Optimal Fresh-produce Packaging: Cost/production Analysis of Packing Styles in the Salinas Valley

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Vegetable-product packaging styles have evolved over time in part because of market demands for greater convenience of handling, product protection, physical post-harvest needs, and availability of materials. Packaging must also identify a product and carry it safely through the distribution system, protecting the product from damage, high moisture, and high relative humidity and accommodating rapid temperature changes. Market demand requires packer/shippers to have several concurrent packing styles[1] to meet customer requests. Prices and quantities adjust market changes, yet no standard production level or single packaging combination fits an entire season, or fills the spectrum of client requests. Packer-shippers must anticipate market demand before planting. Their traditional planning mode is to rely on field-production managers to estimate needs based on their experience with input from marketing personnel. The question remains how much product should be packed in which package style.

The Problem

Given market prices and current packaging costs, we investigate how to develop optimal production schedules and weekly pack-out benchmarks to guide production and product packaging mix, and to enhance firm returns. We hypothesize that linear optimization should provide better estimates of systematic product-demand patterns in leaf vegetables for planning, harvesting, and shipping than do the traditional in-field estimates, specified as Ha: $\mathit{\Pi}_{opt} - \Pi_{TRAD} \geq 5\%$, where $\mathit{\Pi}_{opt}$ are returns generated from a linear programming (LP) model product packing allocation and Π_{TRAD} are returns generated from actual production.

The research objectives included developing weekly benchmarks for quantity of each vegetable packing style by commodity and estimates of relative returns to such planning. This research presents a situation statement, a review of packaging and optimal pack research, a discussion of methods used, and the analysis of seasonal benchmark and weekly market-condition variation in comparison with the traditional packer planning.

The Situation

Fresh leaf-vegetable production and marketing in the Salinas Valley has been characterized by an oligopolistic market structure of large firms alongside a substantial competitive fringe (see Table 1). Monterey County produced 55 million pounds of salad products in 1983, with a total gross value of $18 million. By 2002, when county farmers placed over 61,000 acres in vegetables, the value had reached $308 million for 38 million cartons or 76 million pounds (Lauritzen 2002). The firms involved face the vagaries of a marketplace requiring many packing styles to accommodate variable client demands from week to week. Packaging costs are an important component of the marketing bill, accounting for 8.1% of the consumer produce dollar. Corrugated paper boxes and containers commonly used for fresh produce account for 40% of packaging materials costs (USDA 2000).

Progress in Vegetable Packing

While there are more than 500 various packages used for produce, most packers use some form of corrugated paperboard box, which is designed for product protection and marketing (Thompson and Mitchell 2002). This packaging preserves existing farm or processor quality and prevents further damage (FitzSimmons 1986). Packages also seek to create consumer appeal and provide product information.

[1] For example, naked head lettuce, cello-wrapped head lettuce, cartons with polyethylene liners, collapsible plastic bins, bins of cored product, etc. See Kader et al. for more detail.

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Helpful comments by Sean Hurley and Brad Rickard are greatly appreciated.

Table 1. Salinas Valley Leaf Vegetable Dominant and Competitive Fringe Firms by Reported Total Annual Trucklot Shipping Volumes*.

Competitive Fringe*	Shipments	Dominant Firms	Shipments
Duda California	15,000	Tanimura & Antle	40,000
Nunes Co. Inc.	15,000	Dole Food Co. Inc.	40,000
Growers Veget.Express	15,000	Fresh Express	N/D
River Ranch	15,000	Mann Packing Co.	N/D
Fresh Kist	10,000		
Merrill Farms	10,000		
Mills, Inc.	10,000		
Bruce Church, Inc.	8,000		
Total Market Shipments	260,000	approximate for all grower/shippers	

Source: Producer Reporter Co.
* *The Blue Book* identifies more than 35 Salinas Valley grower-packer-shippers.

Improper packaging can accelerate product spoilage (South 1992). Perforated plastics allow gas exchange and prevent excess humidity, while solid plastics create a better product seal for modifying atmosphere and reduce available oxygen respiration and ripening, thus extending product shelf life.

Harvesting

Vegetable packing often begins in the field, but that field quality cannot be improved (South 1992), although repacking and culling may eliminate products that have incurred physical damage during harvest. Problems with decay, visual quality, and water loss begin with rough initial handling, so the packaging process must begin with quality products and appropriate handling in order to maintain quality (Kasmire and Cantwell 2002).

The goal of quality maintenance is to deliver vegetables that are as fresh as possible, to preserve that initial quality, and to elay subsequent deterioration. Harvesting vegetables that are neither in prime condition nor at satisfactory maturity wastes resources and results in lower quality. Post-harvest damage includes mechanical injury, moisture loss, decay, and aging. Loss of vitamins, sugars, texture, and color are less obvious but adversely affect overall quality. Such losses can be reduced by use of improved packaging, transportation, and handling practices (Woodroof 1988).

Food-packing Studies

Dantzig (1996) identified food processing as perhaps the second most active user of linear programming (LP). The food industry has used LP for analyzing economic questions in broiler processing, sausage processing, and animal-feed rations. Easterling, Conner, and Rogers (1981) created a beef-processing LP model to optimize product-mix returns from animal slaughter. They found firms could increase economic efficiency by defining an optimal product mix under various price, cost, product-demand, and slaughter-supply assumptions. Frazier, Howell, and Fortson (1967) used LP to optimize swine-processing returns. They used LP models to evaluate optimal decisions, avoiding the uncertainty associated with conventional decision-making methods. Kaminer (1984) used LP to define the optimal marketing mix of cut chicken parts (i.e., legs, thighs, backs, etc.), developing one model that simulated current operating procedures and a second model representing a possible reallocation, using LP on a week-to-week basis. Lawrence, Schroeder, and Hayenga (2001) surveyed meat packers on their use of contract production. They also found beef and pork packaging was the single largest materials-cost contributor. They identified the largest individual packaging-cost contributors by allocating costs per-unit and applied each to the cost source.

Data Collection

The study emphasized the product mix from a specific Salinas Valley packer-shipper (hereafter "The Company")[2], choosing their five most important vegetable commodities based on historical Salinas Valley seasonal sales and production records from 1998 to 2001. Package-style selections were based on sales revenues and included palletized lettuce, cello-wrapped lettuce, naked head lettuce, naked Romaine lettuce, 14 and 18 head count broccoli, 9-12-16 head count cauliflower, naked Red Leaf lettuce, naked Green Leaf lettuce, and all commodities for bulk use in the salad plant. The Company's production-planning view was that market highs and lows could not be easily anticipated. Weekly seasonal shipping prices were obtained for the 1998 through 2001 seasons from the Monterey County Agricultural Commissioner reports (Lauritzen 2002).

Identification of packaging components for the chosen pack styles was based on management expert opinion and the company's production department commodity requirements. Packaging-component price sheets were obtained from top valley suppliers based on the number of Salinas Valley shipper labels using that supplier's materials.[3] Input prices for each package type and general prices for commonly used packaging components were defined. Three packaging components suppliers were identified.

Data Analysis

The study used an Integer and LP computer package "WINQSB" (Chang 1998). When establishing the initial LP matrix the pack styles were viewed as real activities, with the net of market price and specific packing costs of each as the objective-function contribution. Each commodity pack style had an associated transfer row, while each commodity had a maximum constraint (ceiling). Prime commodity-packaging styles also received a maximum constraint to reflect market realities as shown in Table 2. A maximum weekly production level was defined as 105,000 carton equivalent units for all commodities based on current weekly production, which represented their then-current capabilities.

The goal was a linear approximation of the profit-maximizing product mix with alternative packaging styles defining a long-run best production-allocation combination, given averaged or proxy for long-run prices and costs.

Lastly, LP analysis used Iceberg lettuce weekly variable prices and supplies for each of the twenty-seven weeks of the 2001 season. This model was run to illustrate LP allocation at set variable prices and yields. The actual number of units packed by week was used to represent the traditional planning control.

Assumptions and Limitations

Production costs were assumed constant. Commodity selection, pack styles, and packaging-component suppliers were based on production data of a single packer/shipper. It was assumed that production data from "the company" could be considered that of a representative firm. Other economically important commodities and packaging suppliers would likely provide different results. Resource and product divisibility were programmed so that the smallest production unit was one acre's carton equivalent. Lastly, the company's top management assumed that in a "no market" condition (net losses on each product unit), contracted growers would be compensated to maintain grower relationships over short-run gains.

Linear Programming Analysis

The initial matrix-production coefficients, price-cost coefficients, and production-constraint values were from the representative firm. Net revenues for each activity on a per-acre basis were calculated as *Net Returns = (Unit Revenue * Total Units Produced) – TC*. Columns were the established vegetable packing activities. Intermediate products were moved by use of transfer rows, and indicated carton units transferred. Each product alternative required a separate transfer row, as product was transferred from at least one source to at least one other use. Costs, per-unit or per-carton, were converted to a per-acre cost using the respective commodity yield and pack style. Costs change daily in practice, but were held constant here for simplicity.

In California's fresh-produce industry, land is an

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[2] The firm wishes to remain anonymous.

[3] A label is the identifiable marketing logo or name known in the wholesale markets up the marketing channel. Examples are Andy Boy, Dole Fresh Fruit, River Ranch, and T&A.

Table 2. Individual Vegetable Packaging Style Weekly Maximization Constraints.

Packaging style	Mnemonic	Amount of Constraint
Palletized lettuce	Let Pall Harv	25,000 Cartons
Naked Romaine lettuce	Rom NK Harv	7,000 Cartons
18 Bunches of broccoli	Bro 18 Harv	12,000 Cartons
12 Heads of cauliflower	Cau 12 Harv	1,500 Cartons
Naked Green Leaf lettuce	Gr NK Harv	1,000 Cartons
All lettuce (above)		60,000 Cartons
Total vegetable limit		105,000 Cartons

Note: Pack-style ceilings interject recognition of inventory risk management, avoiding LP tendency to produce a single product, and define adequate inventory.

asset easily augmented by renting more acreage. It is common practice to rent more vegetable ground when necessary; therefore, land was not considered a constraint on production ability. Similarly, labor was excluded, as the packer/shipper maintains an in-house work force for all growing and harvesting needs. If in-house labor is insufficient, additional outside labor is hired, and has been readily available. All necessary capital was available, since this was not a start-up venture.

Weekly Benchmark Analysis

For weekly benchmarks, the model selected the most profitable commodity pack style and filled it to the maximum commodity constraint; however, a firm's desire for a mix of pack styles requires constraints by pack style within a commodity. The base-model solution values for harvest activities are in acres of production, while sales activities are reported in carton equivalents. Of the four possible methods of packaging lettuce, the base model had 66.7 acres of head lettuce produced, generating 60,000 cartons all placed in Palletized lettuce (Table 3). Of the two packaging styles for Romaine lettuce, all 15,000 cartons would be placed in Naked Romaine lettuce. Of three broccoli packaging styles possible, all 25,000 cartons were placed in Broccoli 18s (18 heads per carton), while of the four packaging options for Cauliflower, all 3,000 cartons available were placed in Cauliflower 9s (9 heads per carton). Lastly, the 2,000 cartons of Mixed lettuce were placed in Naked Green Leaf lettuce packs.

Harvest-activity unit cost and carton revenue for packed-product sales were multiplied by the solution values to define the contributions to the objective function. The total dollar cost of the first activity, Palletized Lettuce Harvest, was $349,733 and its total dollar sale value was $503,400. The five activities generated a net return of nearly $186,000. The shadow price for Naked Head Lettuce suggests that it would enter the solution when price reached $7.74 per carton. The Palletized Lettuce shadow price was $8.39, the current solution value of the base model.

We report the "Number of Weeks > (greater than) PShadow (Price)" as the frequency selling prices exceeded shadow prices over the length of the season. For example, Broccoli 18s had market prices above shadow prices in 19 of 27 weeks. All the salad-plant product activity prices were less than the base-model shadow prices.

Table 3 also illustrates the product mix after adding individual package constraints, showing the product mix by weeks in the solution, number of weeks by commodity pack, and the weekly acreage and pack levels for those activities. All but two alternatives, Mixed Lettuce for salad-plant use and cauliflower 16s (16 heads per carton), were used over the course of the season. Only one product, Salad Plant Romaine, was produced all 27 weeks of the season. Palletized Iceberg Lettuce and Naked Romaine were the only other packs to be scheduled for more than 20 weeks in the season.

The hypothesis sought returns greater than 5% above traditional production for midseason weeks 9–12, which were thought less likely influenced by location-change factors as seasons begin or ebb as production moves to new areas (such as Huron, Santa Maria, or Imperial Valley) with attendant

Table 3. Optimal Vegetable Production Schedule by Commodity and Pack Type, for Weekly Seasonal and Single 4-Year Average (Base) Benchmarks.

Production Activity	Seasonal Production Weekly #Wks	Week of Season	Base Acres-Cartons	Weeks Base Production	> PShadow
Naked Lettuce	13	11 13-16 18 20 22-27	41 – 35,000		14
Lettuce Palletized	24	1 2 5 7-27	28 – 25,000*	60,000**	15
Lettuce Cello	9	1 2 9-12 17 19 21	39 – 35,000		14
Let Plant Mat	6	3 4 6	63 – 60,000		0
		5 7 8	37 – 35,000		0
Romaine Naked	20	1 2 5 11-27	9 – 7,000*	15,000**	11
Rom Plant Mat	27	1 2 5 11-27	10 – 8,000		0
		3 4 6-10	19 – 15,000		0
Broccoli 14s	10	1-4 8 19-21 24-25	19 – 13,000		16
Broccoli 18s	17	1-4 7-9 16 18-26	16 – 12,000*	25,000**	19
Bro Plant Mat	11	5-6 10-15 27	33 – 25,000		0
	16	18 22-23	17 – 13,000		0
Cauliflower 12s	4	1 4-6	2 – 1,500*		11
Cauliflower 16s	0	No activity			14
Cauliflower 9s	15	2-3 7-10 13-16 22	4 – 3,000	3,000**	12
		1 4-6	2 – 1,500		
Cau Plant Mat	12	11-12 17-21 23-27	4 – 3,000		0
Red Leaf Naked	5	1 15-18	2 – 1,000		12
GreenLeaf Naked	10	1-2 12-19	2 – 1,000*	2,000	13
Mixed Plant Mat	0	No activity			0

Notes: * package constraint imposed, ** commodity constraint imposed.

shutdown and start-up problems. The “Actual” weekly net returns were compared to the LP-generated returns using the four-year weekly average price and yields. The margin of improvement appears in Table 4, where for three of four test weeks the LP-model returns were far greater and for the fourth the difference was essentially nil (less than 0.3%). The overall gain was 27% over actual, but this was not tested for statistical significance.

Lastly, the model was run using only Iceberg Lettuce actual weekly market prices and yields from the 2001 season (Model 2 in Table 5) and was compared to the company’s actual run of product mix at 1998–2001 averaged prices (Model 1). The results display noticeable differences in eighteen of twenty-seven weeks. Weeks 3–8 in Model 1 included selling Salad Plant materials and Palletized lettuce activities, while Model 2 included Salad Plant material and Naked and Palletized Lettuce. Model 2 suggests operational shutdown for 5 weeks (5–6 and 25–27), which may be explained by constant costs with variable prices and yields, but is not feasible if it is necessary to have product available for clients. In late season, Model 1 included both Naked and Palletized lettuce, while Model 2 included only Salad Plant lettuce for weeks 23 and 24. Model 1 sent no product to the salad plant after week 8, which is also impractical. Activities for both Models in Weeks 9–10 changed from Cello-packed, Palletized, and Naked lettuce to Salad Plant lettuce only. Net-return means and variability (COV) were about the same. The Models’ patterns were very different—in 16 of 27 weeks the relative difference was more than 100%; however, both Models developed their greatest returns between weeks 16 and 24. The highly variable prices and yields of Model 2 resulted in breakeven or net returns of less than $1,000 in 11 of 27 weeks.

Conclusions

The LP models appear to improve vegetable-packing net returns when compared to actual firm behavior. The addition of reasonable package constraints

Table 4. Vegetable-packing Returns Actual and LP-model Allocations, for Weeks 9–12 of the 4 Year Average Week-to-week Salinas Season.

Week of Season	LP RETURNS	Actual Returns	Margin Improvement
9	$ 68,444	$ 31,936	53%
10	$ 98,656	$ 55,753	43%
11	$ 143,586	$ 143,922	0%
12	$ 138,798	$ 122,622	12%
Total	$ 449,484	$ 354,233	27%

Table 5. Iceberg Lettuce-only Weekly Net Returns from Averaged Versus Actual Weekly Yields and Prices, Average Weeks of 1998–2001 (Model 1) and 2001 Actual (Model 2).

Week	Model 1	Model 2	Change	Week	Model 1	Model 2	Change
1	$84,278	$396,975	371%	15	$212,743	$295,522	39%
2	57,495	298,914	420%	16	704,000	600,146	-15%
3	618	70,027	11231%	17	323,245	468,825	45%
4	618	274	-56%	18	169,343	347,092	105%
5	4,639	0	-100%	19	154,645	546,132	253%
6	618	0	-100%	20	97,593	666,301	583%
7	4,889	229	-95%	21	82,345	690,942	739%
8	18,889	25,625	36%	22	66,643	380,733	471%
9	59,795	1,242	-98%	23	43,543	7,468	-83%
10	96,995	1,158	-99%	24	609,393	224	-100%
11	141,593	785	-99%	25	94,243	0	-100%
12	129,695	469	-100%	26	111,643	0	-100%
13	142,843	177	-100%	27	45,043	0	-100%
14	169,693	30,500	-82%				

Model	Means	Median	Std Dev	COV
1/ 2	134 ,336/178,880*	94,243/ 7468	168,417/ 243,523	1.25/ 1.36

* Insignificant difference in means by two-sample t-test.

to the LP model provides the broader product mix deemed necessary. A comparison of weekly Iceberg lettuce-only weekly average price benchmarks with the actual run of 2001 season prices and yields found apparent large differences week to week, but no significant differences in mean net returns.

Day-to-day prices may change by more than 100%, thus bringing into question the ability of a long-run averaging model to estimate needed production schedules effectively, or conversely the recognition that a set of market-practicality constraints must be added to any model. The full range of package and product constraints would be necessary to generate a more realistic product mix of a larger service-oriented multi-product vegetable packer-shipper. Further work should begin with a broader or more inclusive commodity and packing-style constraint list.

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