Development of Planning Tools for the Supply Chain of Fresh Produce

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Agenda

- Background
- Problem Description
- Related Literature
- Project Objectives
- Models Developed
- Tactical model
- Experiments
The market for fresh fruits and vegetables generates around 80 Billion Dollars in income annually.

Consumption of fresh produce has increased 30% over the last 30 years.

Demand is driven by demographic changes and health concerns.

Produce industry has high logistical costs.

Increased vertical and horizontal coordination
Background

- Consolidation in the industry is changing the balance of power.
- Retailers require a year long supply of fresh products, which strains production and distribution.
- Retail companies, have pushed the producers to expand their activities in the supply chain and do more value added activities such as:
  - Packing and branding
  - Storage and distributing
  - New product development
- Producers (grower/shipper) now need the use of better tools to deal with their production and logistical complexities
Description of the Problem

Fresh agricultural planning:

- High production costs
- High labor requirements
- Uncertain production
- Limited shelf life
- Risky Market
  - Price unknown
  - Variable demand
- Decisions are taken before any knowledge of the demand, price and production.
Description of the Problem

Strategic
- Crop Selection
- Location Analysis
- Technology Selection

Tactical
- Transportation Decisions
- Crop Production
- Scheduling of Activities

Operational
- Harvest Decisions
- Marketing Decisions
- Storage and Transportation
## Description of the Problem

### Planting Periods

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### Harvesting Periods

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### Harvest by week

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</table>
| 26-Feb        | 948      | 6 6 16 12 | 8 8 8 7 | 100
Related Literature

- Van Berlo (1992): Integrated model for crop planning in the field and production at a plant, with deterministic assumptions.
- Darby et. al. (2000): Stochastic programming approach for production planning with risk aversion, but not an integrated model.
- Entrup et. al. (2005) Linear program for production planning with shelf life integrated in the objective function.

Contribution to the literature

1. Designing integrated models that deal with production, harvesting and distribution decisions
2. Incorporation of stochastic features to the integrated planning model
3. Development of operational models focused in fresh agricultural products.
Objectives of the Project

Objective:

Provide vertically integrated producers of highly perishable products, such as fresh fruits and vegetables, with adequate tools to perform their seasonal planning.

Activities:

- Develop a tactical level supply chain planning tool designed for grower/shippers.
- Include shelf life restrictions and/or objectives in the tactical planning model.
- Include uncertainty in the decision planning to account for the characteristics of crop production.
- Develop an operational model to render harvesting and distribution plans.
Models Being Developed

**Tactical Model**
- How much and when to plant
- Land assigned to each crop
- When to harvest and sale
- Transportation decisions

**Operational Model**
- Harvest schedule
- Schedule of shipments
- Storage and selling decisions
- Transportation decisions

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**Tactical Decisions**
- Crop selection
- Area assigned to crops
- Planting scheduling

**Market Analysis**
- Weather Forecast
- Feedback

**Risk Analysis**
- Price Estimates

**Tactical Decisions**
- Labor planning
- Harvest plan
- Distribution plan

**Operational Decisions**
- Spot Prices
- Harvest schedule
- Shipment schedule
- Selling decisions

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Phase I: Tactical  |  Phase II: Operational
Models Being Developed

Model interaction
- Use tactical model a few times in the season (multiple planting dates).
- Use the operational model every week during the season harvesting season.
- Use estimated costs of harvest and transportation from operational model in tactical planning.

**INPUT**
- Seasonal demand
- Available resources
- Crop requirements
- Expected price
- Cost information

**OUTPUT**
- Crops to plant
- Weekly production

**INPUT**
- Weekly prices
- Weekly demand
- Transportation req.
- Daily maturation
- Production capacity

**OUTPUT**
- Weekly harvesting
- Weekly shipments
- Available inventory

**Tactical Plan**

**Operational Plan**
Tactical Model

Locations
L1
L2
L3

Packing
P1
P2

Warehousing
W1
W2

DC’s
D1
D2
D3

Customers
C1
C2
C3
Tactical Model

Locations Packing Warehousing DC’s Customers

L1 P1 W1 D1 C1

Plant Pack Storage Storage
Transport Transport Transport Transport

Harvest
Tactical Model

Objective:

\[
\begin{align*}
\text{Max} & = \sum_{tki} (\sum_f SC_{tkfi} + \sum_h \sum_w SW_{htkwi} + \sum_h \sum_d SD_{htkdi}) \cdot price_{tki} + \sum_{hj} K_{hj} Psalv_j \\
& - \sum_{pjl} \text{Plant}_{pjl} C_{plant}_{jl} - \sum_{pjl} X_{pjl} LabP_{jl} CLabor - \sum_{phjl} \text{Harvest}_{phjl} LabH_{k} CLabor - \sum_{if} Opf_{if} CLabor - \sum_{fjk} Pack_{hfk} Ccase_k \\
& - \sum_{tki} \sum_f TC_{tkfi} CT_{dir} - \sum_{htkwi} TW_{htkwi} CTW_{wir} - \sum_{htkdi} SD_{htkdi} CTD_{dir} \\
& - \sum_{htkfw} \sum_f SW_{htkfw} CTPWD_{wdr} - \sum_{htkfd} \sum_f SD_{htkfd} CTPD_{dfr} - \sum_{htkw} SWD_{htkw} CTWD_{wdr} \\
& - \sum_{tkw} Invw_{tkw} Chw_{kw} - \sum_{tkd} Invd_{tkd} Chd_{kd} - \sum_{tkw} Z_{tkw} Pavg_{tk}
\end{align*}
\]

Decision Variables:

\(Plant_{pjl}\): Area to plant of crop \(j\), in period \(p\) at location \(l\)

\(Harvest_{phjl}\): Harvest (pounds) of crop \(j\) in period \(h\) and planted in period \(p\) from location \(l\)

\(Pack_{hfk}\): Quantity of product \(k\) packed at facility \(f\) in period \(h\)

\(SW_{htkwi}\): Quantity of product \(k\) in period \(h\) shipped from warehouse \(w\) to customer \(i\) in period \(t\)

\(SC_{tkfi}\): Quantity of product \(k\) to ship directly to customer \(i\) from facility \(f\) in period \(t\)

\(SD_{htkdi}\): Quantity of product \(k\) in period \(h\) to ship to DC \(d\) from facility \(f\) in period \(t\)

\(TC_{tkfir}\): Transportation mode \(r\) selected for transporting product \(k\) from \(f\) to \(i\) at time \(t\) \(\{0,1\}\)
Experiments

Factors

- Crops \((J)\)
- Locations \((L)\)
- Customers \((I)\)
- Plants \((P)\)
- DC’s \((D)\)
- Transportation mode \((H)\)
- Time periods \((T)\) in Weeks
- Time Production \((TP)\)
- Time Harvest \((TH)\)
- Warehouses \((W)\)
- Products \((K)\)
Results

- We have gathered information from a medium size grower with a 1,000 acres of fresh produce.
- The crops are tomatoes and bell peppers.
- Before the cropping season the model provides the time and quantity to plant of each crop per week.
- The model also provides an estimate of the harvesting requirements during the harvesting season.
- For marketing decisions: the model indicates which customers to supply and the markets to target, based on prices and transportation costs.
- Finally the model select the best transportation mode based on the shelf life and delivery restrictions.
Future Research

- Use the structure of the model: sparse matrix in a multi-commodity MIP to solve the basic problem faster.
- Include stochastic features to the tactical planning model and use the faster running algorithms developed for the deterministic model.
- Develop operational models based on the tactical plan, but changing the time period from weeks to days.
- Consider other objective functions that are closer to the growers, such as risk-based performance.
- With the use of stochastic programming, we can later consider several production and distribution plans based in their risk, probabilities and benefits.
## Related Literature

<table>
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<th>Applications</th>
<th>Planning Scope</th>
<th>Decision Variables</th>
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S: Strategic
T: Tactical
O: Operational
A: Application of the models
DM: Decision maker for which the model is designed.
P: Production variables/decisions
H: Harvesting variables/decisions
D: Distribution variables/decisions
I: Inventory variables/decisions
SCM: Echelons of the supply chain
References

- USDA ERS (2004b) Read meat per capita consumption.
Operational Model

Changes in the Model
1. Time periods in days instead of weeks
2. Shelf life in the objective function
Stochastic Tactical Model

Tomato pricing data for 25 years (Min, Max, 25th and 75th percentiles)

What we have available to make decisions

- Historical distribution of prices (per week)
- Historical distribution of yields (per week)
- Historical and contracted demand from customers
Two-stage stochastic program

- Based in the original model proposed by Dantzig (1955)
- Overall performance is dependent on
  - First stage decisions
  - Realizations of the stochastic variables
  - Second stage decisions
Scenario Development

Plan for the Preparing Scenarios

- Take advantage of the structure of the problem.
- We will assume that the production has some defined structure according to:
  - Planting date
  - Type of crop
  - Technology used

- Determine the joint distribution of prices and production for each week and crop in the season.
- Price and production are not independent.

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<th>Week 3</th>
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Solution Approach

Solution space reduction
- Partition into finite number of scenarios
- Importance sampling
- Sampling methods

Runtime reduction
- Benders decomposition
- Accelerated bender’s decomposition
- Model relaxation
- Solvers that can deal with nonlinear objective functions
- Stochastic decomposition
Benefits Obtained from Tactical Model

- We plan to model the planting and production decisions for perishable products for an entire season.
- We use current state of OR tools applied to the tactical planning of fresh produce.
- The use of stochastic programming allows the planner to consider the risk incurred in their planting decisions.
- With the use of stochastic programming, we can later consider several production and distribution plans based on their risk, probabilities and benefits.
Tactical Model

What we have available to make decisions

- Available land
- Potential crops (plant date, expected yield, harvest date)
- Labor required for planting, harvesting, etc.
- Packing plants (Capacity, personnel)
- Transportation (Truck, rail, air: cost-time)
- Warehouses (Own, broker, third party)
- Storage restrictions of crops
Scenario Development

Prices vs Production of Season 2002

Data for Seasons 2001-2005

Prices

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More
Scenario Development

Joint Probability

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Prices on Week 10

Production on Week 10
Operational Model

- **Harvest**
- **Packaging**
- **Distribution**
- **Customer**

**Production**

- **Demand**
- **Cost**

**Shelf Life**

- **TL**
- **Train**
- **Air**

**Pick up tomatoes** → **Transport them to packing** → **Select and pack them** → **Put them on pallets** → **Load them on containers** → **Select transportation mode** → **Repack and consolidate** → **Final delivery to customers**
What we have available to make decisions

- Fields (Area, variety)
- Crops in the fields (Harvest start, ripeness, yield)
- Labor at harvest
- Packing plants (Capacity, personnel)
- Cooling warehouses (Capacity)
- Transportation (Truck, rail, air)
  - Lead time
  - Cost
  - Equipment: 48’-53’, 40’-40’