Modeling Product Flow through a Generic Post-Harvest Distribution System

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A spreadsheet-based stochastic model was developed to track fruit numbers and fruit value for 1,000 individual items grown in a farmer's field, sorted at a packinghouse with and without advanced inspection technology, distributed with and without repack, and sold at a retail store. The quantities generated at each step are value per unit volume in the production field and the respective price multipliers and passing fractions at the packinghouse, distribution center, and retail store. Values of these coefficients were set to reflect experience with the onion industry. It was assumed that about 30% (with repackaging) to 40% (without repacking) of the fruit leaving the farmer's field would reach the consumer. The initial price per unit volume and pricing multipliers were configured to give representative prices at the production field and representative price per unit fruit at steps through the system to the consumer. The pass-through percentage was decreased an extra 10% to 15% with technology and up to 20% with repack, with corresponding increases in subsequent steps to maintain the 25% to 35% total pass-through. Repacking and technology addition in the packinghouse tended to result in increased value at the retail level. Placing technology in the packinghouse did not result in increased value for the packinghouse. Vertical integration that included the packinghouse would be required to make it profitable to add sorting technology that increases quality by removing defective items. Both technology addition and repackaging reduce the total number of fruits reaching the consumer. The model suggests that the notion of early removal of fruits with latent damage to avoid increased distribution costs does not really benefit the consumer for the conditions modeled. Additional considerations such as food security are required for one to expect additional equipment adoption under current scenarios.

Packinghouses and other business links in fresh-produce supply chains would benefit from simulation models evaluating potential investments in equipment and the adoption of procedures that improve quality levels by discarding defective items. It is logical to expect that the early removal of defective items would improve performance of the total supply chain by avoiding costs for cooling, packaging, transporting, distributing, and retailing items that entered the chain but are discarded before consumption. However, some evidence of consistently higher prices for improved quality is needed before a business could be expected to invest in changes that reduced the amount of product shipped as a result of removing low-quality items.

A search of existing literature did not reveal any simulation models with adequate details of the post-harvest handling process to evaluate the feasibility of adding procedures or equipment for improved sorting of defective items. A comprehensive review of processes relevant to post-harvest handling systems was presented by Shewfelt and Prussia (1993). They pointed out the potential benefits of the systems approach to analyze post-harvest systems, and highlighted several characteristics of generic post-harvest systems.

An issue related to post-harvest handling that has been largely ignored within the distribution channel is the damage to fruits or vegetables that is not apparent through immediate visual inspection (Hung 1993). Damage is often latent, meaning that it will appear at some point in the system, such as in a retail outlet or consumer's home. Fruits with latent damage incur costs associated with transportation and handling in the system until the damage is detected and the produce discarded. The presence or absence of latent damage is highly stochastic due to differences in the product, position of items in a flow or container, temperature histories, and other handling conditions.

Process and pricing knowledge at each marketing stage from the packinghouse to the retail outlet are frequently hard to determine, due to the proprietary nature of the relevant information. The same may be said about any feed-back and feed-forward information to handling nodes in addition to connections shown in Figure 1. Some of the value added at each stage results from removing obvious

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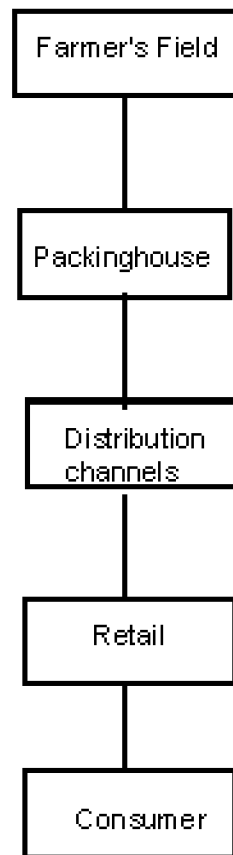
Figure 1. Simplified View of the Post-harvest Handling System (Based on How 1993).

defects. Cook (1999) suggests that producers and packers must use technology in addition to having the best production and marketing information to be competitive.

Jordan, Shewfelt, Hurst, and Prussia (1985) found the primary determinants of snap bean price were defects, maturity, and storability (based on color changes over six days). Their hedonic pricing analyses led to the conclusion that a one-half-percent reduction of damage in a unit of beans at the packinghouse would enable the wholesaler to increase the wholesale price by almost one-half-percent. In a similar study for tomatoes, Jordan, Shewfelt, Prussia, and Hurst (1985) found that size, damage, firmness, and color were the most influential in determining the price. It appears, according to results from earlier studies, that the introduction of suitable technology to detect defects, and other

quality indicators such as maturity, firmness, or storability, would enable higher prices and potential economic feasibility, assuming the technology was reliable.

In summary, there is limited literature for post-harvest handling systems, for the economic effects of latent damage on returns, or for consumer purchase decisions. Lynd (2003) makes a case for agencies such as USDA to provide leadership in facilitating enhanced cooperation between practitioners and academics in order to improve the transparency of handling systems. Without an adequate level of transparency, participants cannot assess economic benefits stemming from the flow of quality product through the distribution system.

An initial effort to develop a model of a generic post-harvest supply chain was made by Tollner (2003) using the key marketing business links

shown in Figure 1 (based on How 1993). The first model was piecewise and did not include the initial value of the product. The objectives of this paper are to develop a computer-simulation model that enables evaluation of changes made to remove an increasing share of the defective items at the time of packing or at a repacking facility, and to determine performance of simulated fresh-produce supply chains with and without technologies for removing latent defects at the packinghouse and with and without repacking facilities.

Simulation-Model Development

A model was developed that generates 1,000 individual items with stochastically determined values based on a quality attribute viewed as the most important by handlers and buyers. Campbell, Prussia, and Shewfelt (1986), in a study of tomato handling that maintained the identity of harvested fruit from field to consumer, observed that 72 percent of tomatoes passing through a packinghouse manifested damage at the consumer level. Without repackaging, about 40 percent of the harvested tomatoes were available to consumers after surviving the packinghouse, distribution center, and retail-store handling. With repackaging, the pass-through dropped to about 30 percent. The values for pass-through rates for tomatoes were used for the current model due to the absence of adequate, publicly available data for many types of produce, e.g., onions and peaches. Future data on pass-through fraction and price-multiplier values for specific situations will enable the modification of the model.

To illustrate the model application we use the size of an onion as the primary attribute determining the price. According to the standards for onion grades, the onion diameter is the most important attribute. A unit-price coefficient based on price per unit of cross-sectional area assigned to the onion (or other product) is taken as 0.001 times the cross-sectional area, resulting in representative prices for onions at the farmer's field. Actually, onions or a similar commodity may be more realistically valued initially (e.g., in a price received by farmer) by the cube (this would reflect volume or weight) rather than by the square of the characteristic length or by a linear relation (e.g., cut flowers may follow a linear trend).

The product price must track value and customers must perceive the value claimed (Nagle and Holden 2002). Price is as much a function of the selected distribution channel and advertising as it is a function of cost. Prices at the packinghouse, distribution center, and retail outlet are based on the application of pricing formulas taking into account a price applied at the prior link in the supply chain. The retail store, in turn, selects a pricing method. It often adds a markup to the distribution center price of produce, which is influenced by costs incurred at the location; for simplicity of presentation, this approach is used in the simulation. Pricing functions at the farm level in the model were scaled and assumed to be representative returns to the farmer. Prices at the subsequent marketing stages were constructed to yield representative prices at the retail level. For example, in the case of onions it was found by trial and error that initial valuation assignment based on a cross-sectional area times 0.001, coupled with the pass-through of only 25 to 35 percent, would result in representative prices per onion typically paid by consumers.

The model is deliberately simple in order to make it accessible for a wide-range of users including retail-chain personnel, students, and personnel employed at various stages of the distribution system. The model was organized into pages using a standard spreadsheet software program (MS Excel). Separate pages are used for the input entry, results output, and model computations.

Grower

The model was built on the computation page by first assigning 1,000 random numbers between zero and one from a uniform distribution in the first column of the spreadsheet. The second column was the Normal Inverse using an assigned onion mean diameter (50, 60, or 70 mm), a standard deviation of the size (5, 10, or 20 mm), and the random number in the previous column. This approach resulted in 1,000 simulated onions with a normally distributed range of sizes for each nominal size.

A value was calculated for each onion by squaring the diameter and multiplying by one of three cost coefficients (0.001, 0.002, or 0.003). The resulting value was proportional to the area of each onion. The sum of the value column resulted in the value per original 1,000 onions grown. By design the model left onions in the field if they failed to meet the threshold of 40 mm in diameter or if they were randomly deleted to meet the criterion

that only 90 percent of the onions from the field would be of sufficient quality for the product to be harvested. In the case of onions, the diameter is an important quality attribute included in the standards for grades. The criteria selected in this study can be readily modified to reflect a particular crop or associated conditions. For example, poor genetics may lead to a higher standard deviation in the original size assignment, while poor harvest conditions or equipment operational characteristics may lead to a larger crop share being left in the field.

Packinghouse Sorting

The effective fraction of onions passing through the packinghouse sorting was assigned at random. Increasing the rigor of inspection (e.g., detecting an internal defects via x-ray) would be expected to lower the effective fraction of onions passing through the packinghouse. Pricing on the onions judged to pass the inspection was set so that pricing per onion was consistent with value per unit customarily observed on onions shipped from the packinghouse, and cumulative value was then computed.

The process at the packinghouse was repeated for the distribution-center and the retail-store stages (Figure 1). Details of the markup and pass-through coefficients depended on the nature of the specific test condition being modeled. One could add a stage depicting a household representing the ultimate con-

sumer if adequate data become available on how onions survive storage until consumption.

Simulation-Model Application

The post-harvest model was developed to evaluate the benefits and costs of adding inspection technology in the packinghouse with and without a re-packing operation. The particular crop in this study was onions. The use of appropriate mean size and standard deviation enables modeling any commodity that is individually inspected. The pass-through and price multipliers for any handling regime applied at a packinghouse could be established and modeled. A repack-x-ray technology addition was the test treatment for this study. This technology allows the selection of internally bruised onions from a packing line for improving the quality of the final pack. Specifically, this technology reduces the risk of latent damage occurring at the later stages in the marketing channel. Currently, internally bruised products cannot be effectively identified and their presence increases the volume of ultimately wasted produce.

Conditions of the repack-technology treatments are given in Table 1. Treatment A is a control. Markup and pass-through coefficients were determined from earlier experiments with the onion industry conducted by authors. Treatment B, the repackaging at the distributor level, is similar to treatment A except that an aggressive removal of

Table 1. Treatment Conditions and Associated Price Markup and Pass-Through Coefficients for a Test Involving Onions.

Link in marketing chain	Criteria	Treatment A No repack No x-ray (Control)	Treatment B Repack No x-ray	Treatment C No repack X-ray	Treatment D Repack X-ray
			Coefficient		
Packinghouse	Markup	2.0	2.0	2.1	2.1
	Pass-through	0.6	0.6	0.5	0.5
Distributor	Markup	1.5	2.5	1.5	2.5
	Pass-through	0.9	0.5	0.9	0.6
Retail	Markup	2.0	2.0	2.0	2.0
	Pass-through	0.8	0.95	0.9	0.97

Note: Pass-through fractions and price-markup multipliers were selected to reflect limited data for pass-through data observed in the tomato industry and pricing observed in the onion industry, respectively.

product occurs at the point of repackaging and less removal occurs at the retail level. Treatment C, the noninvasive testing in the packinghouse, reflects an increased removal, consistent with our experience, and a slightly higher price multiplier to recover the equipment cost. Treatment C reduces the volume of onions removed at the distribution and retail levels, consistent with earlier removal of onions with latent damage. Treatment D adds repackaging to treatment C.

The markup coefficients for the packinghouse link were increased by 0.1 for treatments C and D with the adoption of the x-ray technology to offset the effect of decreasing the pass-through, which was lowered from 0.6 to 0.5. The pass-through for the distribution center was set high (0.9) for treatments A and C because defects would not be visually detected and removed when there was no repacking. Markup at retail was equal for all treatments based on the assumption that customers would not be willing to pay higher prices for items that did not have visible differences. The pass-through coefficients reflect the assumption that repackaging at the distribution center would result in slightly less removal of product at the retail level. The applied markup and pass-through coefficients can be altered as data about specific conditions become available.

The modeling process proceeded, observing that 25 to 30 percent of harvested onions would be sold by the retail outlet (Campbell, Prussia, and Shewfelt 1986), with fractions of the produce being discarded at each stage in the marketing channel. Produce value at each stage was controlled with price markups. The sorting factors were chosen to reflect the notion that technology can identify damage that will ultimately appear by the time the onion reaches the retail shelf. The notion that 2/3 to 3/4 of all onions will be discarded by the time they reach the consumer also moderated the selections, in accordance with Campbell et al. (1986).

Although price is a dynamic factor, the initial area-cost coefficient of 0.001 multiplied by the onion cross-sectional area gave representative prices at the farm level. Area-cost coefficients of 0.002 and 0.003 were also modeled. The other cost coefficients resulted in pricing similar to that in supermarkets. Increasing the packinghouse price markup by 0.1 gave an approximation of the pricing action likely to be taken in an attempt to recover the cost of the inspection technology. It should be noted that all the above-selected coefficients and the cost-fraction

exponent have been arbitrarily selected. The overall markup and pass-through coefficients with each inspection technology reflect cumulative effects on product value from packinghouse through retail. These coefficients are deterministic and assume no stochastic effects due to size variation.

Five instances of each combination of variables were simulated, for a total of 540 runs (4 treatments x 3 sizes x 3 standard deviations x 3 fractions x 5 replications). Coefficients pertaining to units lost, passed-through onion volume, value of passed-through product, and unit costs were analyzed using the GLM ANOVA of Hintze (2002). The spreadsheet model contains pages for input, data summary, several plots, and other conditions to facilitate collecting and gathering the results. Several macros were recorded to reduce the hand operations required to analyze the data. The simulations were run and the data pooled as appropriate.

Results and Discussion

Table 2 shows onions lost per 1,000 units in the field and at various stages in the marketing chain for data pooled from 5 runs, 3 costs, 3 sizes, and 3 standard deviations. The cost interaction (i.e., cost, size, and treatment interaction) became significant with movement through the system. The statistical significance of the interaction was likely due to the structure of the price and pass-through multipliers (see Table 1).

Figure 2 shows the plot of available onions by market position in the system for the four treatments. The number of onions available to consumers after each treatment closely approximated that predicted by the overall values for each treatment (Table 1). Any deviation from the predictions was due to the size variation and stochastic effects. The highest numbers of onions available to consumers are associated with the treatment of no added technology or repackaging. However, the consumer would receive some defective onions that would have been discarded in other treatments. The treatment without the added technology or repack was consistent with the market situation in times of limited supply. Regions with a limited supply of the modeled commodity would discourage technology addition to the packinghouse. Technology will be most likely introduced in a value-quality driven system.

Table 3 shows unit prices by treatment and the

Table 2. Units Lost per 1,000 Individual Onions by Four Handling Treatments at the Field, Packinghouse, Distributor, and Retailer.

Treatment	Field	Packinghouse	Distributor	Retail
A	108[a]	358[b]	53	96
B	108[a]	356[b]	267	13
C	106[b]	447[a]	45	42
D	108[a]	445[a]	179	8
Interactions	--	--	Cost x size[c]	Cost x size x treatment[d]

[a] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[b] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[c] Significant for $P \leq .05$.
[d] Significant for P<.05.
Note: Results are the mean values from pooling data from 3 costs, 3 sizes, and 3 size standard deviations and 5 runs for each combination of conditions.
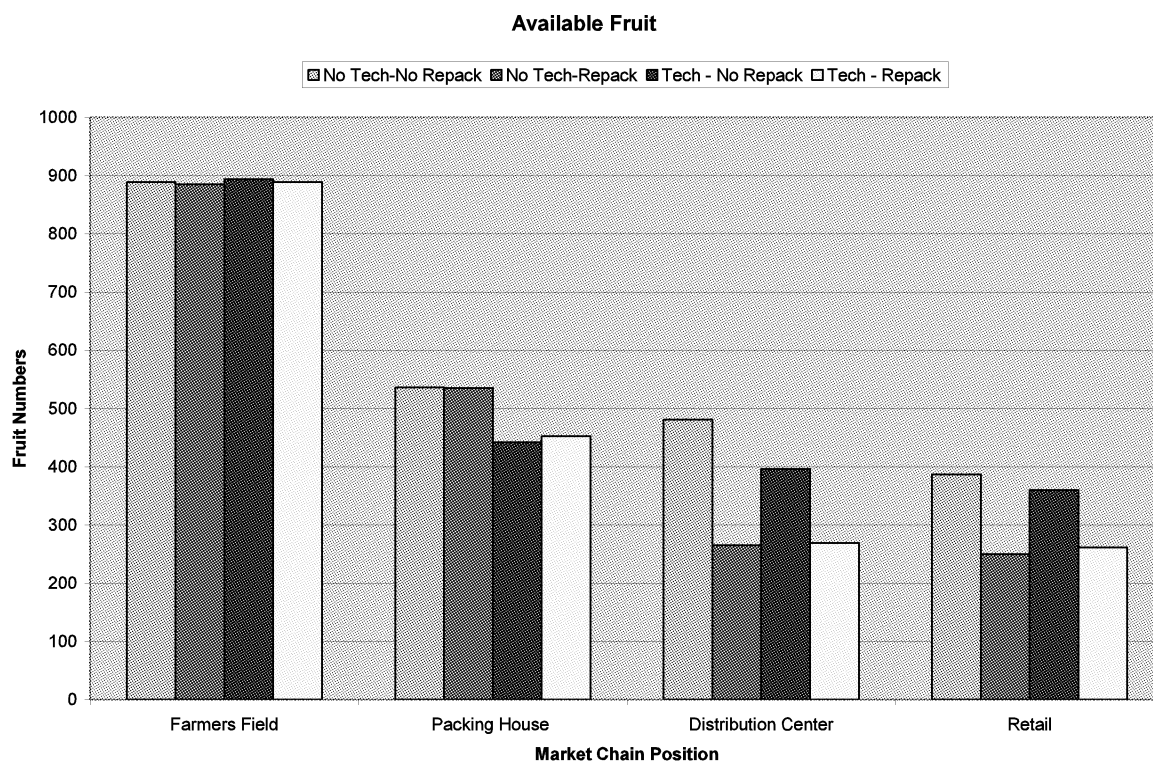
Available Fruit

Figure 2. Onion Numbers per 1000 Simulated Fruits at the Indicated Steps for Each Technology-Repack Test Trial, Specifically for the Area-Cost Coefficient of 0.001, 50 Mm Diameter ± 5 mm Standard Deviation.

Table 3. Unit Price ($/unit) by Four Treatments at the Farmer, Packinghouse, Distributor, and Retailer.

Treatment	Farmer	Packinghouse	Distributor	Retail
A	0.198	0.397	0.59	1.19
B	0.197	0.396	0.99	1.98
C	0.199	0.418	1.04	1.26
D	0.197	0.417	0.62	2.08
Interactions	Cost x size[a]	Cost x treatment[a]	Cost x treatment[a]	Cost x treatment[a]

[a] Significant at $P<0.05$.
Note: Results are the mean values from pooling data from 3 costs, 3 sizes, and 3 size standard deviations and 5 runs for each combination of conditions.

Table 4. Unit Value ($/unit) at Four Marketing Stages, by Treatment, at a Cost Coefficient of 0.001.

Treatment	Farmer	Packinghouse	Distributor	Retail
A	0.099	0.197[a]	0.296[a]	0.59[a]
B	0.099	0.201[a]	0.502[c]	1.01[c]
C	0.1	0.209[b]	0.314[b]	0.63[b]
D	0.1	0.210[b]	0.522[d]	1.05[d]

[a] Mean values did not differ as determined by the Duncan's multiple range test at $P<0.05$.
[b] Mean values did not differ as determined by the Duncan's multiple range test at $P<0.05$.
[c] Significant for $P \leq .05$.
[d] Significant for $P < .05$.
Note: Results are the mean values from pooling data from 3 sizes and 3 size standard deviations and 5 runs for each combination of conditions.
No interaction terms were found to be statistically significant at $P<0.05$.

marketing-chain stage for data pooling 5 runs, 3 costs, 3 sizes, and 3 standard deviations. Cost interactions were confirmed, as expected, by statistical test results. Table 4 shows results with the same conditions as Table 3 except the cost coefficient was fixed at 0.001 rather than allowing for the combination of all three coefficients. Differences by treatment become more pronounced as onions move through the subsequent marketing stages. Unit prices increase five- to ten-fold as onions move from the farmer's field to the consumer, according to simulation results. Under the treatments listed in Table 1, the technology reducing the number of internally damaged onions did not greatly increase the cost per unit, although due to the multiplicative structure of the pricing between the system processes, the difference tended to grow as the product moved closer to the consumer.

On a unit-price basis, the proposed latent-dam-age-reducing technology could best be combined with the repackaging operation according to the model. This is consistent with observed industry practices. The unit price was significantly affected by the size due to the dependence of cost on the diameter of the onion (Figure 3, which shows the case when the cost coefficient equals 0.001). The differences among unit values of the respective treatments became more pronounced through the system. The effect of size (as measured by diameter) is more pronounced in response to an increasing cost coefficient (not shown).

The value sold per 1,000 onions is shown by treatment (A, B, C, or D) in Table 5. Figure 4 visually illustrates the sold value by position and treatment. The use of standard deviation for randomly assigning sizes to 1,000 onions caused a significant interaction at the packinghouse level. The size standard deviation exerted a significant influence on the

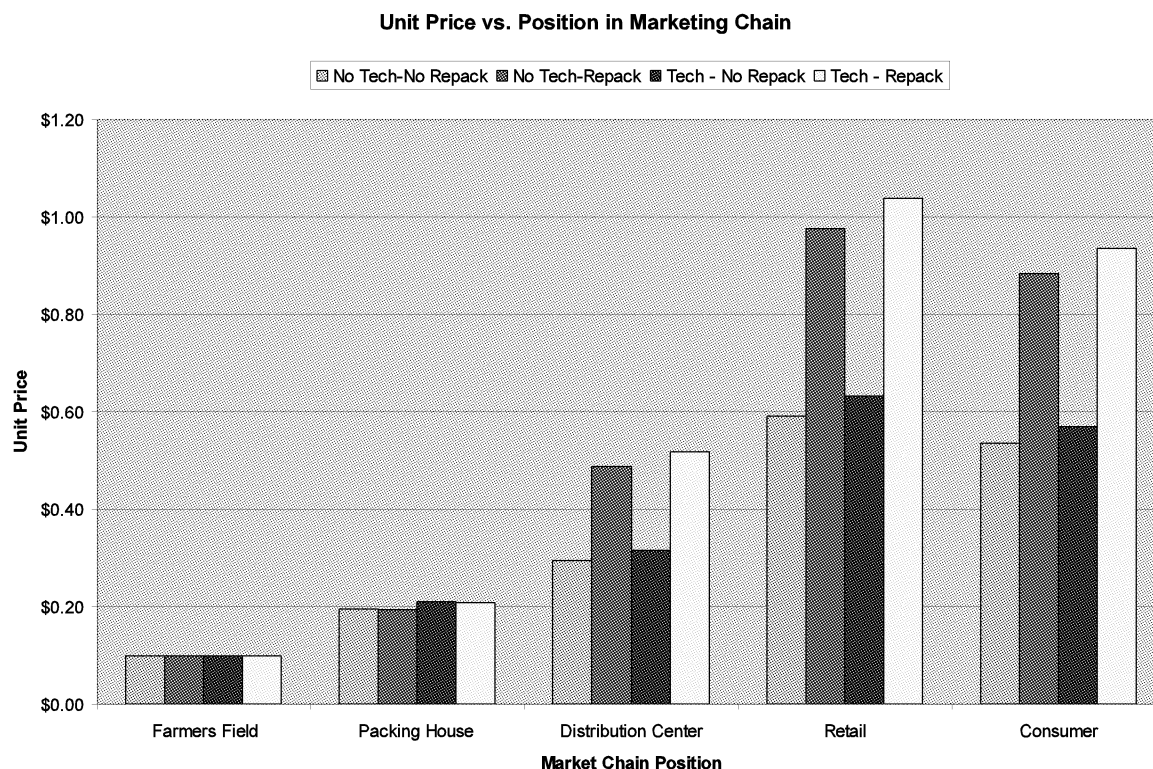**Unit Price vs. Position in Marketing Chain**

Figure 3. Price per Unit of Onions at Four Stages in the Marketing Chain for Four Trial Treatments, Assuming the Area-Cost Coefficient of 0.001 and 50 Mm Diameter ± 5 mm Standard Deviation.

Table 5. Value ($) per 1000 Units by Handling Treatment and Stage in the Marketing Chain.

Treatment	Farmer	Packinghouse	Distributor	Retail
A	177[a,b]	212	286	459
B	176[a]	211	265	505
C	178[b]	186	252	452
D	176[a]	185	279	541
Interactions	--	Cost x treatment x variation[c]	Cost x treatment x variation[c]	Cost x treatment[c]

[a] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[b] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[c] Significant at P<0.05.
Note: Results are the mean values from pooling data from 3 costs, 3 sizes, and 3 size standard deviations and 5 runs for each combination of conditions.

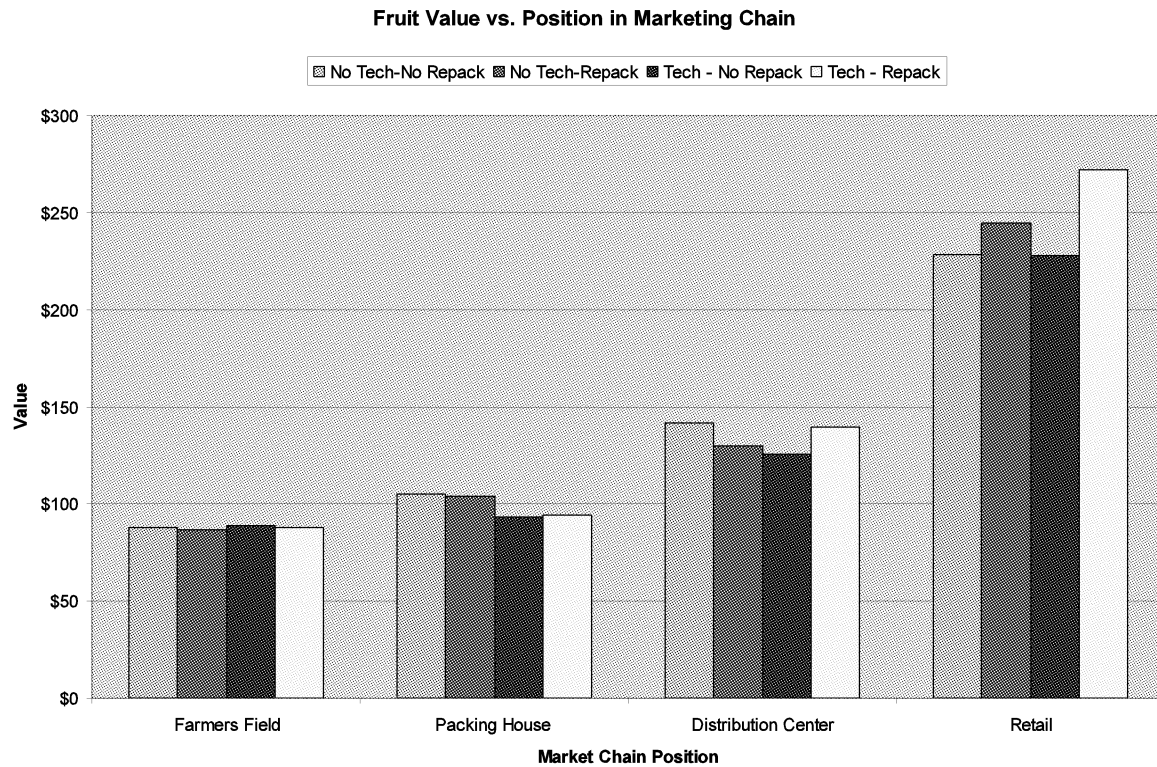**Fruit Value vs. Position in Marketing Chain**

Figure 4. Sold Value per Original 1000 Simulated Onions at the Indicated Steps for Each Technology-Repack Test Trial, Specifically for the Area-Cost Coefficient of 0.001, 50 mm Diameter ± 5 Mm Standard Deviation.

study results. The addition of technology, with the removal of additional onions at the packinghouse level, caused a decrease of the onion value leaving the packinghouse. This result is consistent with the observed reluctance of independent packinghouse operators to adopt additional technology to control for latent damage. Had the price multiplier been increased in the packinghouse, one would observe even greater differences at the retail level. Increasing differences would, in turn, cause additional hesitation to adopt the technology.

The price-multiplier structure for the treatments (see Table 1) presumed that without the addition of technology in the packinghouse, more onions would be discarded in the distribution center and at the retail level. The results of the pricing structure on effective prices for the technologies are shown in Table 6. The increased selection pressure reflects the concept of latent damage (Shewfelt and Prussia 1993) applied in practice. As in the case of unit

value, a larger onion had higher value. The notion that early removal of onions with latent damage and the consequent reduction in transportation costs leads to consumer savings is not supported by the pricing structure inherent in this model. An increase of the cost coefficients increased the size-effect differences (not shown).

Table 7 shows the effect of varying the cost coefficient. Generally, the coefficient is not a simple ratio, as typified by treatment-stage interactions with the markup coefficient, particularly when one moves beyond the packinghouse. The cost interaction likely stems from the nonlinear relation between the cost coefficient and the computed value. The same can be said as the order-of-power function increases between the cost coefficient and an assigned value.

For a commodity such as flowers, one may use a linear cost-value relationship. For nuts and individually inspected grains, one may consider a cubic

Table 6. Price ($) per 1000 Units by Handling Treatment and Stage in the Marketing Chain, Assuming the 0.001 Cost Coefficient.

Treatment	Farmer	Packinghouse	Distributor	Retail
A	88	105	142[a]	227[c]
B	88	108	136[b]	258[b]
C	89	93	126[c]	225[a]
D	89	94	137[b]	266[c]
Interactions	--	Size variation x treatment[d]	--	--

[a] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[b] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[c] Mean values did not differ as determined by the Duncan's multiple range test at P<0.05.
[d] Significant at P<0.05.
Note: Results are the mean values from pooling data from 3 sizes and 3 size standard deviations and 5 runs for each combination of conditions.

Table 7. Value ($) per 1000 Units by Position in the Marketing Chain and the Cost Coefficient.

Cost coefficient	Farmer	Packinghouse	Distributor	Retail
0.001	88	99	135	243
0.002	176	199	272	492
0.003	265	287	405	733

Note: Results are the mean values from pooling data from 3 sizes, 4 treatments, and 3 size standard deviations and 5 runs for each combination of conditions.
Statistical significance not tested due to numerous interactions between cost and treatment.

relationship to relate cost to volume or weight. Interactions in Tables 2–7 arise due to size variability and are apparent only with the use of the stochastic approach. Increased variation in the field will result in greater interaction as product moves through the handling system.

The fundamental difficulty in applying the model is the determination of the cost, pass-through, and pricing-multiplier coefficients (Table 1). Such information is generally guarded closely by the industry. Specific values are probably highly variable in space and time. The approach does provide the capability of simulating some "what-if" cases such as those shown in Table 1. The developed model would best be applied by brokers, packinghouse operators, distributors, and retail-store owners because they have the information needed to operate this model. The primary research value of the model is its ability to gain an understanding of observed behavior.

Results from this study support the paradox that early adopters of new approaches are not generally rewarded. The nondestructive inspection in case of this study (the x-ray technology) does not make an obvious change in appearance of the product; the retailer therefore cannot generally demand a higher price because a nondestructive inspection was applied. The "warm and fuzzy" notion that the product is of superior quality may be difficult to communicate to consumers asked to pay a premium. The introduction of nondestructive testing into a handling system would in many cases require a new grading and pricing system implementation in order to be immediately profitable. Consumers apparently tolerate some produce damage. Therefore the technology will likely find its applications first in niche markets where the premium quality is appreciated. A change in the social environment by realties such as bioterrorism may accelerate the conversion of the previously "warm and fuzzy" quality attribute into a definitive characteristic.

The coupling of technology with repackaging and the vertical integration of the packinghouse,

a distribution center, and the retail outlet might enable more equitable distribution of the burden of improved quality across the marketing stages to jointly experience the technology advantage at the consumer level. Kaufman (1999) also makes a case for consolidation (e.g., vertical integration) as a strategy for supply-chain management. Retail chains are becoming global in scope. External pressures such as biosecurity concerns may result in increased integration in the post-harvest handling system, so that the cost of technology could be more equitably distributed over all units in the handling system. The poultry industry (Vukina 2001) provides an example of how an industry can be globally competitive by consolidating and organizing to capitalize on technology innovations and optimal information flow.

The developed model needs additional refinement and further research. Brokers and managers at each stage of the post-harvest process set a price based on prior probabilities, some of which may be site-specific and hard to know in general. Extending the model to include Bayesian processes that use prior probabilities can increase the ability of the model to reflect realistic dynamics of the pricing process. Factors playing a role most likely will include packaging, seasonal fluctuations, production source, pressure to reach economic goals, and other site-specific factors. The throughput fraction is also a Bayesian process, with the likelihood being determined by the inspection-system designer and practitioner, as discussed in the previous section. An improved cooperation between brokers and researchers as suggested by Lynd (2003) would accelerate advances in this area by providing information concerning effects of various technologies on pass-through and on how costs are recovered at each stage in the handling system.

Implications

Even though the model inputs are subjective, the model seems to mimic what happens in post-harvest handling systems. The stochastic nature of the model enables researchers and brokers to examine effects of markup coefficients, size variations and pass-through coefficients on value as a product moves through a handling system with various treatment options, assuming pass-through and pricing-markup coefficients are known. The notion that early removal of fruits with latent damage and the

consequent reduction in transportation costs leading to consumer savings is not supported by the pricing structure inherent in this model in systems with and without repackaging. Only the people directly involved in operating components of the chain have the insight required to assign pass-through coefficients and price markups.

The addition of technology, while it increases value for the consumer, can cause adverse cashflow implications for an independent packinghouse operator. The addition of technology and additional packaging will be favored by the existence of a quality-value-driven system as opposed to a limited supply-driven system such as is present in the case of niche marketing. Realities such as bioterrorism could convert the intangible superior quality of nondestructively inspected fruits and vegetables into tangible economic returns. Otherwise, a different approach to grading would be required for implementing technology if the packinghouse is to be profitable. Even if a distribution system meets the need of high quality, external pressures such as food-security considerations will be required to motivate the vertical integration needed to share the cost burdens within all components of the existing system.

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