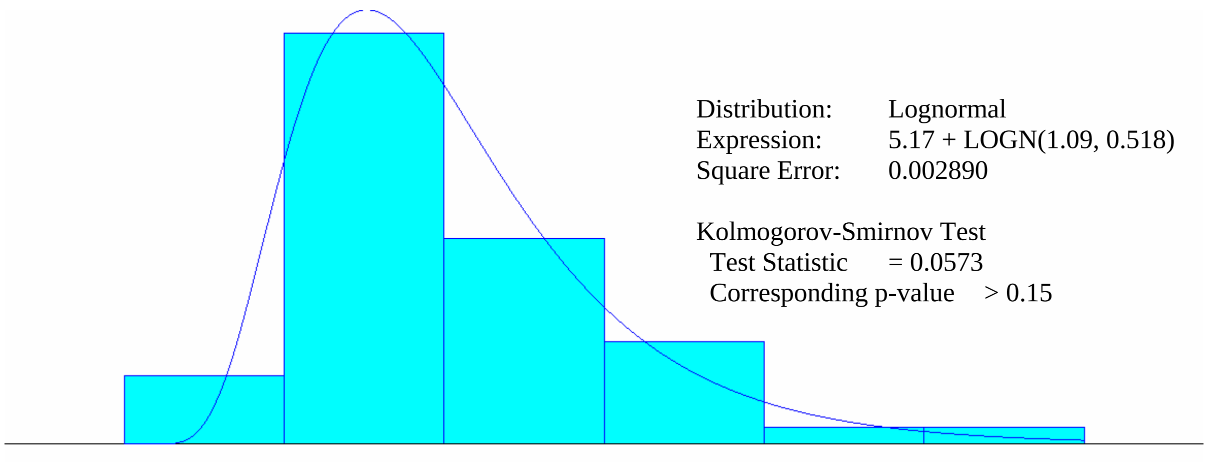

Figure 4.2 Time Spent for X-ray Inspection of Onions, using an X-Ray Line Scanning Unit (EG & G Astrophysics) located at the UGA Driftmier Engineering Center, Athens, GA, May 2006. Approximate conveyor belt speed was 0.17 meter per second.

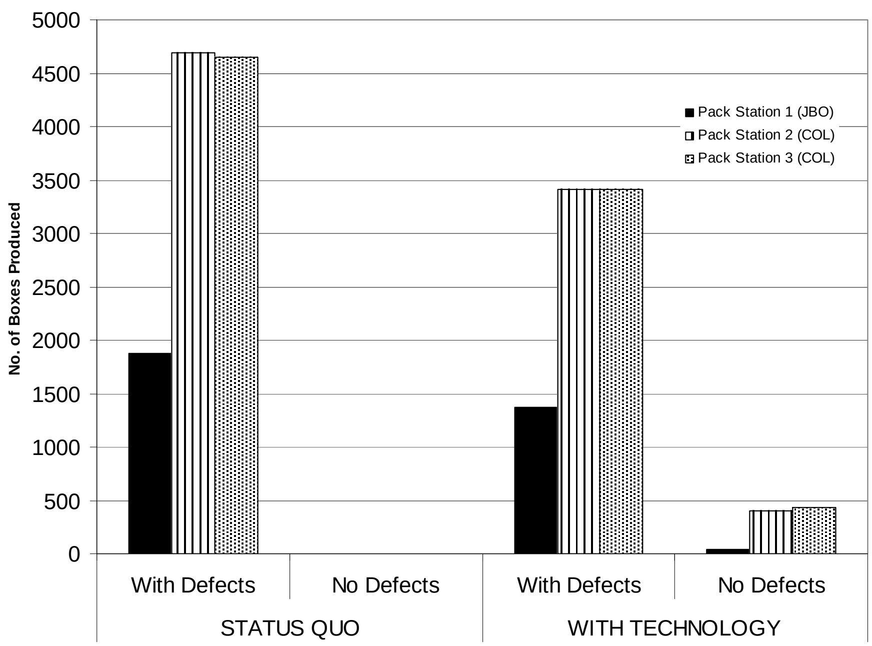

Figure 4.3 Comparison on the Number of Jumbo and Colossal Boxes Containing Internally Defective Onions under the Status Quo and with Technology Conditions of a High Capacity Packinghouse with a 'Low Defect Incidence Crop'.

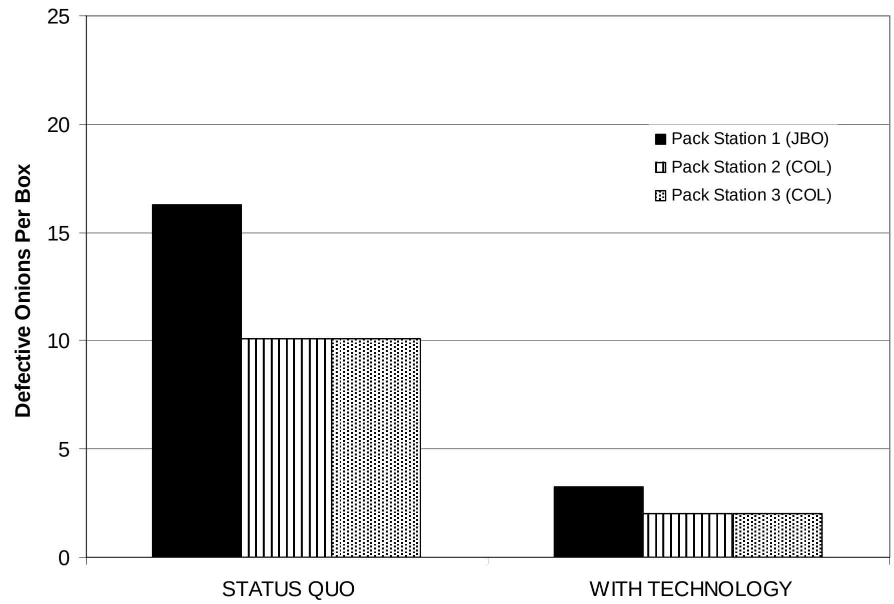

Figure 4.4 Comparison of the Average Number of Internally Defective Onions Contained per Box in a 'Low Defect Incidence Crop' input under the Status Quo and With Technology scenarios

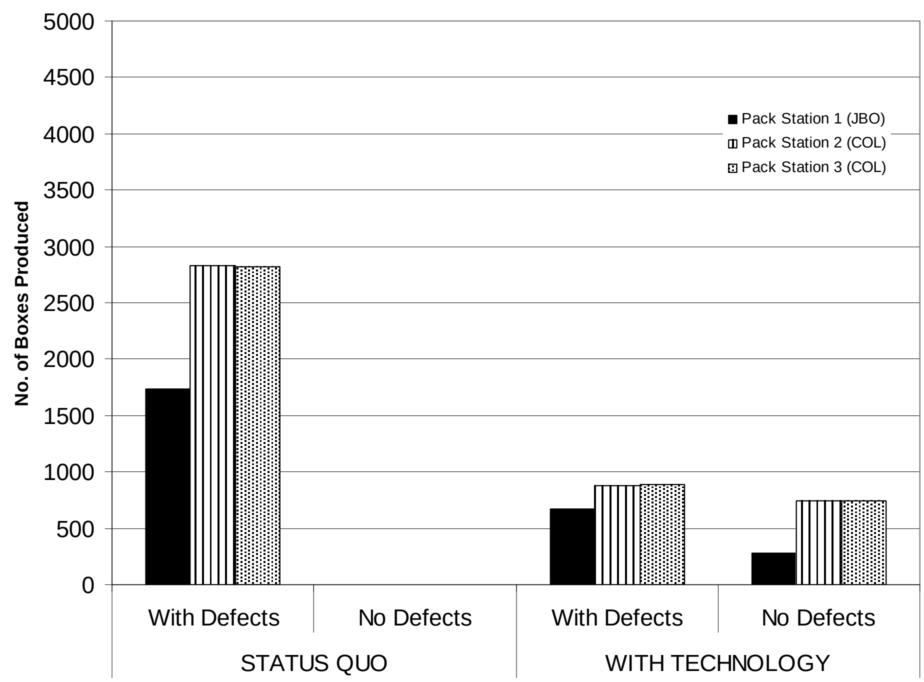

Figure 4.5 Comparison on the Number of Jumbo and Colossal Boxes Containing Internally Defective Onions under the Status Quo and with Technology Conditions of a Low Capacity Packinghouse with a 'High Defect Incidence Crop'

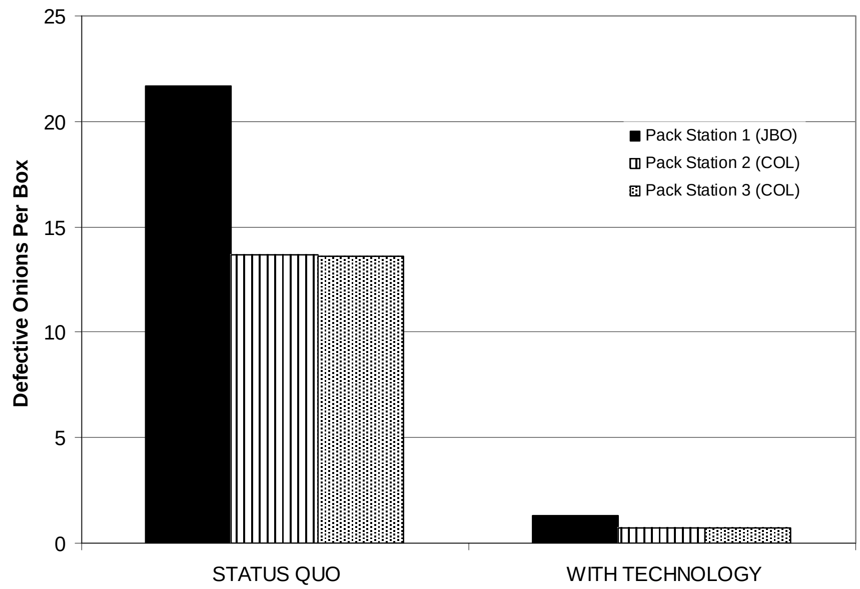

Figure 4.6 Comparison of the Average Number of Internally Defective Onions Contained per Box in a 'High Defect Incidence Crop' input under the Status Quo and with Technology Scenarios

Table 4.1 Assumed Attributes of Onions Entering the Simulated Grading-Packing Line of a Vidalia Onion Packinghouse

Attribute	'High Defect Incidence Crop' (2005 Samples)	'Low Defect Incidence Crop' (2006 Samples)
Mass of Onion, g	0.004*(DIAM$^{2.4631}$)	0.0091*(DIAM$^{2.3056}$)
Equatorial Bulb Diameter, mm	TRIA(46,100,133)	51+ 94 * BETA(6.3, 5.22):
% External Defects	DISC(0.7757,0,1.0,1)	DISC(0.778,1.0,1)
% Internal Defects	DISC(0.6964,0,1.0,1)	DISC(0.748,0,1.0,1)

Table 4.2 Input Volume and Process Times Assumptions Used in Simulating the Grading-Packing Operations of Vidalia Onion Packinghouses

Operation	Packinghouse	
	High Capacity	Low Capacity
A. PROCESS TIME		
Receiving	TRIA(49,56,79)	TRIA(31, 38, 52)
Inspection	TRIA(13,16,19)	TRIA(20, 21, 22)
From Size Sorting to Bins		
Small Mediums		
Large Mediums	TRIA(16, 21, 28)	TRIA(26, 32, 36)
Premium Mediums	TRIA(19, 22, 29)	TRIA(35, 38, 46)
Jumbo		TRIA(35, 42, 51)
Colossal		TRIA(49, 53, 58)
From Size Sorting to Box/Pack Stations		
Jumbo	TRIA(58, 68, 77)	
Colossal Station 1	TRIA(61, 69, 95)	
Colossal Station 2	TRIA(66, 72, 97)	
From Station Exit to Removal for Pallet Stacking	TRIA(34, 38, 41)	
B. INPUT VOLUME		
Number of onions discharged into the grading line per unit time	DISC (0.039,12, 0.1299, 15, 0.2468, 18, 0.4286, 20, 0.6234, 21, 0.8182, 25 0.9221, 27, 0.9610, 32, 0.9870, 34,1.0,36)	DISC(0.016, 6, 0.033, 8, 0.082, 10, 0.131, 12, 0.279, 14, 0.41, 16, 0.639, 18, 0.803, 20, 0.951, 22, 0.967, 24, 1.0, 26)
Time interval between every time a batch of onions is discharged into the grading line, seconds	1.20	1.22

Table 4.3 Performance Measures Obtained during X-ray Inspection of Sampled Vidalia Onions, Driftmier Engineering Center, Athens, GA, 2005-2006

Performance Measure	**‘High Defect Incidence Crop’ (2005 Samples)**	**‘Low Defect Incidence Crop’ (2006 Samples)**
Hit, %	96.76	85.43
False Alarm, %	19.06	7.35
Miss,%	3.24	14.57
Correct Rejection,%	80.94	92.65

Table 4.4 Assumptions Used in Estimating the Cost of Producing a Box of X-ray Inspected Onions at the Packinghouse

COST COMPONENT	ESTIMATED COST, $			
	Unit of Measurement	Yield per Acre, no. of 50lb field bags		
		400	500	600
Raw Material	Field Bag	6.16	4.93	4.11
Drying	Field Bag	0.15	0.15	0.15
Grading	Field Bag	1.00	1.00	1.00
Packaging Material	Labelled Box	1.00	1.00	1.00
	Labelled Mesh Bag	0.40	0.40	0.40
Cost of Vidalia Onion Committee Assessment	Labelled Box and Mesh Bag	0.12	0.12	0.12
Cost of X-ray Inspection				
Four machines	One day operation	4,196.65		
Three machines	One day operation	3,120.85		

Table 4.5 Estimated Unit Cost and Selling Price for an 18.14 kg Box/Bag of X-ray Inspected Onions Produced at a <u>High</u> Capacity Packinghouse under Status Quo and with 4-X-ray Machine Addition Scenarios

ESTIMATE	NUMBER OF X-RAY UNITS INSTALLED			
	LOW DEFECT CROP		HIGH DEFECT CROP	
	None	4	None	4
Number of 18.14 kg Boxes Produced Per Day	11,661	8,873	8,588	4,164
Cost to Produce a 18.14 kg box of X-ray Inspected Onions, $/box				
400 bags/acre yield	8.74	11.83	8.71	15.24
500 bags/acre yield	7.45	10.10	7.41	12.99
600 bags/acre yield	6.59	8.94	6.55	11.49
Unit Selling Price, $/box				
at 20% Gross Profit Margin				
400 bags yield/acre	10.92	14.79	10.88	19.04
500 bags yield/acre	9.31	12.62	9.27	16.23
600 bags yield/acre	8.24	11.18	8.19	14.36
at 30% Gross Profit Margin				
400 bags yield/acre	12.48	16.90	12.44	21.76
500 bags yield/acre	10.64	14.42	10.59	18.55
600 bags yield/acre	9.42	12.77	9.36	16.41
at 40% Gross Profit Margin				
400 bags yield/acre	14.56	19.72	14.51	25.39
500 bags yield/acre	12.41	16.83	12.35	21.64
600 bags yield/acre	10.98	14.90	10.92	19.14

Table 4.6 Estimated Unit Cost and Selling Price for an 18.14 kg Box/Bag of X-ray Inspected Onions Produced at a Low Capacity Packinghouse, under Status Quo and with 3-X-ray Machine Addition Scenarios.

ESTIMATE	NUMBER OF X-RAY UNITS INSTALLED			
	LOW DEFECT CROP		HIGH DEFECT CROP	
	None	3	None	3
Number of 18.14 kg Boxes/Bags Produced Per Day	9,142	6,673	6,401	3,868
Cost to Produce a 18.14 kg box of X-ray Inspected Onions				
400 bags/acre yield	8.74	12.02	8.83	15.20
500 bags/acre yield	7.45	10.26	7.52	12.95
600 bags/acre yield	6.59	9.08	6.65	11.45
Unit Selling Price				
at 20% Gross Profit Margin				
400 bags yield/acre	10.92	15.02	11.04	19.01
500 bags yield/acre	9.31	12.82	9.40	16.19
600 bags yield/acre	8.24	11.35	8.31	14.31
at 30% Gross Profit Margin				
400 bags yield/acre	12.48	17.17	12.61	21.72
500 bags yield/acre	10.64	14.65	10.74	18.50
600 bags yield/acre	9.42	12.98	9.50	16.36
at 40% Gross Profit Margin				
400 bags yield/acre	14.56	20.03	14.72	25.34
500 bags yield/acre	12.42	17.10	12.53	21.59
600 bags yield/acre	10.99	15.14	11.08	19.09

CHAPTER 5

INTERDISCIPLINARY STUDENT LEARNING THROUGH THE SYSTEMS APPROACH: A FRESH PRODUCE SUPPLY CHAIN EXAMPLE[1]

[1] Maria Rosario P. Mosqueda, S.E. Prussia and E.W. Tollner. To be submitted to the *NACTA Journal*.

ABSTRACT

An interdisciplinary undergraduate course is proposed. Specifically designed for senior students from the Crop Science, Food Technology, Agricultural Engineering and Agricultural Economics programs of a Philippine university, it is aimed at providing them an opportunity to work cooperatively with colleagues from other disciplines by evaluating a local postharvest problem situation. Viewing the postharvest sector as an integrated chain linking producers, packers, truckers, distributors, retailers and consumers, interdisciplinary student teams spend the first eight weeks of the semester in lecture-discussion sessions led by an interdisciplinary team of faculty members. The last eight weeks are devoted to independent work, where they draw upon the principles of the Soft Systems Methodology to assess and present recommendations to improve a problem situation. Challenges to the course's implementation as well as its potential benefits are identified. The course is seen as an appropriate response to the challenge of making the university's curricular programs more responsive to locally important concerns.

***Keywords**:* interdisciplinary learning, postharvest education, developing countries, pedgagogy, Soft Systems Methodology, supply chain management, andragogy

INTRODUCTION

Upon graduation, students in food and agriculture are expected to deal with many complex problems and opportunities that would often require interdisciplinary collaborations. The increasing importance of a closer integration of harvesting, handling, processing, storage, transportation, marketing and distribution activities of the fresh produce supply chains, for example, should infiltrate into the education and training of these future producers, processors, distributors, researchers, educators and other professionals.

In a FAO Asia-Pacific round table discussion in 1990, the challenge of incorporating the systems approach in educating students about postharvest loss prevention was posed (FAO, 1997). The need for an interdisciplinary, systems approach to agriculture and rural development education in developing countries was also stressed by Lindley (1998). Goletti (2003) and Yahia (2005) also advocated the use of multidisciplinary systems approach as one of the strategies in reducing postharvest losses of developing countries. High postharvest losses continue to plague these countries despite the considerable advances in postharvest research and development during the last few decades (Yahia, 2005). In the Philippines, for example, average postharvest losses for fruits and vegetables remained unacceptably high at 28% and 42%, respectively (Castro, 2003). No literature, however, was found on how this challenge of incorporating the systems approach into the Philippine postharvest education was addressed.

In the United States, systems analysis was one of the priority areas for curriculum development when a nationwide project was undertaken in the 1980s to strengthen higher education in agricultural, food and natural sciences programs plagued with declining enrollments and criticisms from the agricultural and business communities (Wilson and Morren, 1990). The book, *Systems Approaches for Improvement in Agriculture and Resource Management*, by

Wilson and Morren (1990), was a product of this nationwide curriculum project. It emphasized the soft systems perspective as a new way of looking at, and learning about, food, agriculture and natural resources situations and advocated it as a part of a broad range of inquiry methodologies in responding to the challenges and opportunities in food and agriculture.

Several cases in the literature (Arthur and Thompson, 1999; Dooley and Neill, 1999; Karsten and O'Connor, 2002; Murphy et al., 1990; Salvador et al., 1994; Schelhas and Lassoie, 2001; Schmidt et al., 2001; Wiedenhoeft et al., 2003) already illustrate the incorporation of the interdisciplinary perspective and systems approach to problem-solving into the undergraduate programs of agriculture and natural sciences. A brief description of these cases and the plethora of teaching methodologies employed are presented below.

An intensive field course in agroecosystems analysis was developed wherein interdisciplinary student teams, engaged in farm visits, group work activities, consultations with faculty members and oral presentations for eight days, evaluating and analyzing the productivity, economics, environmental impacts, and social viability of several farms in the Midwest (Wiedenhoeft et al., 2003). This course involved undergraduate and graduate students and faculty members from Iowa State University, University of Minnesota and University of Nebraska Lincoln in 1998 and 1999 and has attracted students from various disciplines (agronomy, general agriculture, horticulture, natural resources, environmental science, agricultural economics and anthropology).

Interdisciplinary teaching characterized the site-specific agriculture (Schmidt et al., 2001) and sustainable agriculture science and policy (Karsten and O'Connor, 2002) courses offered in Kansas and Pennsylvania State Universities, respectively. The site-specific agriculture course was team taught by faculty members from the agronomy, biological and agricultural engineering and geography departments. The course is open to juniors, seniors and graduate students, with the majority (77%) coming from agronomy and agricultural technology and management areas and the remaining proportion from agriculture business, agricultural economics, animal science and industry, biological and agricultural engineering, chemical engineering and geography. The sustainable agriculture science and policy course, on the other hand, was taught by an agroecologist and a political scientist with invited guest lecturers in soil conservation, nutrient management and agricultural economics. Enrolled students were from agriculture, political science, business and liberal arts.

The capstone course for the natural resources conservation and management majors at the University of Kentucky employed the problem-based learning approach (Arthur and Thompson, 1999). Immersed in a natural resource issue, student teams identify and understand the interests of key stakeholders through the various data collection methods and present alternative courses of action. The issue is judiciously chosen by the instructor using a set of criteria. A team of faculty members representing relevant fields served as advisors. This problem-based learning approach was also seen in the forestry capstone course at Iowa State University. In this case, however, student teams choose the problem they would like to work on from the list of actual problems submitted by foresters and other interested parties throughout the state (Salvador et al., 1994).

A seminar course, which was first offered in the 1989 spring semester at the University of Illinois, utilized the soft systems approach for solving problem situations in agriculture (Murphy et al., 1990) . Unlike the other previously described courses that catered to seniors, this course focused on freshmen and sophomore students.

Bawden (2005) has described personal lessons from his experiences leading innovative changes toward student-centered curriculum development based around concepts of experiential learning, action research and systems thinking. He and his colleagues at the University of Western Sydney Hawkesbury, Richmond, NSW, Australia have provided many practical experience for others to build on for improving agricultural education.

These cases reported positive student response on the pedagogical approaches employed, despite the attendant challenges (Arthur and Thompson, 1999; Dooley and Neill, 1999; Murphy et al., 1990; Salvador et al., 1994; Schmidt et al., 2001; Wiedenhoeft et al., 2003). For example, students appreciated the varied perspectives provided by individual instructors with different expertise (Schmidt et al., 2001; Wiedenhoeft et al., 2003), the opportunity for experiential learning (Wiedenhoeft et al., 2003), and the presentation of course material using a variety of approaches, such as the incorporation of field trips, guest lectures, videos, interpersonal interactions along with traditional readings and lectures (Karsten and O'Connor, 2002). Salvador et al. (1994) also indicated that students displayed a “natural ability to deal with complex situations in a holistic fashion” and that such “tendency may be suppressed by standard curricula that seek to shape specialized “scientific agriculturists””.

While no study was found that focused on postharvest-related programs, these various cases nonetheless illustrate the feasibility and the gains of incorporating this pedagogical approach into the undergraduate curricular programs.

The importance of an interdisciplinary, systems approach in postharvest research was exemplified at the University of Georgia (UGA) when a team of researchers from the horticulture, food science, engineering and agricultural economics was formed in 1981 (Prussia et al., 1986). Their book, *Postharvest Handling: A Systems Approach*, showed how certain issues, including preharvest quality (Beverly et al., 1993), food safety (Brackett, 1993; Brackett et al., 1993), quality management (Lidror and Prussia, 1993), marketing (Fletcher, 1993; How, 1993), and consumer perceptions and attitudes (Fletcher et al., 1993) are closely integrated into the postharvest continuum of fruits and vegetables and how challenges to improving fresh produce supply chains could be best understood and overcome through cooperation of a wide range of stakeholders (Shewfelt and Prussia, 1993).

Figure 5.1 depicts a simplified supply chain with four business links: a producer, a packer, a retailer and a trucker who facilitates produce movement across the chain, along with the various disciplines that support each link's operations. While each business link can independently strive for its own optimal performance by exploiting available knowledge and technology base, greater efficiency can be achieved when creative alliances are established among these businesses and among key disciplines associated with the supply chain. Hewett (2003) and Prussia (2006) highlighted cases that illustrate the importance of these collaborations in the fresh produce industry. Hewett (2003) cited a case in New Zealand where growers and scientists undertook a collaborative trial shipment that demonstrated an acceptable shelf life and a much improved eating quality of apricots that were harvested more mature and transported in hard sided refrigerated containers compared to those that were harvested less mature and transported in curtain sided refrigerated trucks. The improved system, however, was not successful as the supermarket buyers were not part of the experiment. Growers did not receive any incentive for using the improved system. Prussia (2006) noted the importance of systems thinking in improving postharvest operations when a peach harvest wagon was designed to reduce bruise damage during transport so growers are encouraged to harvest more mature fruits. Although the improved wagon was able to reduce bruise damage by 1-4% (Nguyen et al., 2004) during the transport, bruise damage at the packinghouses still prevented growers from harvesting more mature fruits. According to Collins (2003), suppliers and retailers of fresh fruits and vegetables are under increasing perform as food retailing sector is becoming more concentrated, competitive and demanding of its supply chains. He highlighted the benefits within and between firms when chain members collaborate in achieving quality in fresh produce handling. These include lower error rate, creation of more value, improved confidence in outcomes, improved economics and sustained competitiveness.

The importance of collaborative supply chains to ensure success in a rapidly changing environment, the success of some US university programs incorporating the systems approach and that of the interdisciplinary postharvest research program that was implemented at the University of Georgia clearly demonstrated the feasibility and desirability of incorporating an interdisciplinary, systems approach in the education of future food and agriculture professionals. This paper, then, proposes an interdisciplinary undergraduate course as a means of introducing curricular enhancements to better prepare future Philippine food and agriculture professionals in responding to the challenges of their work environments. The proposed course draws upon the complexity of fresh produce supply chains to provide students an excellent ground to explore the importance of an interdisciplinary, systems approach in evaluating and improving problem situations.

OVERVIEW OF THE PROPOSED COURSE

The motivation to develop this course, *Systems Approach to Improving Fresh Produce Supply Chains,* stemmed from the author’s desire to introduce new pedagogical approaches that enhance existing curricular offerings and provide both students and faculty in a traditionally teaching institution a formal venue to be more actively engaged in the concerns of the local fresh food supply chains. Building on the students' advanced discipline-based skills, the course draws upon the soft systems methodology to emphasize the importance of considering technical, managerial and social aspects when improving problem situations in local fresh produce supply chains. Attachment I presents the condensed syllabus of this proposed course.

The course aims to provide students an opportunity to integrate prior knowledge in their respective disciplines and work cooperatively with partners from other fields in evaluating a postharvest problem situation. Upon completion of the course, it is envisioned that the student would be able to (1) understand and appreciate the importance of a holistic approach in considering and evaluating problem situations; (2) gain confidence in his/her ability to locate, synthesize, present available information about a problem situation and the diverse viewpoints of key stakeholders, and recommend feasible and desirable solutions to locally important concerns; and (3) improve his/her team working and communication skills.

Target Students

This proposed course is designed for the senior students of Xavier University-College of Agriculture, Philippines, specifically from disciplines which form the basic core of fresh produce supply chains: Crop Science, Food Technology, Agricultural Engineering and Agricultural Economics. Aside from sharing some common technical courses, students from these programs also share a common liberal arts formation, often taking the same classes together. These previous interactions during curricular, as well as extra-curricular, activities could facilitate the subsequent formation, and functioning, of interdisciplinary student teams.

Proposed Instructional Approach

Students spend the first eight weeks of the semester in class. Faculty instruction focuses on three areas: (1) The roles and the interdependence of various business links and academic disciplines, using fresh produce supply chains as example cases; (2) Teamwork and Individual Learning Styles, and (3) Soft Systems Methodology (SSM). A team of four faculty members from Crop Science, Agricultural Economics, Food Technology and Agricultural Engineering lead the lecture-discussions. Guest lecturers from other departments, such as those from psychology or other relevant units, would be invited to conduct sessions on teamwork and individual learning styles.

During in-class sessions, basic principles and concepts of the three major areas are presented followed by group activities that illustrate the application of these principles. Interdisciplinary student teams, for example, work on a test case, at the end of each SSM stage discussion to gain experience with applying the principles of the methodology. Results of these group activities would be summarized in a two-page report and presented before the class for 10 minutes.

In addition to lecture-discussions, field visits, team games, simulation games, such as the Beer Game and the Peach Game hose developed by Aggarwal et al. (2004), Prussia (2005) and Mosqueda et al. (2006a; 2006b) that involve fresh produce business links are incorporated in these discussions to enhance student understanding.

The last eight weeks of the semester are devoted to independent work, where interdisciplinary student teams work on two related projects and conduct peer education sessions. In the first project, student teams develop a comprehensive picture of a local postharvest chain, starting at the consumer and tracing the various links backwards to the producer. To ensure efficient use of resources, all investigations for a particular semester are focused on a single commodity identified by the faculty members. Teams, however, could work on different supply chains. The written report, the final product of this activity, is reflective of the team's understanding of the interconnected systems of relationships that exist within and among the various business links in the provision of fresh fruits and vegetables.

The second project builds on the results of the first. After documenting a supply chain, student teams identify a problem situation within that chain and, using the soft systems approach, present recommendations to improve the problem situation. The output is both a written report and a 30-minute oral presentation before the class and interested parties, such as the key stakeholders of the chosen supply chain and other faculty members.

Peer education sessions are incorporated to provide formal venues for student team members to learn from one another. During these sessions, students share relevant principles of their respective disciplines that they think would be helpful in considering their chosen problem situation. Peer educators decide on the course material, the method of delivery and evaluation of student understanding. Each team member conducts at least one 50-minute session.

Each of the four collaborating faculty members mentor a specific number of student teams. Scheduled consultations with faculty mentors are set up, at two-week intervals, to provide guidance and to monitor team progress in the projects. Student teams, which are also required to maintain journals to document all their activities and reflections, are expected to discuss their concerns during these fortnightly meetings.

Soft Systems Methodology

The soft systems methodology (SSM) was the chosen pedagogical approach for this proposed course because it offers a way of integrating both technical and social issues inherent in managing each of the business links comprising a fresh produce supply chain. The work of Rohs et al. (2002) and Prussia (2000) illustrated how this methodology can be applied in understanding the postharvest sector and in facilitating improvement of problem situations. Rohs et al. (2002) used the soft systems methodology to design a postharvest extension program in the University of Veracruz in Mexico to help growers, handlers and shippers to export quality produce. Prussia (2000) conducted two roundtable workshops in 1997, with participants representing restaurants, supermarkets, fresh-cut processors, wholesale dealers, truckers, packinghouses, growers and researchers. They discussed ways to reduce losses and to improve the quality of fresh produce. Participants learned about the soft systems methodology and modeled each of the postharvest businesses as a human activity system. The models developed by the participants helped clarify their understanding of the complex interactions between the various postharvest businesses and identified the need to improve their understanding of their own business links as well. Other cases illustrating its use in agriculture and in agricultural education were seen in Macadam and Packham (1989), Macadam et al. (1990) and in the sample cases used by Wilson and Moreen (1990).

The methodology was developed by Peter Checkland and his colleagues at the Lancaster University, UK (Checkland, 1981; Wilson and Morren, 1990). In SSM, the focus is on problem situations and modeling involves human activity systems. Checkland (1981) and Wilson and Morren (1990) describe SSM as comprised of seven stages, of which Stages 1,2,5,6, and 7 are considered the real-world activities while Stages 3 and 4 are the systems-thinking activities. Stages 1 and 2 involve identification of a problem situation, rather than looking for the problem, and descriptions of the related structures and processes. Basic facts are gathered from documentary sources and from the accounts and opinions of people involved in the situation. The objective is to display the problematic situation from a diverse range of viewpoints and to synthesize what has been gathered into useful alternative conceptualizations of the meaning of the situation. After the present situation is understood, a vision of what one wants the future state to look like is defined. Stages 3 and 4 are aimed at using systems thinking to design and describe proposed future improvements. These stages involve describing relevant human activity systems from several viewpoints and then using the CATWOE[2] mnemonic to ensure the descriptions are complete. Then conceptual models of each human activity system are developed. Stage 5 compares the conceptual models with the situation summary developed during stages 1 and 2. This comparison should provide new insights about the problem situation and should introduce specific proposals for change. Stage 6 is focused on debating desirable and feasible change among the people concerned. To be desirable, the changes must be desired by the people in relation to their world views. For a change to be feasible, on the other hand, it must be implemented with the resources and capabilities at hand and should be environmentally appropriate, avoiding unacceptable costs and factors over which people have no control. Stage 7, the implementation stage, is focused on planning for and taking the necessary steps to implement the agreed changes to improve the problematic situation.

Simulation games and models

As previously indicated, some simulation games and models are incorporated in the course to enhance student understanding. When properly used and integrated into the teaching methodology, these tools heighten understanding of real-life situations as they provide learners with opportunities for reflection and experimentation without the associated, often costly, consequences. The Beer Game, which was developed at MIT's Sloan School of Management in the 1960s and which has been played all over the world from high school students to business and government executives (Sterman, 2006), vividly illustrated the importance of the systems approach in managing supply chains. The Irrigation Management Game (Burton, 1993) where

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[2] CATWOE stands for Customers, Actors, Transformation, Weltanschauung (world view or mental framework), Owners and Environmental constraints

players take the roles of farmers, village water manager, water bailiff, crop trader, and irrigation agency section officer, also enabled better understanding of the broader issues involved in managing an irrigation system. The computer simulations developed by the UGA postharvest search team, depicting the dynamics of fresh produce retailing (Aggarwal et al., 2004) and the prediction of fresh produce quality during distribution (Prussia, 2005), can be excellent instructional tools in demonstrating the importance of systems thinking in fresh produce supply chains.

Course Evaluation and Student Performance Assessment

Pre-test and post-test assessment would be conducted to measure how well students understood the subject matter. A preliminary sample of assessing student performance is provided as Attachment II. Students would also be encouraged to accomplish a course evaluation form, aside from the regular end-of-the-semester course evaluation administered by the College. Attachment III is a preliminary draft of this evaluation form.

POTENTIAL BENEFITS

This course opens up a wide range of benefits and opportunities for students, collaborating faculty members and the university. As students gain exposure and understanding on the complexity of the fresh produce supply chains and the differing viewpoints of key stakeholders, they will enhance their capability to craft more feasible alternatives to problem situations. Through team projects, faculty team teaching and student peer education sessions, they will have a good venue to engage in stimulating discussions and exchange of information with colleagues and professionals from other disciplines. This exposure to diverse fields will hopefully foster among students broader understanding and better appreciation of other disciplinary perspectives in considering a problem situation. Students will also have ample venues to harness their team working, decision-making and written and oral communications skills, which are important requisites in their future careers.

Collaborating faculty members also benefit from teaching this course. Local knowledge that can be generated in student team projects can be used to enrich their course materials. Sample problems and test case scenarios will be meaningful to the students if these are lifted from the local community rather from textbook cases that are often drawn from the realities of more technologically advanced nations. Being more informed about concerns of local postharvest chains through exposure in student projects, faculty members would also be in a better position to seek research or extension opportunities, whether individually or in collaboration with other faculty members, to help address the needs of the local community. Using student project results as foundation, faculty members can develop a more comprehensive documentation, breadth and depth-wise, of the existing postharvest chains of locally important fruits and vegetables not only in the Northern Mindanao region but in the entire Mindanao Island as well. Such an involvement could spawn the identification of research and extension opportunities covering the entire supply chain.

Since the course inherently seeks linkages with the local community, government agencies and industry, its implementation contributes to the strengthening of the University's ties with these sectors and highlights its continued involvement to the solution of locally relevant problems, as espoused in the University's mission: *"As a University, Xavier pursues truth and excellence in teaching, research and service to communities: it is concerned with contemporary problems; it prepares men and women with competencies, skills and a keen sense of responsibility to their communities.*" (Xavier University-Ateneo de Cagayan, 2005).

It has also the potential to strengthen the program offerings of the College, as engagement in local problem scenarios through interdisciplinary cooperation can bring forth the strengths and weaknesses relating to faculty instruction, student formation, instructional tool development and other aspects of administering the curricular programs.

Moreover, the course could also spark interest to form more interdisciplinary collaborations not only within the departments of the College of Agriculture but also with other colleges and departments of the university as well. It is axiomatic that the applications of the interdisciplinary, systems approach clearly go far beyond the fresh produce supply chain example discussed. The varied academic programs cited in this paper that incorporated interdisciplinary, systems-level approaches clearly illustrated this as well as the numerous cases reported in literature.

PERCEIVED CHALLENGES TO ITS IMPLEMENTATION

While there are, undoubtedly, a number of challenges to incorporating an interdisciplinary systems approach into existing curricular programs, only three concerns that will likely confront collaborating faculty members are presented here. Firstly, seeking approval for its formal inclusion into the curricular programs involves considerable time and effort. Introducing a course that cuts across departments, particularly one that is not part of the minimum requirements set by the national technical panel on agricultural education, needs to be championed by the college administration. Its importance and relevance as a complement to disciplinary inquiry needs to be communicated properly to gain support.

Secondly, the course requires the formation of a cohesive and committed faculty team who share a common understanding and appreciation of the principles and importance of the systems approach to problem solving. It may be necessary for the faculty members, for example, to experience one complete one cycle of the soft systems methodology together through engagement in an actual local postharvest problem situation. This can be done during the summer session. Such an activity will also enable faculty members to: (1) develop closer camaraderie among themselves, (2) test their own team working skills, (2) learn more about one another's disciplinary perspectives, (3) develop a better understanding and appreciation of the challenges that students will eventually encounter when they work on their projects, and (4) define and clarify logistics concerns or issues relating to course administration.

Lastly, the course demands considerable preparation time from collaborating faculty members. Considering that faculty members will be dealing with a relatively more diverse student group than what they have been used to in previous years, it may be necessary for them to modify their teaching styles and the way their course materials are prepared and presented to cater to this greater student diversity. Sustaining student interest in the course and motivating them to learn something outside of their technical backgrounds and to collaborate with students from other disciplines require faculty members to be more discerning and innovative in their teaching approaches.

CONCLUSIONS

An interdisciplinary undergraduate course was developed to provide students in food and agriculture a more holistic perspective when considering and improving problem situations in their work environments. Proposed student activities, such as the interdisciplinary team projects and peer education sessions, are geared toward enabling students to develop the necessary skills in working cooperatively with other disciplines, to appreciate different disciplinary perspectives and inquiry skills, and to value the importance of the systems approach in improving fresh produce supply chains. While this proposed course focused solely on Philippine fresh produce supply chains, its approach can easily be adapted into the education and training of future professionals engaged in the other food supply chains.

The course could also spawn opportunities for greater interdisciplinary cooperation among faculty members in the Philippine university as well as strengthening existing food and agriculture programs to make them more relevant to the needs of local communities.

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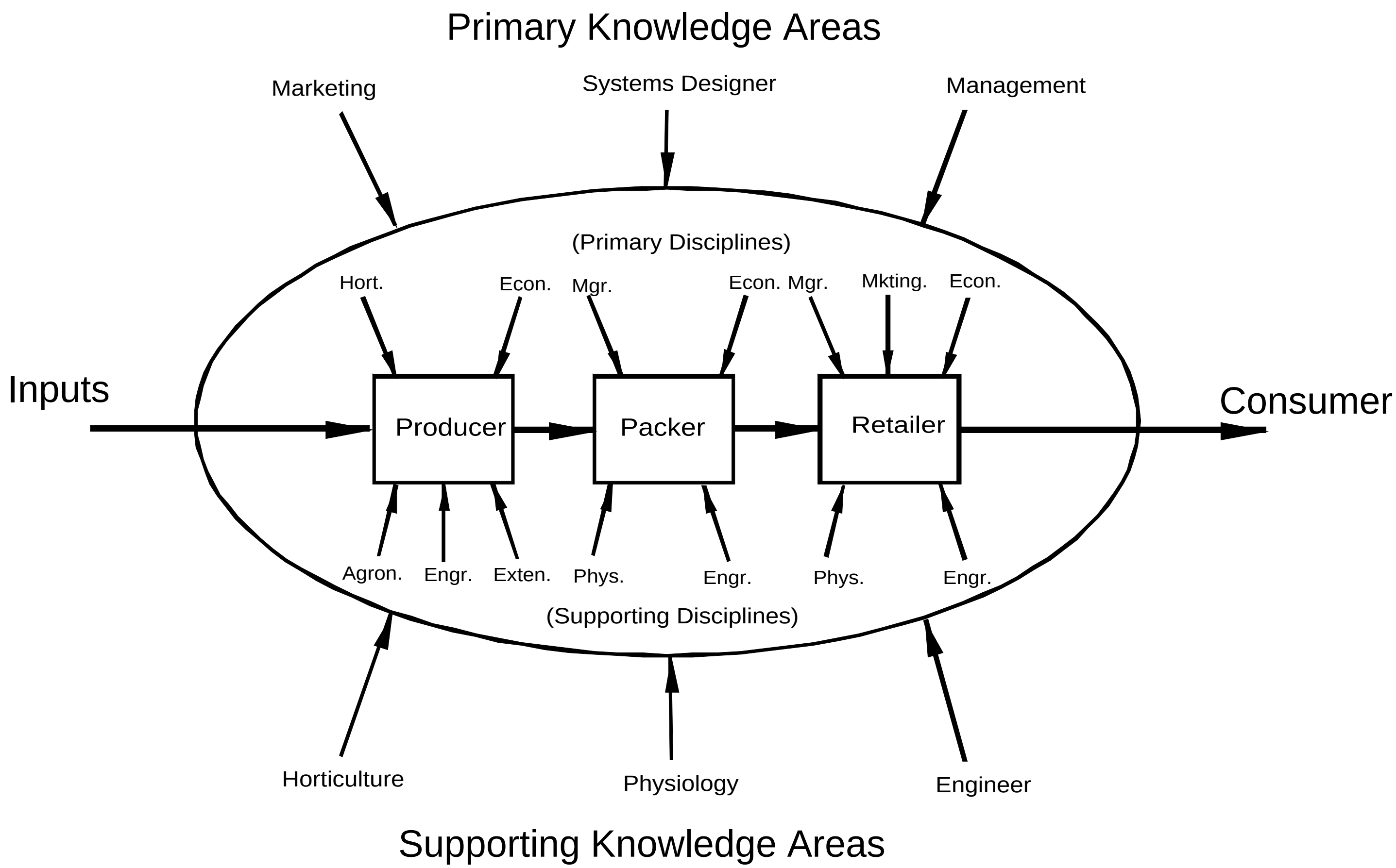

Figure 5.1 Key Knowledge Areas/Disciplines and Business Links of a Simplified Integrated Fresh Produce Supply Chain

Attachment I: A Condensed Syllabus for the Proposed Course 'Systems Approach for Improving Fresh Produce Supply Chains'

COURSE DESCRIPTION Use of systems thinking to complement disciplinary inquiry in designing and improving fresh produce supply chains.

COURSE CREDIT 4 credit units (4 hours per week)

PREREQUISITE Senior standing. The course is designed for students completing their baccalaureate degrees in Crop Science, Food Technology, Agricultural Engineering and Agricultural Economics.

COURSE CONTENT

Unit 1 Working In Teams

1. **Specific Objectives.** At the end of this section, the student will: a) Gain a better insight of his/her personality and learning style; b) Develop a greater sense of awareness and respect for the individual differences that exist among team members; c) Learn how to work more harmoniously with others.
2. **Timetable**. 0.75 week (3 50-minute sessions)
3. **Subject Matter Outline. (1)** Introduction- Importance of collaboration (2) What is a Team, its importance and characteristics of effective teams, (3) Understanding Personal Learning Style: Myers-Briggs' Psychological Types (Myers, 1998).
4. **Student Team Activities.** (1) A Team Report on Personal and Team Player Styles and on Team Building Exercises; (2) Collaboration Games

Unit 2 The Fresh Produce Supply Chain

1. **Specific Objectives.** At the end of this section, the student will be able to: a) Explain the role of each business link in selected the fresh produce supply chains; b) Describe or visually illustrate the key activities of each link and its interaction with other links; and, c) Explain the role and the interdependence of the various disciplines in the provision of fresh fruits and vegetables.
2. **Timetable.** 2 weeks (8 50-minute sessions)
3. **Subject Matter Outline**. (1) Introduction- What is a supply chain? (2) The Various Links of the Fresh Produce Supply Chains; Role, Key Activities, Interactions with Other Business Links, (3) Overview of Various Disciplinary Perspectives vis-à-vis Fresh Produce Supply Chains and the Opportunities for Interdisciplinary Cooperation: Crop Science, Agricultural Engineering, Food Technology, Agricultural Economics, Quality and Food Safety Management
4. **Student Team Activities.** (1) Peer Education Sessions, (2) Exposure Trip to Various Business Links, (3) Project 1: Documenting a Fresh Produce Supply Chain, Due Date: Midterm Examination Week

Unit 3   Systems and Systems Thinking

1. **Specific Objectives.** At the end of this unit, the student will: a) Have the basic knowledge on the concepts and principles of the systems approach and b) Use systems thinking tools to deepen his/her understanding of complex food and agricultural systems;
2. **Timetable.** 1 week (4 50-minute meetings)

3. **Subject Matter Outline.** (1) Introduction - The Blind Men and the Elephant (2) What is a System? (3) Linear vs. Systems Thinking- Examples from various fields will be cited, (4) Models and Modeling, (5) Approaches to System-Based Inquiry and their Differences.

4. **Student Team Activities**. The Beer Game, The Peach Game, Post-game discussions The source of these games should be cited.

Unit 4 Defining Problem Situations (SSM Stages 1 And 2)

1. **Specific Objectives.** At the end of this section, the student will: a) Appreciate the importance of such concepts as structure, process and climate in understanding a problem situation better; b) Experience how to responsibly gather information from divergent and relevant sources to understand a problem situation; c) Be able to describe and present the essential features of a problem situation being studied based from the perspectives of the various people involved; d)Appreciate the importance of seeking as many relevant perspectives as possible in considering a problem situation.

2. **Timetable.** 1 week (4 50-minute sessions)

3. **Subject Matter Outline.** (1) Introduction Overview of the 7 Stages of the Soft Systems Methodology and Focus on Stages 1 and 2 - Description, analysis and synthesis of the present state of affairs, (2) Importance of Looking at Problem Situations, not at Problems (3) Understanding the Structure, Process and Climate of a Situation – Structure, Process, Climate (4) Common Themes of Concerns Raised by People (5) Key Things to Remember in Gathering Information - do’s and don’ts (6) Synthesis-Purpose: Key Elements of a Synthesis Report

4. **Student Team Activities**. Improving the Supply Chain of the Manresa Farm Products (Test Case): Stage 1 and 2. Teams will be required to give a 10-minute oral presentation of their results and to submit a 1 to 3-page written report.

Unit 5 Systems Thinking About Improved Situations (SSM Stages 3 And 4)

1. **Specific Objectives.** At the end of this section, the student will: a) Be capable of defining a human activity system model and of creating a conceptual model relevant to the situation studied; b) Gain an insight on the hierarchical complexity of a system and on the importance of these supra- and subsystems in its existence.
2. **Timetable.** 1.25 weeks (5 50-minute sessions)
3. **Subject Matter Outline.** (1) Introduction a) Focus of Stages 3 and 4 -Designing Future Improvements of the Problem Situation by Developing Human Activity System (HAS) Models; b) HAS and Its importance, (2) Defining the Human Activity Systems using the CATWOE outline, (3) Conceptual Modeling of Each Defined Human Activity System
4. **Student Team Activities.** Improving the Supply Chain of the Manresa Farm Products: Stage 3 and 4. Teams will be required to give a 10-minute oral presentation of their results and to submit a 1-3-page written report.

Unit 6 Defining Desirable And Feasible Changes (SSM Stages 5 And 6)

1. **Specific Objectives.** At the end of this section, the student will: a) Have an insight on the significant amount of work involved, and the various considerations, when proposing changes in organizations. b) Appreciate the importance of keeping an open mind, of

rethinking basic assumptions and of exercising sensitivity in dealing with others during discussions.

2. **Timetable.** 1 week (4 50-minute sessions)

3. **Subject Matter Outline.** (1) Introduction -Focus of Stages 5 and 6 -Determination of Desirable and Feasible Changes by Comparing Conceptual Models with the Perceived Problem Situation (2) Some Techniques for Comparing Conceptual Models with 'What Exists' Situations, (3) Discussing and Defining Proposed Changes – Feasibility and Desirability

4. **Student Team Activities.** Improving the Supply Chain of the Manresa Farm Products: Stage 5 and 6. Teams will be required to give a 10-minute oral presentation of their results and to submit a 1 to 3-page written report.

Unit 7 Implementing Proposed Change/s (SSM Stage 7)

1. **Specific Objectives.** At the end of this section, the student will: a) Know how to prepare an implementation plan for a proposed action; b) Understand how each element of the plan contributes to a successful implementation of the proposed action.

2. **Timetable.** 1 week (4 50-minute sessions)

3. **Subject Matter Outline.** (1) Introduction -Focus of Stage 7 -Planning for and Taking Action to Improve Situations, Kinds of Changes that Could Result from Stages 5 and 6, Importance of Effective Communication (2) Main Tasks - Development of an Implementation Plan, Conduct of Strategic Actions of the Plan, Communication to All Affected Parties, Performance and Environment Monitoring and Evaluation of Results, Modification of Some Aspects of the Plan, (3) Elements of an Implementation Plan -Strategic

Action, Performance Measures, Responsible Actors, Timetables, Needed Resources, Budget, Overall Leadership, Communication (4) SSM as tool for continual improvement

4. **Student Team Activities.** Improving the Supply Chain of the Manresa Farm Products: Stage 7. Teams will be required to give a 10-minute oral presentation of their results and to submit a 1- 3-page written report.

EVALUATIVE INSTRUMENTS

Project 1 - Documenting a Fresh Produce Supply Chain (20%) Student teams will document a fresh produce supply chain of their choice, starting at the consumer and tracing the various links backwards to the producer. Documentation for each business link, at the minimum, should include the detailed descriptions of the following: (a) functions/role; (b) individual processes that make up their operation; (c) quality and food safety management practices; (d) interactions with other links in the chain; and (e) the role and importance of various disciplines. The report should reflect the team's comprehensive understanding of the interconnected systems of relationships that exist within and among the various business links as they work together in providing fresh fruits and vegetables. Written report submissions and oral presentations of their work will be held on the midterm examination week.

Project 2 - Improving a Fresh Produce Supply Using SSM (50%) The second project builds on the results of the first. From the chosen supply chain, the team will identify a problem situation and address associated problem/s using the soft systems methodology. Teams will present the results of their work to the class and when possible, to representative/s of the organization for whom they have developed their analyses and recommendations. Written report submission and oral presentations will be on the final examinations week.

Regular Team Reports, Presentations and Peer Education Sessions (30%) Student teams will conduct specific activities/exercises at the end of each topic and performance in oral and written presentations will be evaluated. Schedules for oral presentations and for written reports will be distributed on the first day of class.

General Grading Guidelines For each of the above activities, half of the grade is a team score, assigned equally to all the student team members while the second half of the grade is individualized for each member. Specific grading breakdown for each evaluative instrument will be agreed upon at the start of the semester and will be reflective of the evaluations made by the student team members, the faculty and whenever applicable, interested third parties.

Attachment II: Pre-test and post-test assessment questions

Directions: Answer each question as concisely as you can.

1. What is a postharvest loss? Give an example and discuss how this loss can be prevented or minimized.
2. What is a supply chain? Give one example and discuss why you consider it a supply chain.
3. Name one harvested fruit or vegetable. Describe one path that this fruit or vegetable would follow as it is moved from the field until it is available to the public.
4. Identify the parties involved in moving a fruit or vegetable from the field to the marketplace. Describe the role/s and discuss the importance of each of these parties.
5. Describe the role of the following disciplines in the path that you have described in item#3.
    a. Agricultural Engineering
    b. Food Science and Technology
    c. Agricultural Economics
    d. Crop Science
6. Rank the disciplines in item #4 according to importance with respect to the path you have described in item #4. Explain your reasons of your ranking.
7. What is a team? Give 3 characteristics of a successful team and explain how each of these characteristics contributes to the success of a team.
8. What is a system? Give one example and discuss why you consider it a system.
9. What is systems thinking? State one situation where you think systems thinking is important or not important. Give your reasons.
10. Name one systems thinking tool and discuss how you can use this tool in improving the scenario you have described in item #1.

Attachment III: Course Evaluation

Gender: _______ Major/Discipline: ____________________

Directions: Read each statement carefully and check the number corresponding to your FIRST reaction concerning your opinion. You are highly encouraged to elaborate on your reaction by providing a brief statement/explanation after each item.

1. Before taking this course, your interest on local fresh produce supply chains was

○ 1 very low ○ 2 ○ 3 ○ 4 ○ 5 very high

____

____

2. Your interest on these fresh produce supply chains increased significantly in this course

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

3. Your knowledge on fresh produce supply chains increased significantly in this course:

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

4. The opportunities provided in the class to learn from, and about, other disciplines involved in the fresh food supply chains are adequate.

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

5. The projects assigned in this course provide an opportunity for you to integrate the knowledge and skills you have acquired so far in your stay in the university.

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

6. The opportunities provided to apply concepts in actual problem situations or in simulated conditions using computer games and models are relevant and adequate.

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

7. The amount of work you put into this course was

○ 1 very low ○ 2 ○ 3 ○ 4 ○ 5 very high

____

____

8. Students were active participants in the teaching and learning process of this course.

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

____

____

9. The instructors give you timely and detailed feedback on your work.

○ 1 Strongly disagree ○ 2 ○ 3 ○ 4 ○ 5 Strongly agree

10. What is your overall rating of the quality of the course?

○ 1 very low ○ 2 ○ 3 ○ 4 ○ 5 very high

11. If you were not in your last semester in college, would you be willing to take another course that was designed in this format?

○ 1 Yes ○ 2 No

12. Please comment on your work with your interdisciplinary team.

13. Please comment on the strengths and weaknesses of this course.

14. Please comment on the quality and adequacy of resource materials provided in this course

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____

15. Please comment on how the instructors can improve the content and delivery of this course.

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CHAPTER 6

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

This work was based on three major objectives: (1) provide information on the performance of Vidalia onion packinghouses relating to sizing and inspection, (2) assess the economic and operational impact of incorporating an X-ray imaging-based inspection system into the operations of a Vidalia onion packinghouse using a simulation model, and (3) develop a team-oriented systems approach course to train future fresh produce supply chain participants. The following conclusions were drawn from this work:

1. There is a significant difference ($p<0.05$) among packinghouses in the incidence rate of incorrectly sized onions. Among the three packinghouses studied, packinghouse B was significantly different from A and C.
2. High incidence of oversized onions in a size category is common in all packinghouses. The percentage by weight of oversized onions exceeded the tolerance limit set by the US Grade Standards.
3. There was no significant difference between packinghouses in terms of incidence of rejects in the sorted batch of Grade 1 onions. Reject incidence averaged 13% among the three packinghouses. Packinghouse A exceeded the defect tolerance limit by weight.

4. Under the simulated conditions of two Vidalia onion packinghouses, The incorporation of three- and four- X-ray inspection machines before the size sorting process was feasible at an approximate conveyor belt speed of 0. 25 meter per second.
5. Results suggest that pricing necessary for X-ray inspected onions seemed to be economically sustainable. Estimated selling price per box, at 20, 30 and 40% gross profit margins, were within the range of historical prices of the Vidalia district shipping point, published by the USDA Agricultural Marketing Service (2006). Estimated cost of producing an 18.14 kg box of X-ray inspected onions ranged from $9.00 to $15.20, depending on the quality of the incoming crop.
6. An interdisciplinary course for the undergraduate students from Agricultural Engineering, Crop Science, Food Technology and Agricultural Economics programs was developed. It focused on hands-on learning of local fresh produce supply chain problem situations and on the provision of the necessary skills to enable students to work cooperatively with other disciplines in seeking more feasible solutions to locally important concerns.

Future Directions

This packinghouse study is but a small step toward achieving greater transparency and understanding of the Vidalia onion supply chain. While this current work is limited to investigating and modeling the flow of onions through the various operations, it is recognized that the adoption of the x-ray inspection technology will have economic implications beyond the packinghouse. Thus, the development of an integrated model incorporating the storage, distribution and sales systems will be necessary to provide a more accurate assessment of the technology's full impact on the Vidalia onion industry.

There are several improvement opportunities that can still be explored to make the simulation model more useful to Vidalia onion packinghouse operators and other interested parties. Some possible enhancements to current model features include: (a) incorporation of bruise damage incidence at the packinghouse, (b) inclusion of other essential postharvest operations such as curing and storage, and (c) analysis of the labor and equipment utilization. These improvements will provide a more comprehensive picture of the challenges facing Vidalia onion packers.

The model can also be used as a springboard to study the packing operations of other fruits and vegetables, particularly in developing countries. Investigations into, and documentation of, such operations remained sparse. Developing similar models can be useful in assisting managers in the identification and evaluation of possible packinghouse improvements and also in providing more relevant instructional tools for postharvest education and training. Other software programs employing more graphical enhancements may also be explored to make the model more adaptable to the needs and interest of the target clients.

The proposed interdisciplinary course will be piloted in the student’s home institution upon approval for inclusion into the agriculture and food curricula. Its implementation and subsequent evaluation by students, faculty members and participating business firms will be properly documented and results will be disseminated in public forums. Similar collaborations between the agricultural engineering department and other disciplines, such as animal science, will also be explored.

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APPENDIX A

Model Diagrams and Corresponding SIMAN Program Codes for Simulating Vidalia Onion Packinghouse Operations

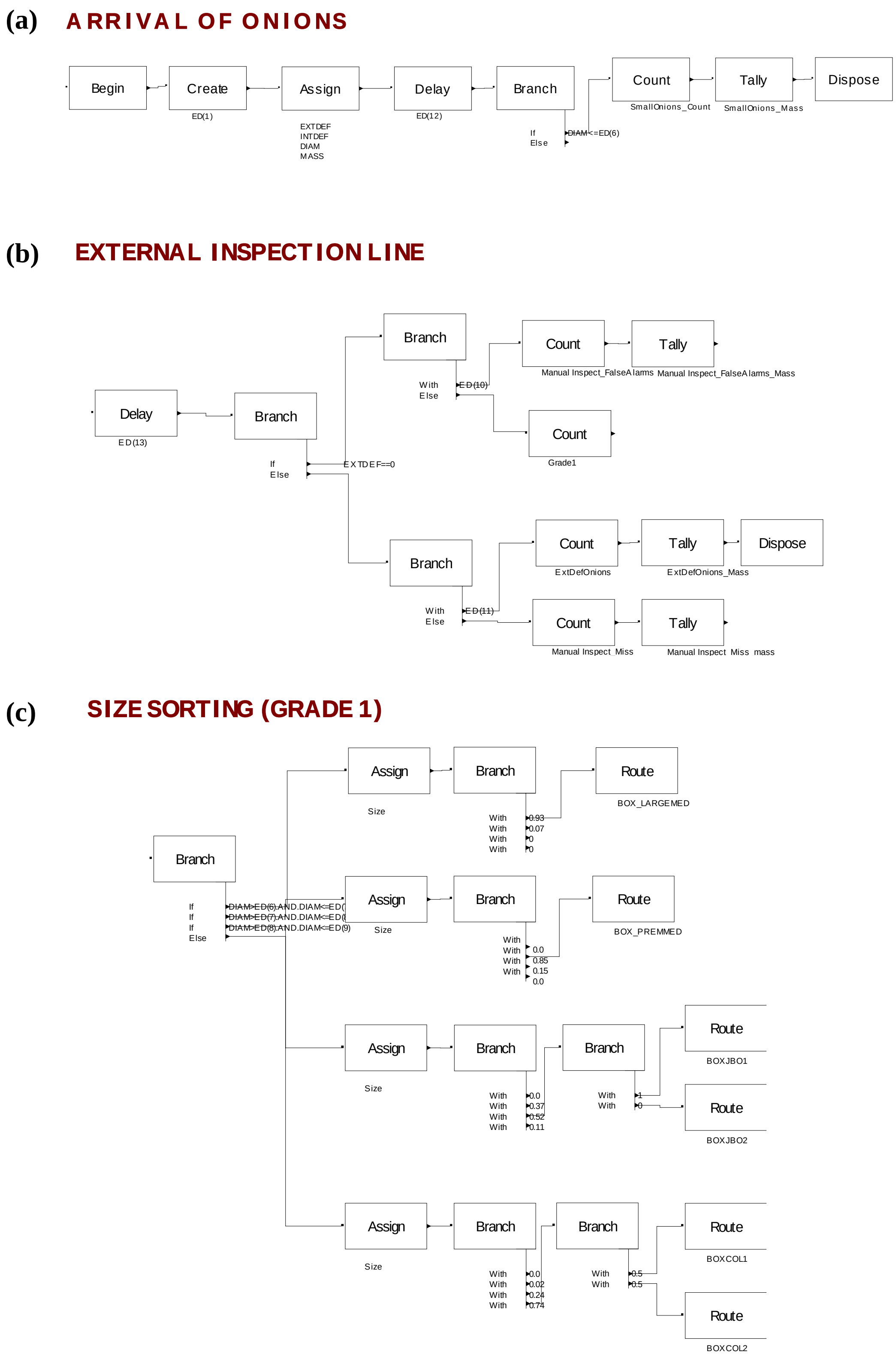


Figure A.1 Portion of the Model Showing Receiving – Size Sorting Operations Used in Simulating Product Flow in a Vidalia Onion Packinghouse under Status Conditions

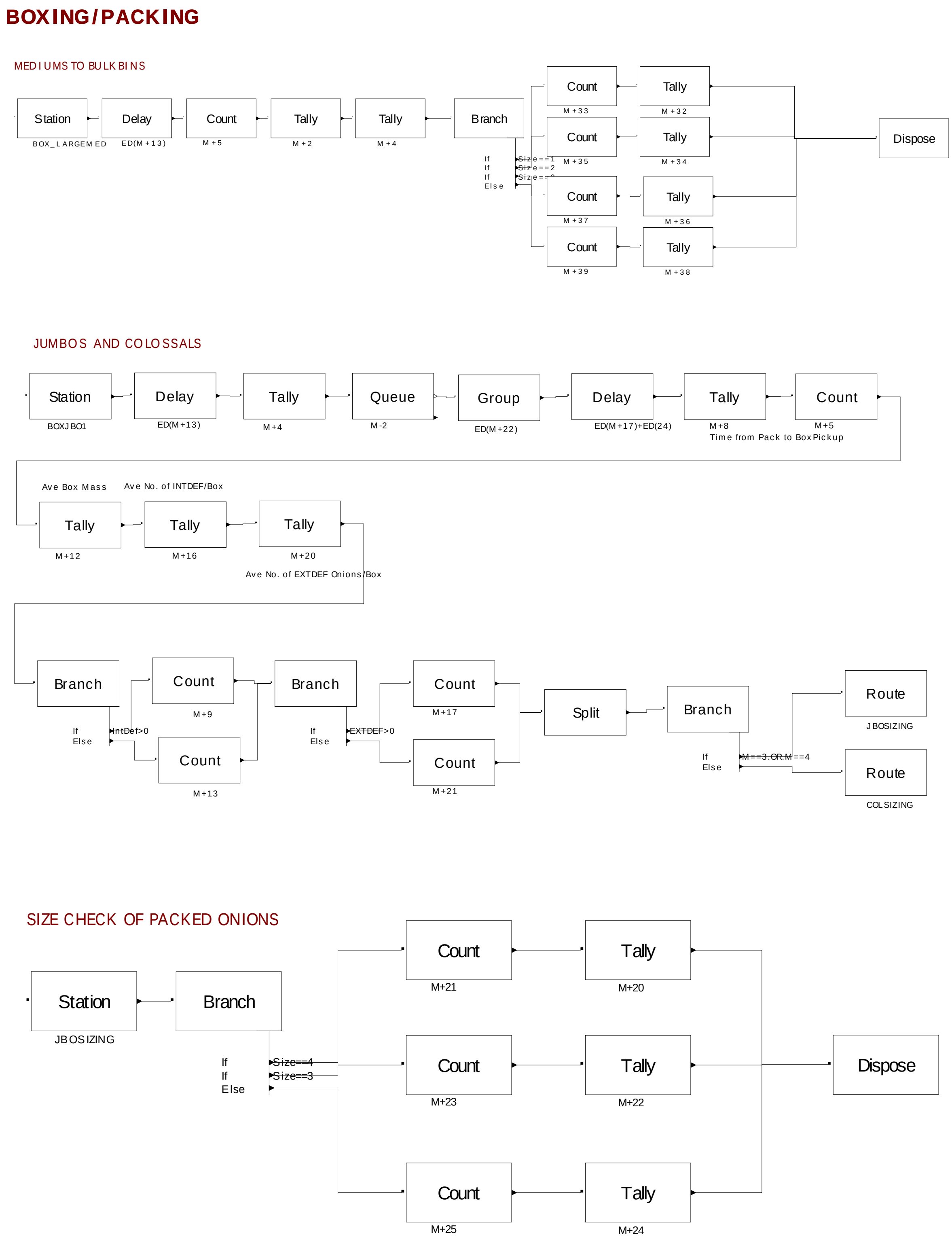


Figure A.2 Portion of the Model Showing Boxing/Packing Operations Used in Simulating Product Flow in a Vidalia Onion Packinghouse under Status Quo Conditions

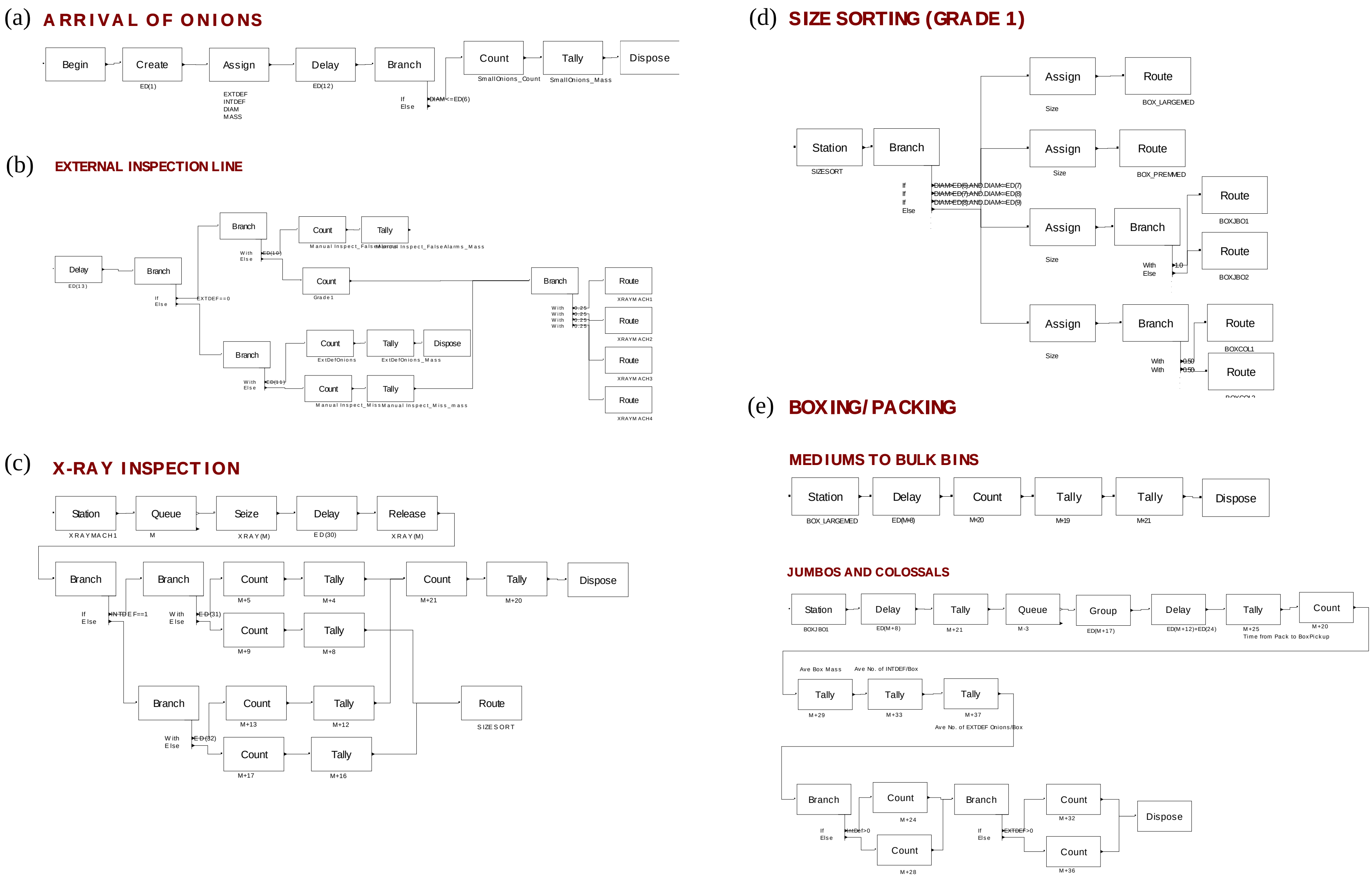


Figure A.3 Simulation Model for a Vidalia Onion Packinghouse Incorporating a Four-Unit X-ray Inspection system Before Size Sorting

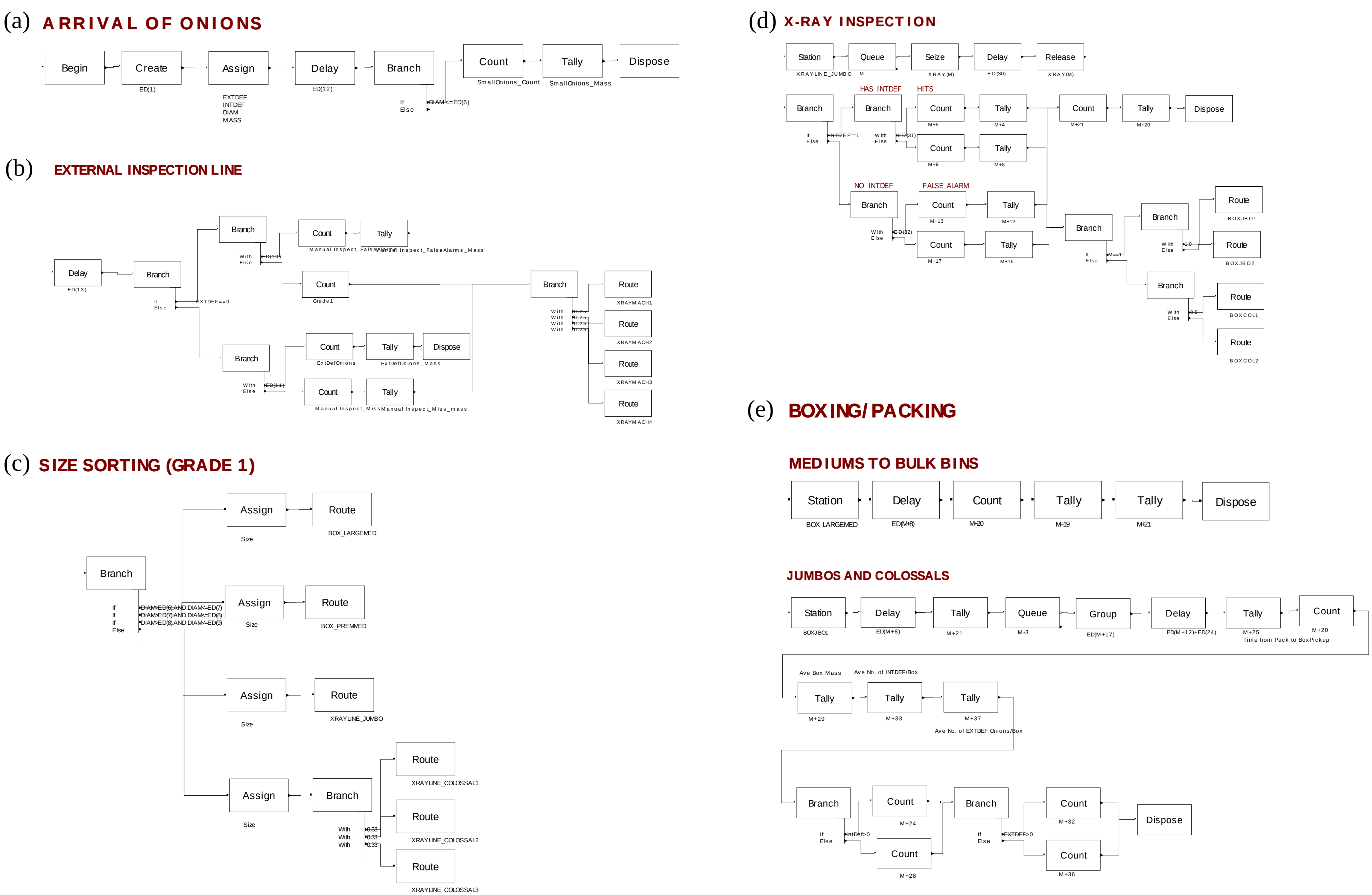


Figure A.4 Simulation Model for a Vidalia Onion Packinghouse Incorporating an X-ray Inspection System After the Size Sorting

Table A.1 SIMAN Code for Simulating Vidalia Onion Packinghouse Operations under Status Quo Conditions

```
1$            BEGIN,          Yes;

3$            CREATE,         ED(29):ED(1),30984:MARK(ArrTime):NEXT(0$);

0$            ASSIGN:         EXTDEF=ED(4):
                              INTDEF=ED(5):
                              DIAM=ED(3):
                              MASS=ED(2);
2$            DELAY:          ED(12),,Other:NEXT(30$);

30$           BRANCH,         1:
                              If,DIAM<=ED(6),4$,Yes:
                              Else,INSPECT,Yes;
4$            COUNT:          SmallOnions_Count,1;
5$            TALLY:          SmallOnions_Mass,mass,1;
44$           DISPOSE:        No;

INSPECT       DELAY:          ED(13),,Other:NEXT(9$);

9$            BRANCH,         1:
                              If,EXTDEF==0,10$,Yes:
                              Else,23$,Yes;
10$           BRANCH,         1:
                              With,ED(10),11$,Yes:
                              Else,12$,Yes;
11$           COUNT:          Manual Inspect_FalseAlarms,1;
73$           TALLY:          Manual
Inspect_FalseAlarms_Mass,mass,1:NEXT(REJECTS);

REJECTS       COUNT:          ExtDefOnions,1;
31$           TALLY:          ExtDefOnions_Mass,mass,1;
28$           DISPOSE:        No;

12$           COUNT:          Grade1,1:NEXT(SIZESORT);

SIZESORT      BRANCH,         1:
                              If,DIAM>ED(6).AND.DIAM<=ED(7),6$,Yes:
                              If,DIAM>ED(7).AND.DIAM<=ED(8),7$,Yes:
                              If,DIAM>ED(8).AND.DIAM<=ED(9),48$,Yes:
                              Else,50$,Yes;
6$            ASSIGN:         Size=1;
45$           BRANCH,         1:
                              With,1.0,LARGE,Yes:
                              With,0.0,PREMIUMS,Yes:
                              With,0,JUMBOS,Yes:
                              With,0,COLOSSALS,Yes;
LARGE         ROUTE:          0.0,BOX_LARGEMED;

PREMIUMS      ROUTE:          0.0,BOX_PREMMED;

JUMBOS        BRANCH,         1:
                              With,1,32$,Yes:
                              With,0,34$,Yes;
32$           ROUTE:          0.0,BOXJBO1;

34$           ROUTE:          0.0,BOXJBO2;

COLOSSALS     BRANCH,         1:
                              With,0.5,8$,Yes:
                              With,0.5,35$,Yes;
```

```
8$              ROUTE:          0.0,BOXCOL1;

35$             ROUTE:          0.0,BOXCOL2;

7$              ASSIGN:         Size=2;
46$             BRANCH,         1:
                                With,0.0,LARGE,Yes:
                                With,1.0,PREMIUMS,Yes:
                                With,0.0,JUMBOS,Yes:
                                With,0.0,COLOSSALS,Yes;
48$             ASSIGN:         Size=3;
47$             BRANCH,         1:
                                With,0.0,LARGE,Yes:
                                With,0,PREMIUMS,Yes:
                                With,1.0,JUMBOS,Yes:
                                With,0.0,COLOSSALS,Yes;
50$             ASSIGN:         Size=4;
49$             BRANCH,         1:
                                With,0.0,LARGE,Yes:
                                With,0.0,PREMIUMS,Yes:
                                With,0.0,JUMBOS,Yes:
                                With,1.0,COLOSSALS,Yes;
23$             BRANCH,         1:
                                With,ED(11),REJECTS,Yes:
                                Else,24$,Yes;
24$             COUNT:          Manual Inspect_Miss,1;
74$             TALLY:          Manual Inspect_Miss_mass,mass,1:NEXT(SIZESORT);


19$             STATION,        BOXJBO1-BOXCOL2;
33$             DELAY:          ED(M+13),,Other:NEXT(42$);

42$             TALLY:          M+4,INT(ArrTime),1;
20$             QUEUE,          M-2;
13$             GROUP,
,Temporary:ED(M+22),Sum:MARK(ARRIVatPACK):NEXT(21$);

21$             DELAY:          ED(24),,Other:MARK(ARRIVatPACK):NEXT(29$);

29$             TALLY:          M+8,Int(ARRIVatPack),1;
Time from Pack to BoxPickup
43$             COUNT:          M+5,1;
14$             TALLY:          M+12,Mass,NG;
Ave Box Mass
18$             TALLY:          M+16,IntDef,NG;
Ave No. of INTDEF/Box
22$             TALLY:          M+20,ExtDef,NG;
Ave No. of EXTDEF Onions/Box
16$             BRANCH,         1:
                                If,IntDef>0,15$,Yes:
                                Else,17$,Yes;
15$             COUNT:          M+9,1;
25$             BRANCH,         1:
                                If,EXTDEF>0,26$,Yes:
                                Else,27$,Yes;
26$             COUNT:          M+17,1;
51$             SPLIT::NEXT(59$);

59$             BRANCH,         1:
                                If,M==3.OR.M==4,60$,Yes:
                                Else,61$,Yes;
60$             ROUTE:          0.0,JBOSIZING;
```

```
61$           ROUTE:         0.0,COLSIZING;

27$           COUNT:         M+21,1:NEXT(51$);

17$           COUNT:         M+13,1:NEXT(25$);


36$           STATION,       BOX_LARGEMED-BOX_PREMMED;
40$           DELAY:         ED(M+13),,Other:NEXT(38$);

38$           COUNT:         M+5,1;
37$           TALLY:         M+2,mass,1;
41$           TALLY:         M+4,INT(ArrTime),1;
64$           BRANCH,        1:
                             If,Size==1,69$,Yes:
                             If,Size==2,70$,Yes:
                             If,Size==3,71$,Yes:
                             Else,72$,Yes;
69$           COUNT:         M+33,1;
65$           TALLY:         M+32,mass,1;
39$           DISPOSE:       No;

70$           COUNT:         M+35,1;
66$           TALLY:         M+34,mass,1:NEXT(39$);

71$           COUNT:         M+37,1;
67$           TALLY:         M+36,mass,1:NEXT(39$);

72$           COUNT:         M+39,1;
68$           TALLY:         M+38,mass,1:NEXT(39$);


62$           STATION,       JBOSIZING-COLSIZING;
55$           BRANCH,        1:
                             If,Size==4,52$,Yes:
                             If,Size==3,53$,Yes:
                             Else,54$,Yes;
52$           COUNT:         M+21,1;
56$           TALLY:         M+20,mass,1;
63$           DISPOSE:       No;

53$           COUNT:         M+23,1;
57$           TALLY:         M+22,mass,1:NEXT(63$);

54$           COUNT:         M+25,1;
58$           TALLY:         M+24,mass,1:NEXT(63$);
```

Table A.2 SIMAN Code for Simulating Vidalia Onion Packinghouse Operations Incorporating a Four-Unit X-ray Inspection System before Size Sorting

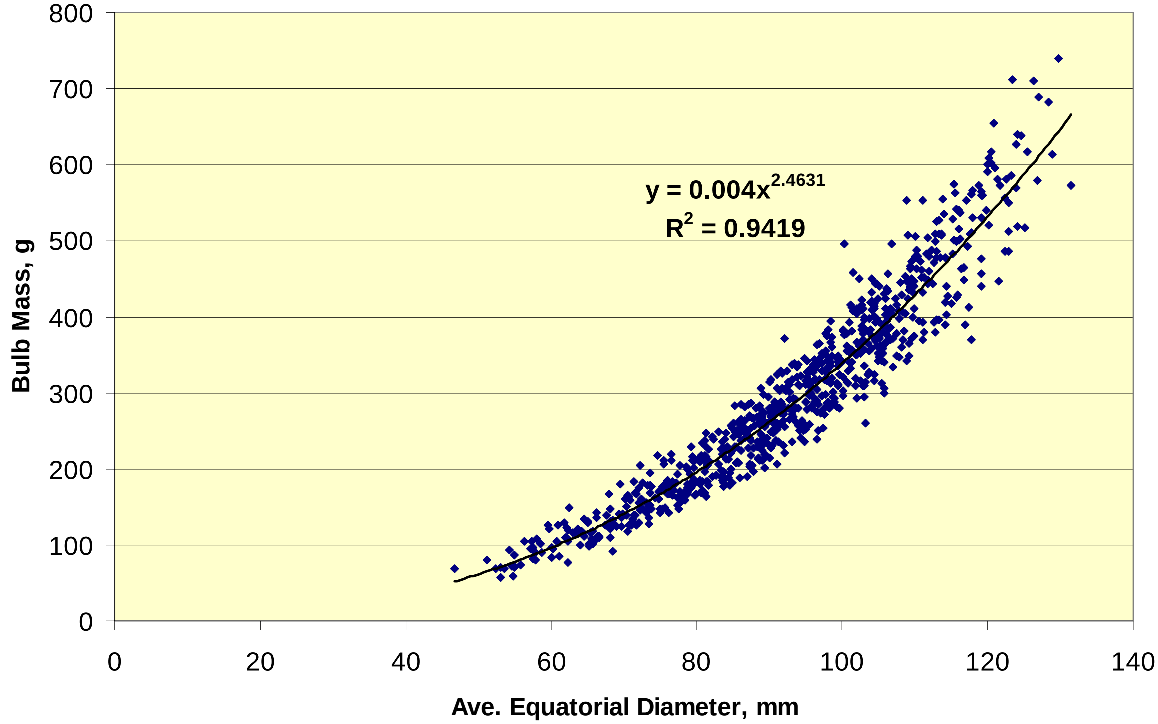
```
1$             BEGIN,         Yes;

3$             CREATE,        ED(29):ED(1),31500:MARK(ArrTime):NEXT(0$);

0$             ASSIGN:        EXTDEF=ED(4):
                              INTDEF=ED(5):
                              DIAM=ED(3):
                              MASS=ED(2);
2$             DELAY:         ED(12),,Other:NEXT(30$);

30$            BRANCH,        1:
                              If,DIAM<=ED(6),4$,Yes:
                              Else,INSPECT,Yes;
4$             COUNT:         SmallOnions_Count,1;
5$             TALLY:         SmallOnions_Mass,mass,1;
41$            DISPOSE:       No;

INSPECT        DELAY:         ED(13),,Other:NEXT(9$);

9$             BRANCH,        1:
                              If,EXTDEF==0,10$,Yes:
                              Else,23$,Yes;
10$            BRANCH,        1:
                              With,ED(10),11$,Yes:
                              Else,12$,Yes;
11$            COUNT:         Manual Inspect_FalseAlarms,1;
44$            TALLY:         Manual
Inspect_FalseAlarms_Mass,mass,1:NEXT(REJECTS);

REJECTS        COUNT:         ExtDefOnions,1;
31$            TALLY:         ExtDefOnions_Mass,mass,1;
28$            DISPOSE:       No;

12$            COUNT:         Grade1,1;
77$            TALLY:         Grade1_mass,mass,1;
68$            BRANCH,        1:
                              With,0.25,69$,Yes:
                              With,0.25,70$,Yes:
                              With,0.25,71$,Yes:
                              With,0.25,72$,Yes;
69$            ROUTE:         0.0,XRAYMACH1;

70$            ROUTE:         0.0,XRAYMACH2;

71$            ROUTE:         0.0,XRAYMACH3;

72$            ROUTE:         0.0,XRAYMACH4;

23$            BRANCH,        1:
                              With,ED(11),REJECTS,Yes:
                              Else,24$,Yes;
24$            COUNT:         Manual Inspect_Miss,1;
45$            TALLY:         Manual Inspect_Miss_mass,mass,1:NEXT(68$);
```

```
19$            STATION,       BOXJBO1-BOXCOL2;
32$            DELAY:         ED(M+8),,Other:NEXT(39$);

39$            TALLY:         M+21,INT(ArrTime),1;
20$            QUEUE,         M-3;
13$            GROUP,
,Permanent:ED(M+17),Sum:MARK(ARRIVatPACK):NEXT(21$);

21$            DELAY:         ED(24),,Other:MARK(ARRIVatPACK):NEXT(29$);

29$            TALLY:         M+25,Int(ARRIVatPack),1;
Time from Pack to BoxPickup
40$            COUNT:         M+20,1;
14$            TALLY:         M+29,Mass,NG;
Ave Box Mass
18$            TALLY:         M+33,IntDef,NG;
Ave No. of INTDEF/Box
22$            TALLY:         M+37,ExtDef,NG;
Ave No. of EXTDEF Onions/Box
16$            BRANCH,        1:
                              If,IntDef>0,15$,Yes:
                              Else,17$,Yes;
15$            COUNT:         M+24,1;
25$            BRANCH,        1:
                              If,EXTDEF>0,26$,Yes:
                              Else,27$,Yes;
26$            COUNT:         M+32,1;
67$            DISPOSE:       No;

27$            COUNT:         M+36,1:NEXT(67$);

17$            COUNT:         M+28,1:NEXT(25$);


33$            STATION,       BOX_LARGEMED-BOX_PREMMED;
37$            DELAY:         ED(M+8),,Other:NEXT(35$);

35$            COUNT:         M+20,1;
34$            TALLY:         M+19,mass,1;
38$            TALLY:         M+21,INT(ArrTime),1;
36$            DISPOSE:       No;


46$            STATION,       XRAYMACH1-XRAYMACH4;
47$            QUEUE,         M;
48$            SEIZE,         1,Other:
                              XRAY(M),1:NEXT(49$);

49$            DELAY:         ED(30),,Other:NEXT(50$);

50$            RELEASE:       XRAY(M),1;
51$            BRANCH,        1:
                              If,INTDEF==1,52$,Yes:
                              Else,53$,Yes;
52$            BRANCH,        1:
                              With,ED(31),54$,Yes:
                              Else,55$,Yes;
54$            COUNT:         M+5,1;
58$            TALLY:         M+4,MASS,1;
63$            COUNT:         M+21,1;
62$            TALLY:         M+20,mass,1;
64$            DISPOSE:       No;
```

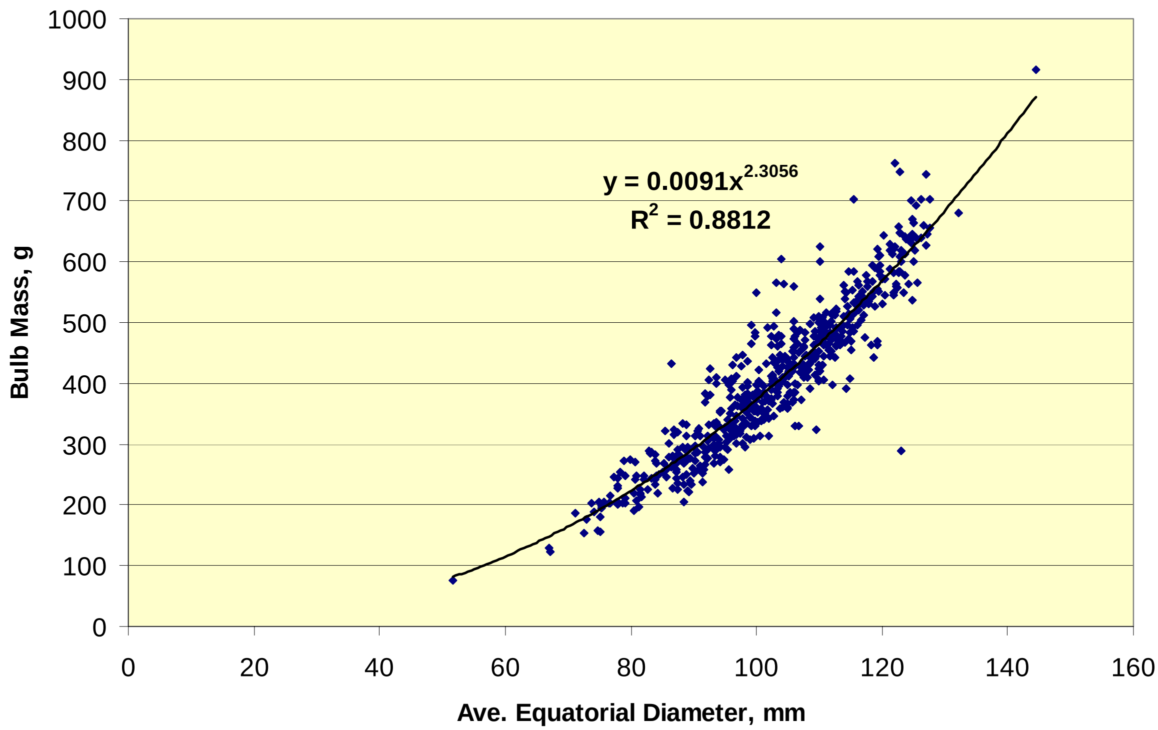
```
55$           COUNT:         M+9,1;
59$           TALLY:         M+8,mass,1;
73$           ROUTE:         0.0,SIZESORT;

53$           BRANCH,        1:
                             With,ED(32),56$,Yes:
                             Else,57$,Yes;
56$           COUNT:         M+13,1;
60$           TALLY:         M+12,mass,1:NEXT(63$);

57$           COUNT:         M+17,1;
61$           TALLY:         M+16,mass,1:NEXT(73$);


74$           STATION,       SIZESORT-SIZESORT;
6$            BRANCH,        1:
                             If,DIAM>ED(6).AND.DIAM<=ED(7),7$,Yes:
                             If,DIAM>ED(7).AND.DIAM<=ED(8),8$,Yes:
                             If,DIAM>ED(8).AND.DIAM<=ED(9),42$,Yes:
                             Else,43$,Yes;
7$            ASSIGN:        Size=1;
LARGE         ROUTE:         0.0,BOX_LARGEMED;

8$            ASSIGN:        Size=2;
PREMIUMS      ROUTE:         0.0,BOX_PREMMED;

42$           ASSIGN:        Size=3;
75$           BRANCH,        1:
                             With,1.0,JUMBOS,Yes:
                             Else,76$,Yes;
JUMBOS        ROUTE:         0.0,BOXJBO1;

76$           ROUTE:         0.0,BOXJBO2;

43$           ASSIGN:        Size=4;
65$           BRANCH,        1:
                             With,0.50,COLOSSAL,Yes:
                             With,0.50,66$,Yes;
COLOSSAL      ROUTE:         0.0,BOXCOL1;

66$           ROUTE:         0.0,BOXCOL2;
```

APPENDIX B

Details of the Onion Attributes from the Four Cultivar-Samples Obtained from the Vidalia Onion and Vegetable Research Center, Lyons, GA, 2005 and 2006 Harvest Seasons

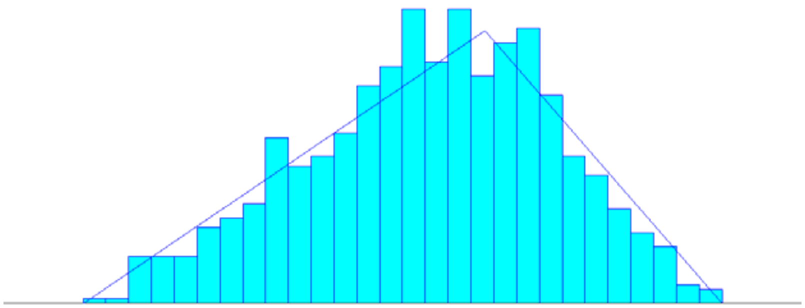


(a)



(b)

Figure B.1 Relationship between Bulb Mass and Average Equatorial Diameter of the All Sampled Vidalia Onions during the (a) 2005 and (b) 2006 harvests. Sampled onions were from four cultivars 'Sugar Belle', 'Pegasus', 'Savannah Sweet' and 'Sweet Vidalia'.

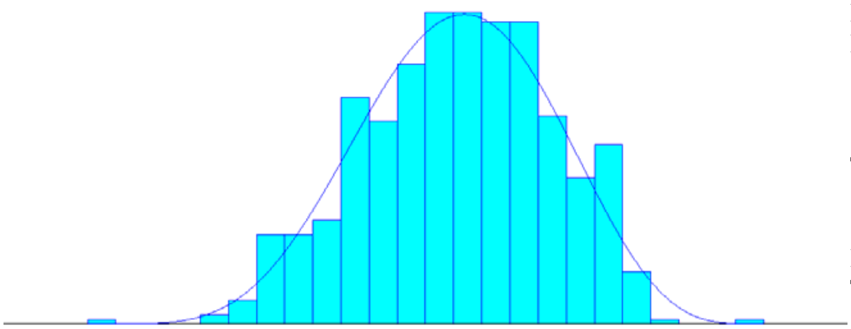


Distribution: Triangular
Expression: TRIA(46, 100, 132)
Square Error: 0.001206

Chi Square Test
Test Statistic = 21.8
Corresponding p-value = 0.534

Kolmogorov-Smirnov Test
Test Statistic = 0.0342
Corresponding p-value > 0.15

(a)



Distribution: Beta
Expression: 51 + 94 * BETA(6.3, 5.22)
Square Error: 0.001628

Chi Square Test
Test Statistic = 24.7
Corresponding p-value = 0.018

Kolmogorov-Smirnov Test
Test Statistic = 0.0334
Corresponding p-value >0.15

(b)

Figure B.2 Fitted Probability Distributions for Average Equatorial Diameter of All Sampled Vidalia Onions during (a) 2005 and (b) 2006 Harvests. Sampled onions, from four cultivars 'Sugar Belle', 'Pegasus', 'Savannah Sweet' and 'Sweet Vidalia', were obtained from the Vidalia Onion and Vegetable Research Center in Lyons, GA.

(a) External Defects

(b) Internal Defects

Figure B.3 Some of the external and internal defects of Vidalia onions that were obtained from the Vidalia Onion and Vegetable Research Center during the 2005-2006 harvest seasons

Table B.1 Relationship Between Bulb Mass (y) and Average Equatorial Diameter (x) of Sampled Vidalia Onions, per Cultivar, 2005-2006 Harvests.

Cultivar	2005		2006	
	Relationship	R^2	2005	2006
Sugar Belle	**$y = 0.0054x^{2.3786}$**	$R^2 = 0.9549$	**$y = 0.0119x^{2.2419}$**	$R^2 = 0.8755$
Savannah Sweet	**$y = 0.0027x^{2.5516}$**	$R^2 = 0.9566$	**$y = 0.0075x^{2.3615}$**	$R^2 = 0.8284$
Sweet Vidalia	**$y = 0.0061x^{2.3818}$**	$R^2 = 0.9431$	**$y = 0.0035x^{2.5091}$**	$R^2 = 0.8534$
Pegasus	**$y = 0.0026x^{2.6788}$**	$R^2 = 0.9549$	**$y = 0.0052x^{2.4245}$**	$R^2 = 0.9528$

Table B.2 Fitted Probability Distributions and the Corresponding p-values for Average Equatorial Diameter of Sampled Vidalia Onions, per Cultivar, 2005-2006 Harvests.

Cultivar	2005		2006	
	Distribution	p-value*	Distribution	p-value*
Sugar Belle	54 + 78 * BETA(2.8, 2.65)	> 0.15	73 + 52 * BETA(1.87, 1.41)	> 0.15
Savannah Sweet	52 + 76 * BETA(1.93, 1.98)	> 0.15	NORM(95, 10.7)	> 0.15
Sweet Vidalia	NORM(87.6, 14.9)	> 0.15	TRIA(77, 110, 128)	> 0.15
Pegasus	TRIA(53, 108, 130)	< 0.01	51 + WEIB(61.1, 4.29)	> 0.15

* from Kolmogorov-Smirnov Test

Table B.3 External Quality Classification of Onions Sampled during the 2005 and 2006 Harvest Seasons, Based on the US Grade Standards for Bermuda Grano-Granex Type Onions (USDA Agricultural Marketing Service, 1995)

Cultivar	Maturity Classification	2005		2006	
		% Good (Grade1)	% Rejects	% Good	% Rejects
Sugar Belle	Early	87	13	77	23
Savannah Sweet	Mid-season	87	13	89	11
Sweet Vidalia	Mid-season	86	14	79	21
Pegasus	Late	52	48	67	33
Overall		**77.57**	**22.43**	**77.80**	**22.20**

Table B.4 Internal Quality Classification of Onions Sampled during the 2005 and 2006 Harvest Seasons, Based from Visual examination of Cut Onions.

Cultivar	Maturity Classification	2005		2006	
		% Good (Grade1)	% Rejects	% Good	% Rejects
Sugar Belle	Early	83	17	76	24
Savannah Sweet	Mid-season	77	23	85	15
Sweet Vidalia	Mid-season	82	18	87	13
Pegasus	Late	26	74	51	49
Overall		**69.64**	**30.36**	**74.80**	**25.20**

APPENDIX C

Time Data and Formulas Relating to X-ray Inspection of Sampled Vidalia Onions

Using a EG&G Astrophysics Line-Scan Unit

Table C.1 Raw data on the amount of time (in seconds) it takes for the onions to move through the EG &G Astrophysics X-ray line scan unit (measured belt length = 1.04m (41 inches)), Driftmier Engineering Center, May 2006.

5.44	6.1	7.25	6.81	6.22
5.66	6.13	6.87	6.22	6.41
5.82	6	6.34	6.81	6.47
5.66	6.66	5.72	6.37	5.93
5.75	5.85	6	6.25	5.97
7.55	6.57	5.66	6.81	6.04
5.94	6.06	5.78	6.37	6.22
7.25	5.86	5.88	6.47	6.32
8.1	5.94	6.31	6.09	
6.16	6.19	6.05	6.29	

Table C.2 Definition of Defect Detection Performance Measures

SIGNAL (Defect)	RESPONSE	
	Defect is Present	Defect is Absent
Present	HIT	MISS
Absent	FALSE ALARM	CORRECT REJECTION

$$\% \text{ Hit} = \frac{\text{number of hits}}{\text{number of actual defective onions}}$$

$$\% \text{ False Alarm} = \frac{\text{number of false alarms}}{\text{number of actual non-defective onions}}$$

$$\% \text{ Miss} = \frac{\text{number of misses}}{\text{number of actual defective onions}} = 100 - \% \text{ Hit}$$

$$\% \text{ Correct} = \frac{\text{number of correct rejections}}{\text{number of actual non-defective onions}} = 100 - \% \text{ False Alarm}$$

Figure C.1 Formulas Used in Computing Defect Detection Performance Measures

APPENDIX D

Output of the Sizing and Inspection Performance and Process Time Measurement Conducted During the May 2006 Three-Packinghouse Study

Table D.1 Comparison of bulb size classification used by the three Vidalia onion packinghouses and those reflected in the Rules and Regulations Applicable to Vidalia onions (Georgia Department of Agriculture, 2005).

Size Classification	DIAMETER, millimeters		
	GA Dept of Agriculture	Packinghouse A & B	Packinghouse C
SMALL	25.4 - 57.15	< 53.975	< 47.625
SMALL MEDIUM			47.625 – 57.15
MEDIUM	50.8 – 82.55		
LARGE MEDIUM	63.50- 88.90	53.975 – 73.025	57.15 – 79.375
PREMIUM MEDIUM		73.025 – 82.55	
JUMBO	76.2 or larger	82.55 – 95.25	79.375 or larger
COLOSSAL	95.25 or larger	95.25 or larger	

Table D.2 Actual size distribution of 50 onions obtained from each of the size categories of Packinghouse A during the 2006 harvest season. Values are in percentages.

Classification of sampled onions, based on measured equatorial diameter	SIZE CATEGORIES WHERE THE SAMPLED ONIONS WERE OBTAINED						
	First Visit (April 27, 2006)			**Second Visit (May 13, 2006)**			
	PREMIUM MEDIUM	JUMBO	COLOSSAL	LARGE MEDIUM	PREMIUM MEDIUM	JUMBO	COLOSSAL
LARGE MEDIUM	18.00	0.00	0.00	100.00	8.00	0.00	0.00
PREMIUM MEDIUM	42.00	2.00	0.00	0.00	44.00	8.00	0.00
JUMBO	38.00	58.00	2.00	0.00	46.00	66.00	14.00
COLOSSAL	2.00	40.00	98.00	0.00	2.00	26.00	86.00

Table D.3 Average Time* Spent by an Onion as It Moves through the Grading and Packing Operations of Packinghouse A

Section	TIME, seconds			
	Large Medium	Premium Medium	Jumbo	Colossal
Inclined Conveyor to Entry to Inspection Line1	57.91	57.91	57.91	57.91
Inspection Line 1	16.20	16.20	16.20	16.20
Entry to Size Sorter until it passes through the chain links	1.86	5.66		
Conveyor to Bulk Bin	18.95	16.60		
End of Inspection Line 1 to Entry of Inspection Line 2			23.88	34.38
Inspection Line 2			16.15	16.15
End of Inspection Line 2 to End of Boxing Conveyor				
Box Station 1			27.67	
Box Station 3				23.55
Box Station 4				20.36
Time to Fill 1-18.1kg box				
Box Station 1 (open-top box)			13.15	
Box Station 3				55.74
Box Station 4				46.28
Boxing Station Exit to Box Lid Closing to the point when boxes are removed from the line for pallet stacking			37.91	37.91
Total Time	**94.92**	**96.37**	**192.88**	**241.84**** **229.19*****

***** Arithmetic mean of 10 measurements
** Total time measured at Box Station 3
*** Total time measured at Box Station 4

Table D.4 Average Time* Spent by an Onion as It Moves through the Grading and Packing Operations of Packinghouse B

Section	TIME, seconds			
	Large Medium	Premium Medium	Jumbo	Colossal
Start of Conveyor 1 To End of 1st Size Sorter	38.64	38.64	38.64	38.64
End of 1st Size Sorter To End of 1st Inspection	21.02	21.02	21.02	21.02
End of 1st inspection to end of 2nd size sorter	4.66	8.29	11.77	16.18
After sizing to after labeling	13.84	17.43	15.15	16.87
After labeling to bin	13.29	13.20	22.41	20.57
Total Time	**91.45**	**98.58**	**108.99**	**113.28**

Table D.5 Average Time* Spent by an Onion as It Moves through the Grading and Packing Operations of Packinghouse C

Section	TIME, seconds			
	Small Medium	Large Medium	Packed Jumbo	Jumbo for Storage
Inclined Conveyor to First Size Sorter	23.55	23.55	23.55	23.55
First Size Sorter to End of Scale Brusher	35.07	35.07	35.07	35.07
First Inspection Line	33.33	33.33	33.33	33.33
Small Mediums to Bin (for Storage)	35.75			
Sorted Large Mediums to Bin (for Storage)		51.51		
End of Inspection Line 1 to End of Second Size Sorter			11.32	11.32
Second Inspection Line to Labelling			27.43	
Third Inspection			19.52	
Conveyance to Box Filling			8.81	
Box Filling			4.20	
End of Box Filling to Lifting for Palleting			20.48	
Sorted Jumbos to Bin (for Storage)				32.54
Total Time	**127.7**	**143.46**	**183.71**	**135.81**

***** Arithmetic mean of 10 measurements

Figure D.1 Sample of the Grade 1 onions from Packinghouse C that were evaluated as rejects during the May 11, 2006 visit.

APPENDIX E

Assumptions Used in Simulating Product Flow and Incorporation of X-ray-Imaging Based Inspection in Vidalia Onion Packinghouses

Table E.1 Interarrival Time and Distribution of the Number of Onions Entering the Grading-Packing Lines

PACKINGHOUSE	NUMBER OF ONIONS PER UNIT TIME	INTERARRIVAL TIME, seconds
A	DISC (0.039,12, 0.1299, 15, 0.2468, 18, 0.4286, 20, 0.6234, 21, 0.8182, 25 0.9221, 27, 0.9610, 32, 0.9870, 34,1.0,36)	1.20
B	DISC(0.016, 6, 0.033, 8, 0.082, 10, 0.131, 12, 0.279, 14, 0.41, 16, 0.639, 18, 0.803, 20, 0.951, 22, 0.967, 24, 1.0, 26)	1.22
C	DISC (0.0541, 7, 0.1351, 8, 0.2973, 9, 0.4324, 10, 0.4865, 11, 0.7567, 12, 0.8649, 13, 0.9730, 15, 1.0, 17) + DISC (0.0862, 0, 0.1767, 1, 0.3362, 2, 0.50, 3, 0.6552, 4, 0.8103, 5, 0.8879, 6, 0.9483, 7, 0.9828, 8, 0.9914, 9, 0.9957, 10, 1.0, 12)	1.59 0.51

Table E.2 – Onion Attribute Assumptions

Attribute	BAD CROP (Using 2005 Samples)	GOOD CROP (Using 2006 Samples)
Mass of Onion, g	0.004*(DIAM**2.4631)	0.0091*(DIAM**2.3056)
Equatorial Bulb Diameter, mm	TRIA(46,100,133)	51+ 94 * BETA(6.3, 5.22):
% External Defects	DISC(0.7757,0,1.0,1)	DISC(0.778,1.0,1)
% Internal Defects	DISC(0.6964,0,1.0,1)	DISC(0.748,0,1.0,1)

Table E.3 Process Times Assumptions Used in Simulating the Grading-Packing Operations of Vidalia Onion Packinghouses

Operation	PACKINGHOUSE		
	A	**B**	**C**
Receiving	TRIA(49,56,79)	TRIA(31, 38, 52)	TRIA(43, 58, 76)
Inspection	TRIA(13,16,19)	TRIA(20, 21, 22)	TRIA(32, 33, 34)
Size Sorting to Bins			
Small Mediums			TRIA(33, 36, 41)
Large Mediums	TRIA(16, 21, 28)	TRIA(26, 32, 36)	TRIA(48, 51, 58)
Premium Mediums	TRIA(19, 22, 29)	TRIA(35, 38, 46)	
Jumbo		TRIA(35, 42, 51)	TRIA(39, 43, 48)
Colossal		TRIA(49, 53, 58)	
Size Sorting to Box/Pack Stations			
Jumbo	TRIA(58, 68, 77)		
Colossal1	TRIA(61, 69, 95)		
Colossal2	TRIA(66, 72, 97)		
From Station Exit to Removal for Pallet Stacking	TRIA(34, 38, 41)		

Table E.4 Details in Estimating the Associated Cost of X-ray Inspection for a 48 Day-Operation per Year with Four Machines

Cost Component	**Assumptions**	**4 units**
Annual Depreciation*	Straight line depreciation, 4 years useful life	$ 109,417.00
Taxes & Insurance	1.4% of equipment cost	1,531.84
Interest on Investment	8%	8,753.36
Direct Labor	1 operator per unit, 12 hours/day	19,284.48
Electricity	4.8kW, $0.12/kWh, 12 hours/day	1,327.10
Service & Preventive Maintenance	Per schedule from manufacturer	27,552.00
TOTAL		167,865.78
Contingencies	20% of total cost	33,573.16
GRAND TOTAL		$ 201,438.94

***** Refer to Table E.5 for the breakdown

Table E.5 Details in Estimating the X-ray Inspection Equipment Acquisition Cost as Basis for Computing Annual Depreciation

Equipment Cost Component	Assumptions	4 units
Equipment, including reject mechanism	$89,570 per unit	$ 358,280.00
Installation Cost		
O&M Training	$ 1500 per class	1,500.00
Meals	3 persons, 3 days per unit, $55/day	1,980.00
Travel Hours	8 hours one-way per person, $75/hr	3,600.00
Regular Hours	8-5pm, 3 days per unit, $120/hr	36,480.00
Freight & Shipping	10% of equipment cost	35,828.00
TOTAL		437,668.00
Annual depreciation	Straight line, 4 year-life	$ 109,417.00