Development of Planning Tools for the Supply Chain of Fresh Produce

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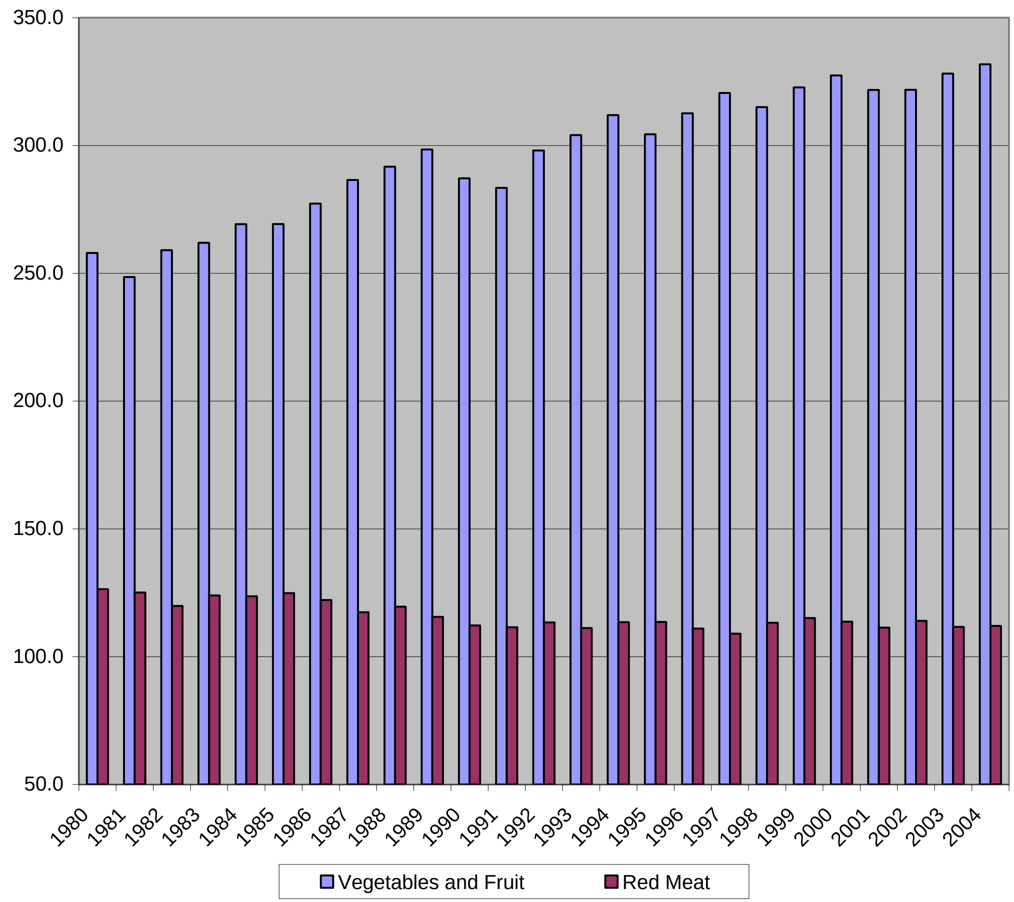
Agenda

- Background
- Problem Description
- Related Literature
- Project Objectives
- Models Developed
- Tactical model
- Experiments

Background

- 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

Source: USDA ERS 2000a, 2000b



Background

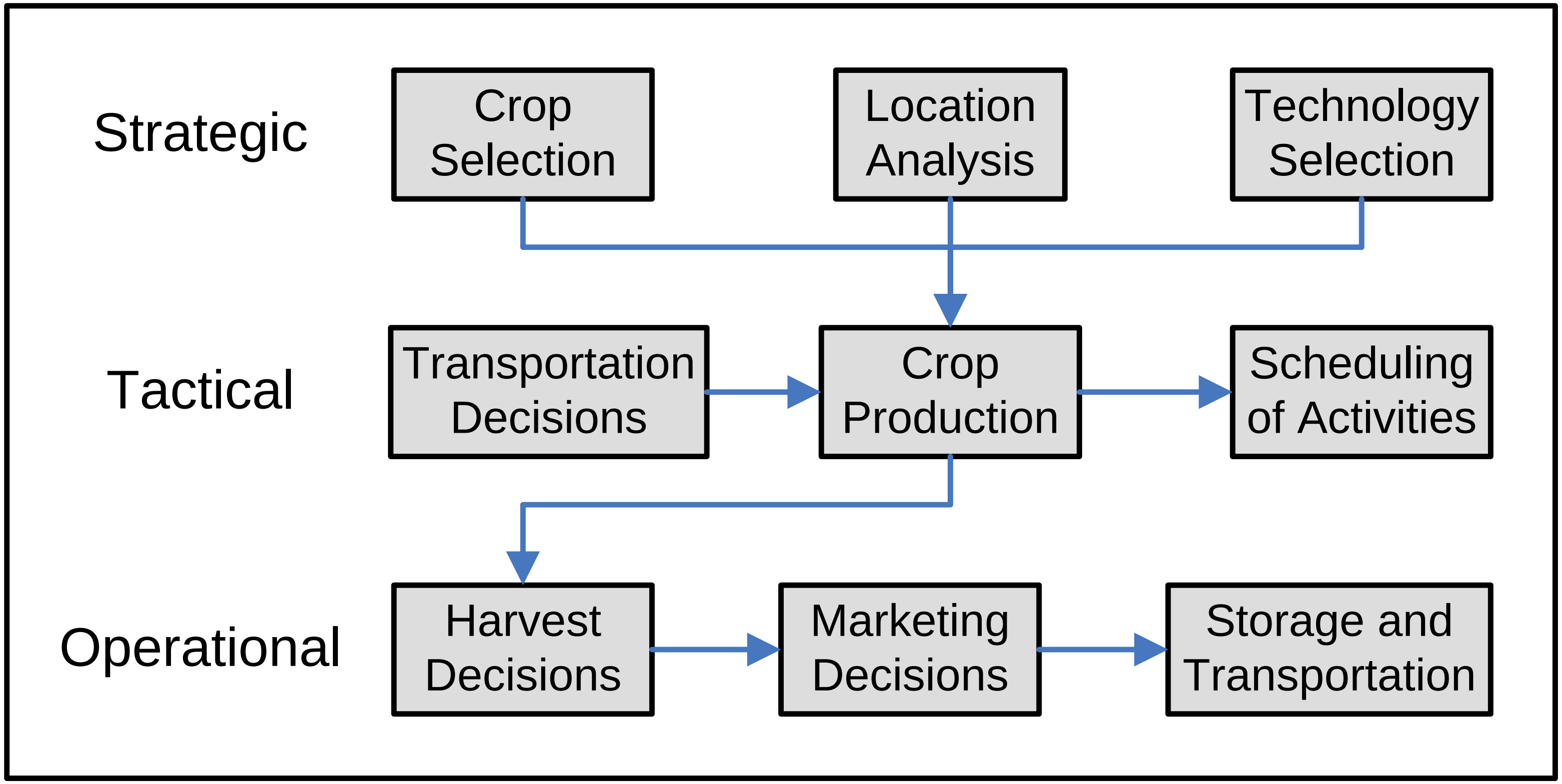
- Consolidation in the industry is changing the balance of power.
- Retailers require a year long supply of fresh products, which strains production and distribution.
- Retail companies, have pushed the producers to expand their activities in the supply chain and do more value added activities such as:
  - 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

<u>Fresh agricultural planning:</u>

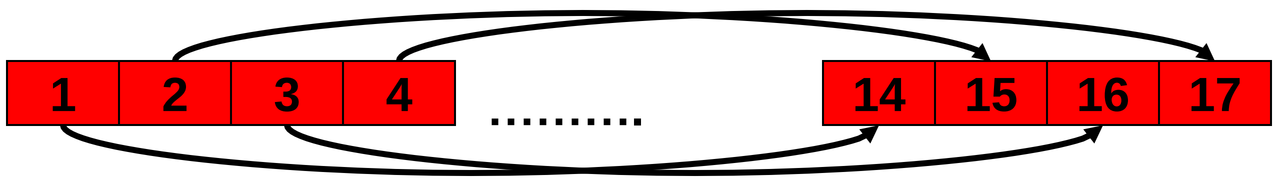
- High production costs
- High labor requirements
- Uncertain production
- Limited shelf life
- Risky Market
  - Price unknown
  - Variable demand
- Decisions are taken before any knowledge of the demand, price and production.

Description of the Problem



Description of the Problem

Planting Periods **Harvesting Periods**



		Harvest by week																																	
		November				December				January				February				March				April				May				June				
Date of Plant	Production	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	%
15-Aug	1,662			5	5	10	10	10	10	9	9	8	8	8	8																			100
30-Aug	1,828					5	5	10	10	10	10	9	9	8	8	8	8																	100
14-Sep	2,373					5	5	6	10	10	10	10	10	9	9	8	8																	100
29-Sep	2,564							5	5	10	10	10	10	9	9	8	8	8	8															100
14-Oct	2,698									5	5	10	10	10	10	9	9	8	8	8	8													100
29-Oct	2,684											5	5	10	10	10	10	9	9	8	8	8	8											100
13-Nov	2,896													5	5	10	10	10	10	9	9	8	8	8	8									100
28-Nov	2,837															5	5	10	10	10	10	9	9	8	8	8	8							100
13-Dec	2,337															5	5	10	10	10	10	9	9	8	8	8	8							100
28-Dec	2,183																	5	6	10	20	22	10	8	7	6	6							100
12-Jan	1,794																			4	5	10	15	22	10	9	9	8	8					100
27-Jan	1,385																					7	7	13	13	18	18	9	9	4	2			100
11-Feb	1,200																					7	7	21	21	15	15	5	4	3	2			100
26-Feb	948																							6	6	16	17	12	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.
- Caixeta-Filho et. al. (2002) Optimization of production and trade of lily flowers (Tactical plan).
- 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.

<u>Contribution to the literature</u>

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.

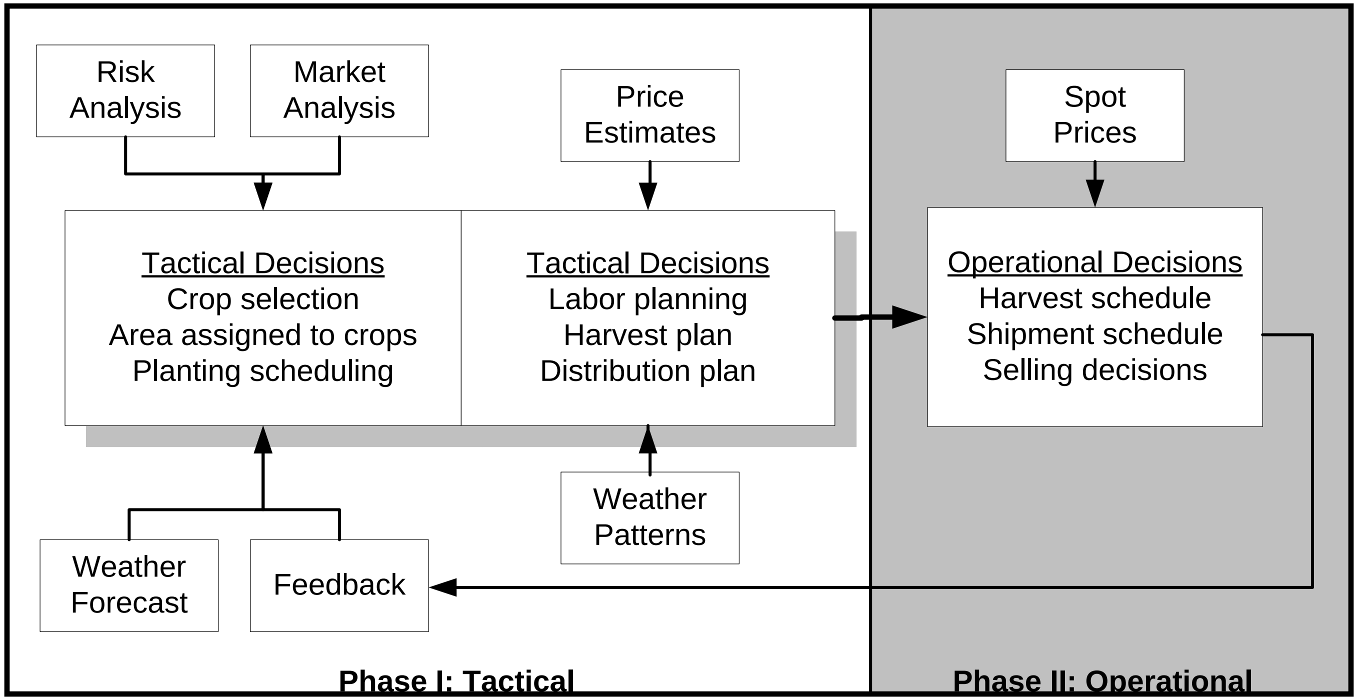
Models Being Developed

Tactical Model

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

Operational Model

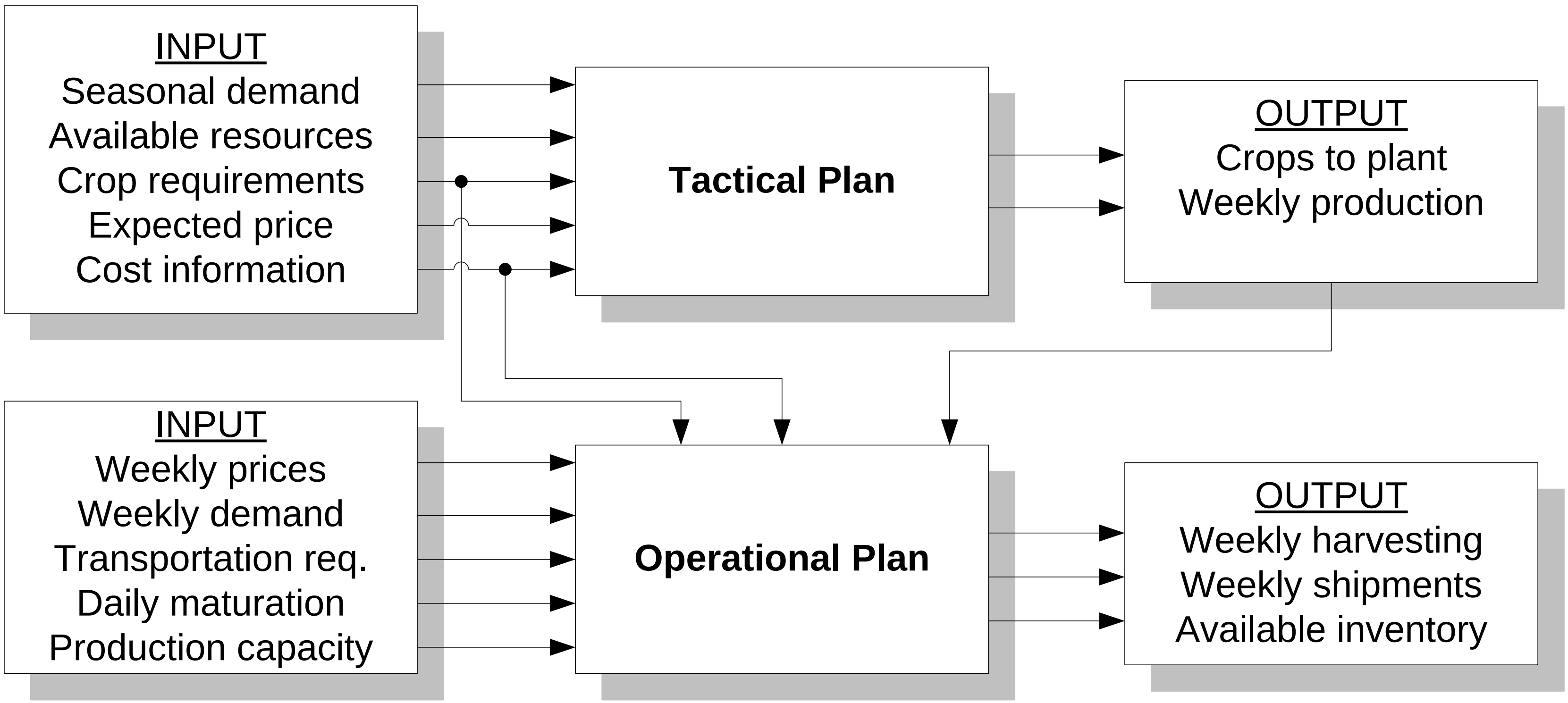
- Harvest schedule
- Schedule of shipments
- Storage and selling decisions
- Transportation decisions



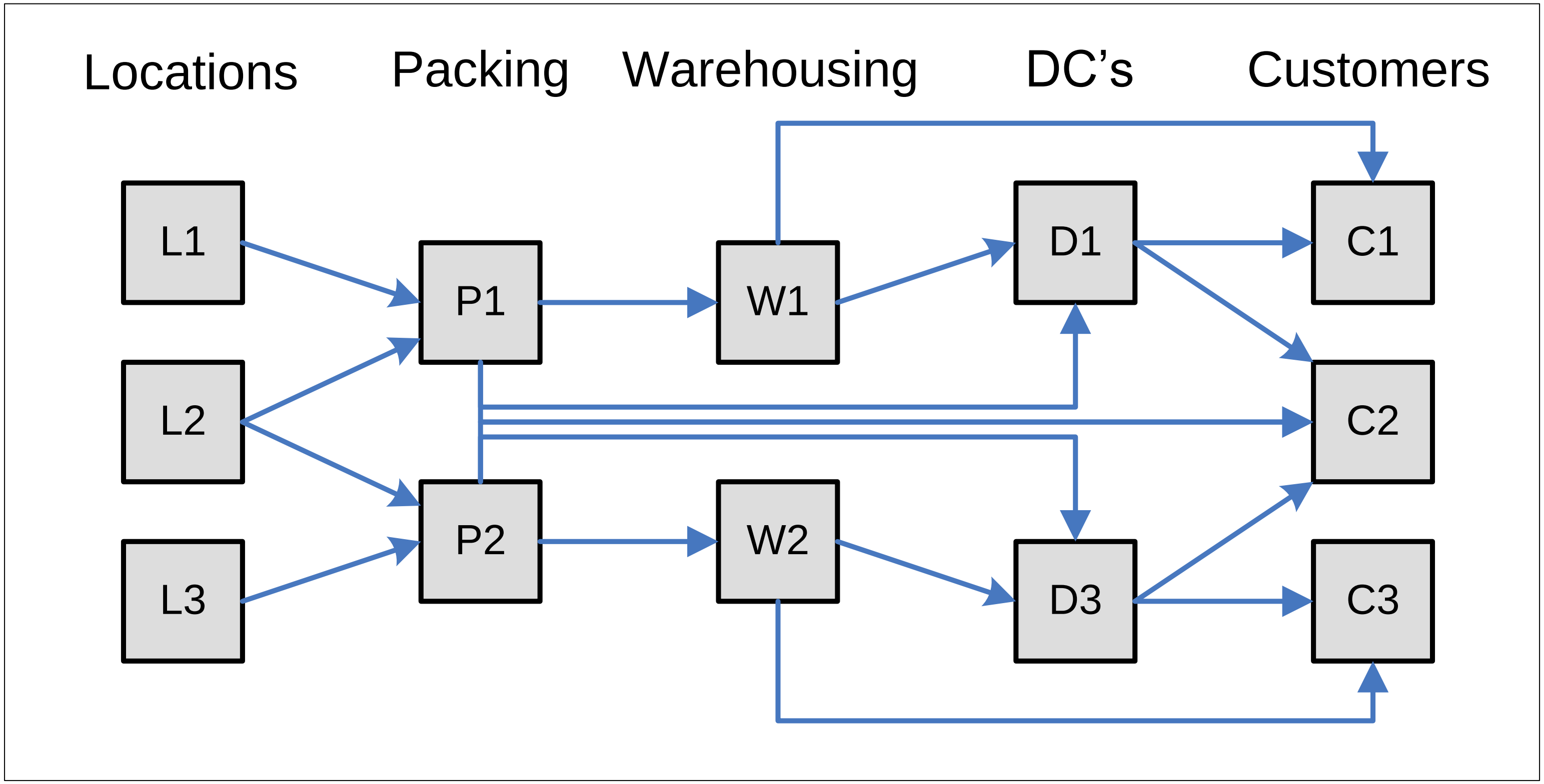
Models Being Developed

<u>Model interaction</u>

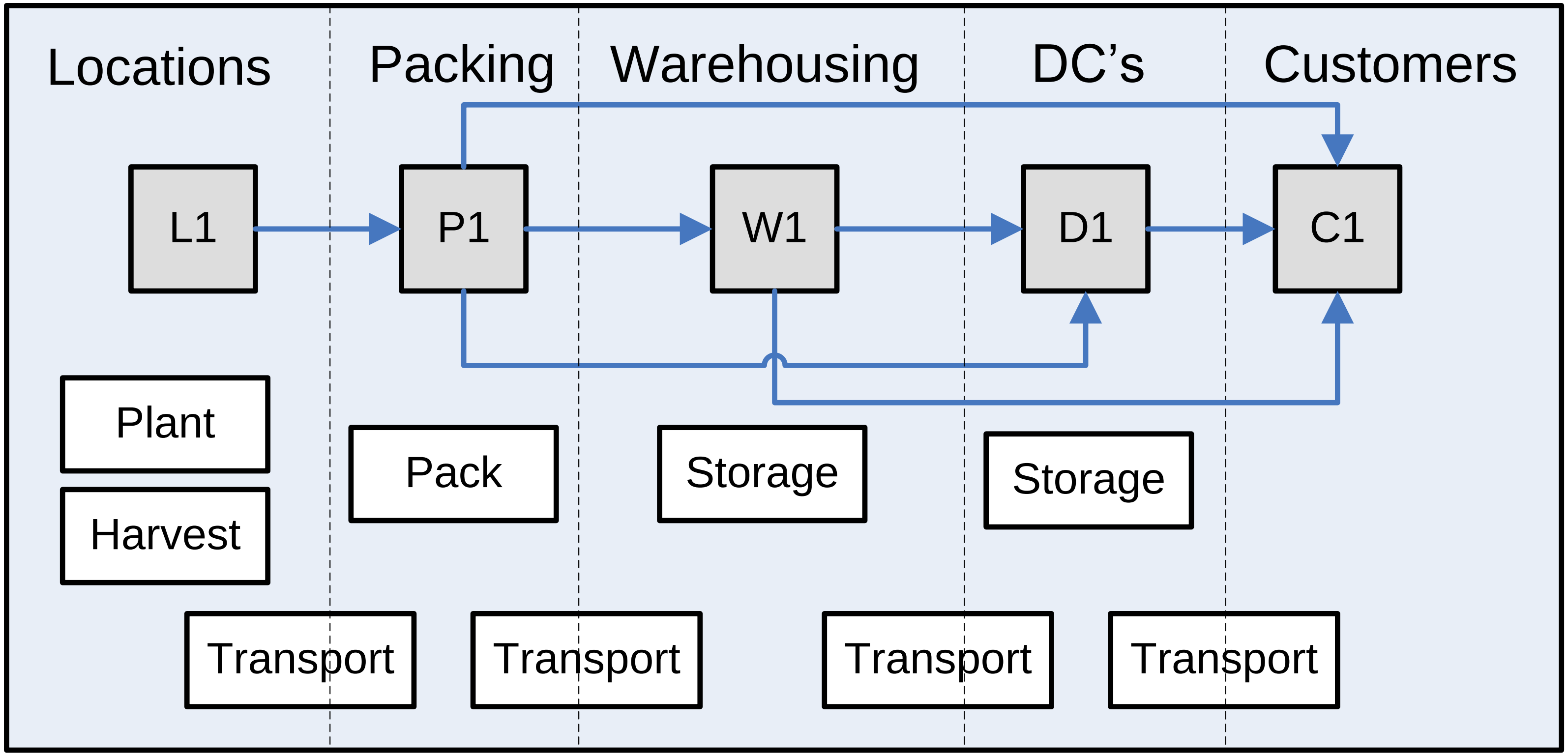
- Use tactical model a few times in the season (multiple planting dates).
- Use the operational model every week during the season harvesting season.
- Use estimated costs of harvest and transportation from operational model in tactical planning



Tactical Model



Tactical Model



Tactical Model

Objective:

$$Max = \sum_{tki}(\sum_{f} SC_{tkfi} + \sum_{h}\sum_{w} SW_{htkwi} + \sum_{h}\sum_{d} SD_{htkdi}) \cdot price_{tki} + \sum_{hj} K_{hj} Psalv_{j}$$

Revenue

$$-\sum_{pjl} Plant_{pjl} Cplant_{jl} - \sum_{pjl} X_{pjl} LabP_{j} CLabor - \sum_{phjl} Harvest_{phjl} LabH_{k} CLabor - \sum_{tf} Opf_{tf} CLabor - \sum_{fhk} Pack_{hfk} Ccase_{k}$$

Production

$$-\sum_{tkfi} SC_{tkfi}(\sum_{r} TC_{tkfir} CT_{fir}) - \sum_{htkwi} SW_{htkwi}(\sum_{r} TW_{tkwir} CTW_{wir}) - \sum_{htkdi} SD_{htkdi}(\sum_{r} TD_{tkdir} CTD_{dir})$$

$$-\sum_{htkfw} SPW_{htkfw}(\sum_{r} TPW_{tkfwr} CTPW_{fwr}) - \sum_{htkfd} SPD_{htkwi}(\sum_{r} TPD_{tkfdr} CTPD_{fdr}) - \sum_{htkwd} SWD_{htkwd}(\sum_{r} TWD_{tkwdr} CTWD_{wdr})$$

Transportation

$$-\sum_{tkw} Invw_{tkw} Chw_{kw} - \sum_{tkd} Invd_{tkd} Chd_{kd} - \sum_{tkw} Z_{tkw} \cdot Pavg_{tk}$$

Holding

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*

$Pack_{hkf}$: 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

J	T	TP	TH	I	L	P	W	D	K	H	Row	Col	Non	Time
2	30	8	16	3	2	2	2	2	8	3	47,090	53,964	171,390	54
2	40	20	26	3	2	2	2	2	8	3	109,361	118,745	360,368	200

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

Applications	Planning Scope						Decision Variables					
	S	T	O	SL	A	DM	P	H	D	I	SCM	Other
Widodo et. al. (2006)		X	X	X	N	SC	X			X	2	
Caixeta-Filho (2006)		X			Y/N	Planner		X			2	
Ferrer et. al. (2005)		X	X	X	Y/N	Planner		X			1	Labor and routing
Kazaz (2004)		X		X	Y/N	Planner	X	X			1	Purchase from other source
Allen and Schuster (2004)	X				Y/Y	Planner	X	X			1	Capacity planning
Rantala (2004)	X	X			Y/N	SC	X		X	X	2	Open/close facilities
Itoh et. al. (2003)		X			N	Farmer	X				1	
Caixeta-Filho et. al. (2002)		X	X		Y/Y	Farmer	X	X			1	
Berge et. al. (2000)	X	X			Y/N	Advisor	X				1	Technology selection
Darby-Dowman et. al. (2000)		X			Y/N	Farmer	X	X			1	Capacity decisions
Romero (2000)		X			N	Planner	X				1	
Leutscher et. al. (1999)		X	X		N	Farmer	X				1	Operational policies
Stokes et. al. (1997)		X			Y/N	Farmer	X				1	Selling or retain
Aleotti et. al. (1997)	X	X			Y/N	Farmer		X	X	X	1	Preservation technology
Miller et. al. (1997)			X		Y/N	Planner		X		X	1	
Hammer (1994)		X			Y/N	Farmer	X				1	Variety selection
Purcell et. al. (1993)		X			Y/N	Advisor	X				1	
Van Berlo (1993)	X	X			Y/N	Farmer	X	X		X	2	Processing schedule
Annevelink (1992)			X		N	Farmer	X				1	Spatial location
Saedt et. al. (1991)		X	X		Y/Y	Farmer					1	Transition planning

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

- U.S. Department of Agriculture, economic Research Service (ERS) (2004a). Fruits and vegetables per capita consumption.
- USDA ERS (2004b) Read meat per capita consumption.
- Cook, R. (2001) The U.S. Produce Industry: An Industry in Transition, Chapter 2 in Postharvest Technology of Horticultural Crops, Adel A. Kader (eds.), University of California Division of Agriculture and Natural Resources, Publication 3311, 2001, pp.5-30.

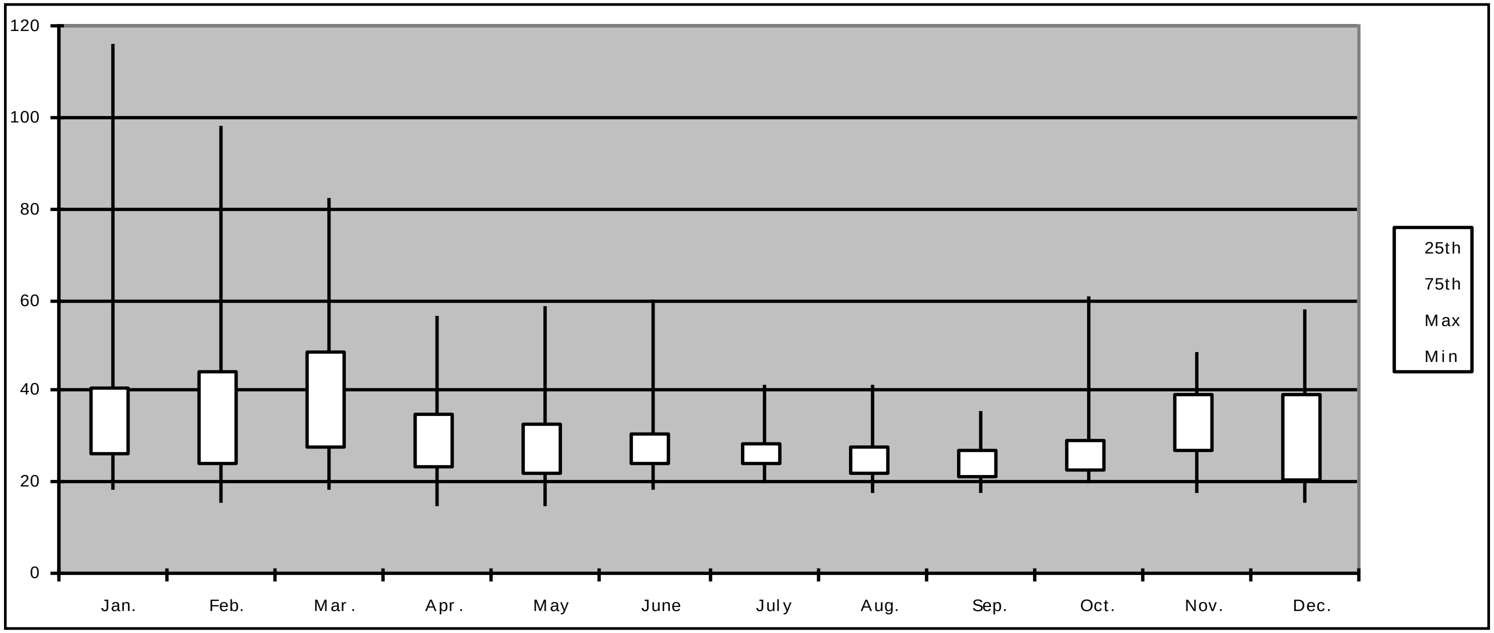
Operational Model

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)



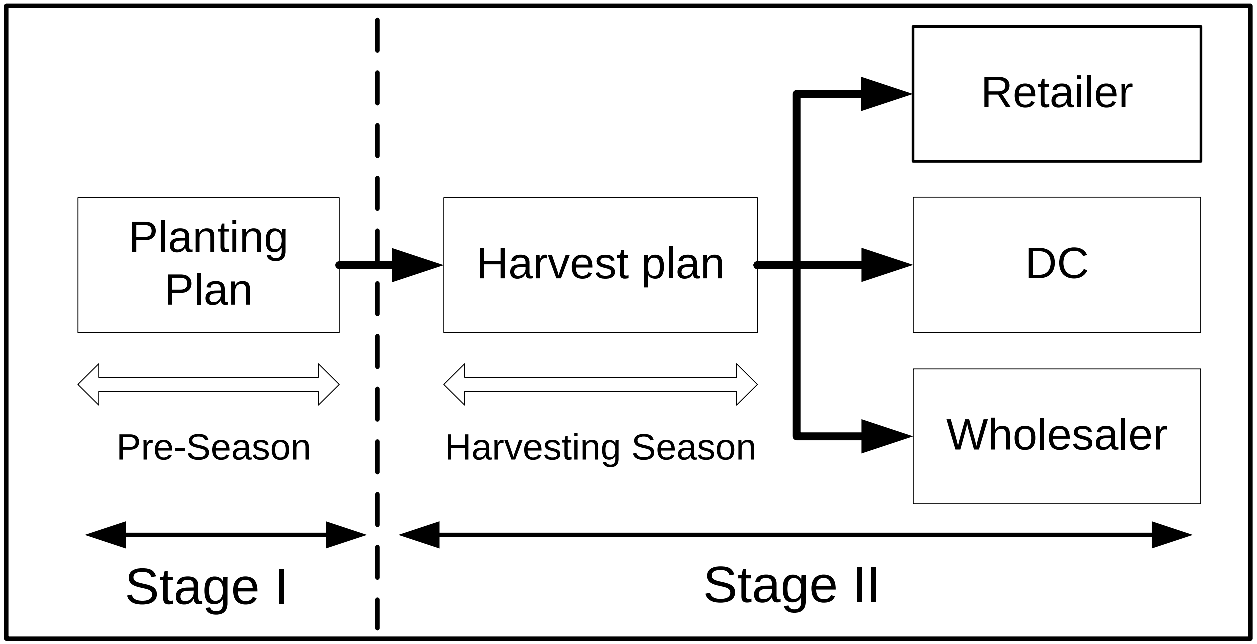
<u>What we have available to make decisions</u>

- Historical distribution of prices (per week)
- Historical distribution of yields (per week)
- Historical and contracted demand from customers

Stochastic Tactical Model

<u>Two-stage stochastic program</u>

- 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

Date	Production	Week 1	Week 2	Week 3	Week 4
1-Aug	X	20%	30%	25%	25%

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

	Y_1	Y_2	Y_3	Y_4
X_1				
X_2				
X_3				
X_4				

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 in their risk, probabilities and benefits.

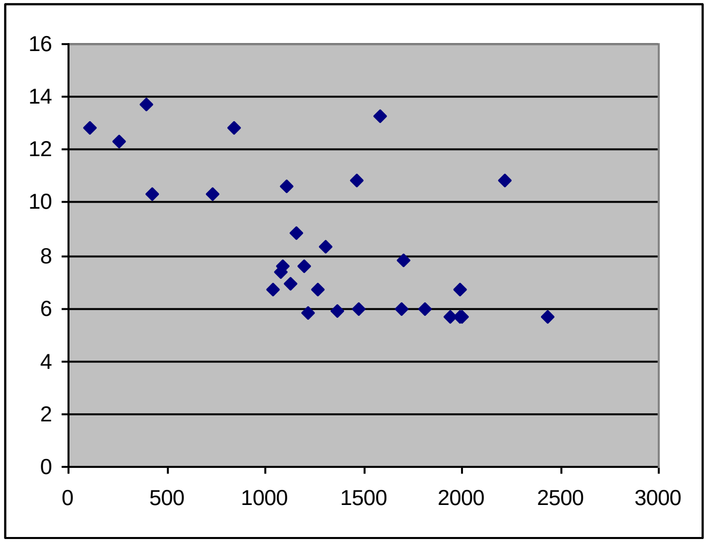
Tactical Model

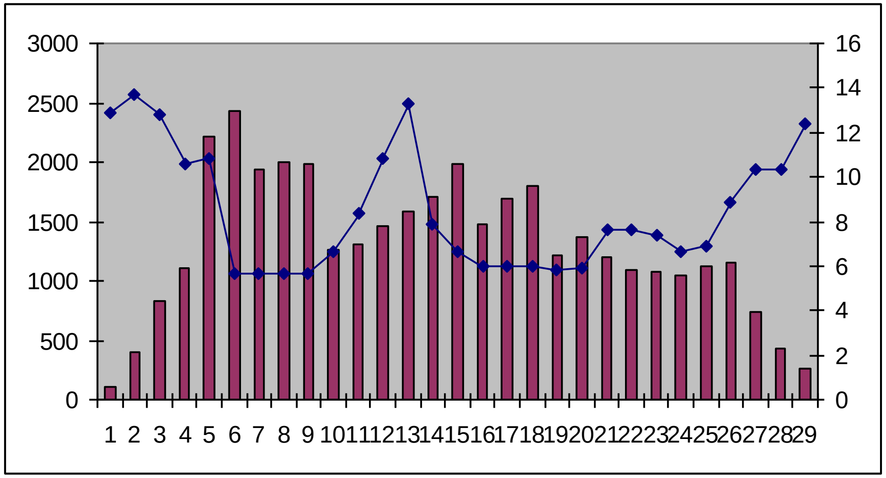
<u>What we have available to make decisions</u>

- 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

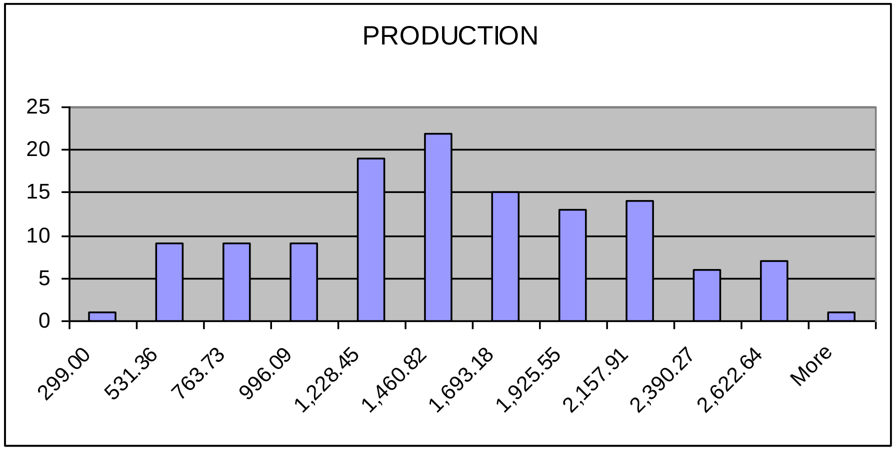
Scenario Development

Prices vs Production of Season 2002





Data for Seasons 2001-2005



Scenario Development

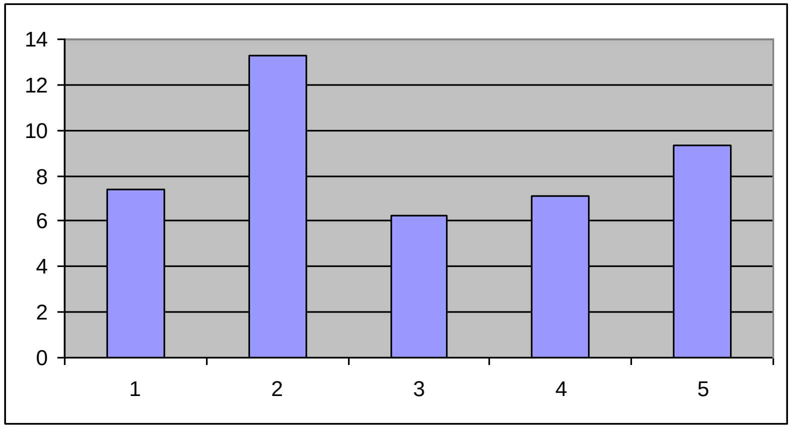
Joint Probability

	PRODUCTION					
PRICE	**500**	**1000**	**1500**	**2000**	**2500**	**More**
6	-	0.03	0.07	0.11	0.02	-
8	0.02	0.04	0.13	0.09	0.04	-
10	0.02	0.02	0.06	0.02	0.02	0.02
12	-	0.03	0.04	0.01	0.02	-
14	0.01	0.02	0.02	0.02	0.02	-
More	0.01	0.02	0.02	0.02	0.01	0.01

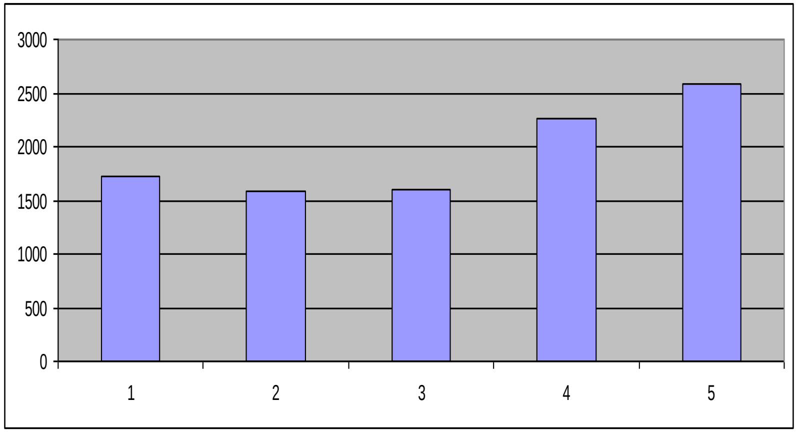
Correlation

	PRICE	*PROD*
PRICE	1.00	
PROD	-0.10	1.00

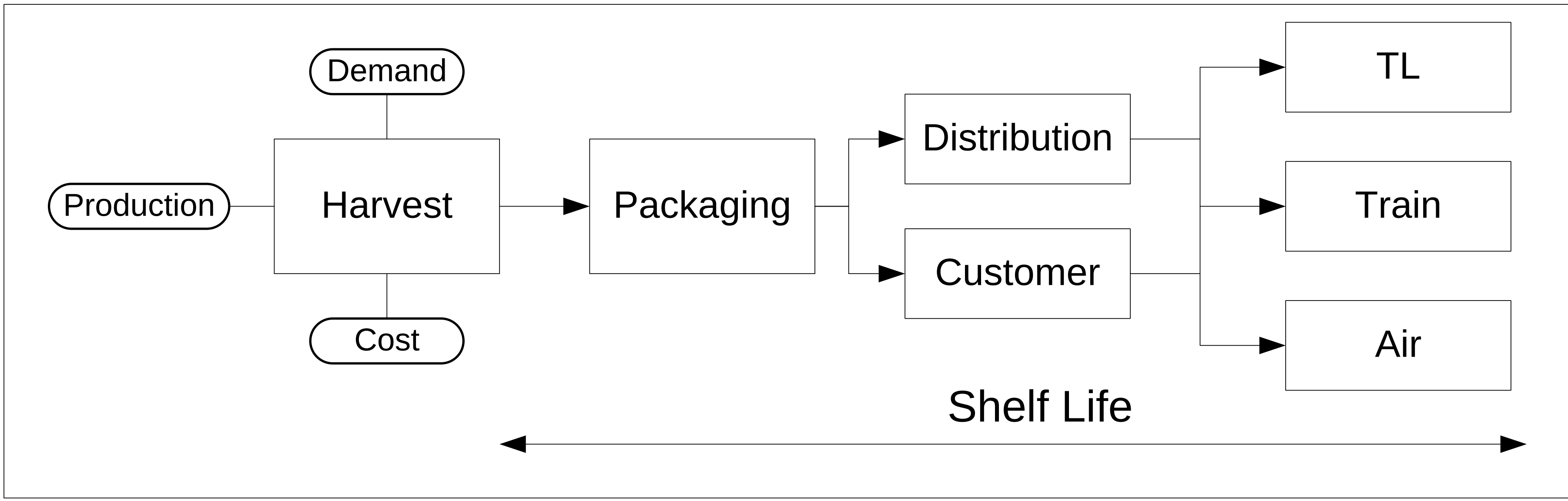
Prices on Week 10

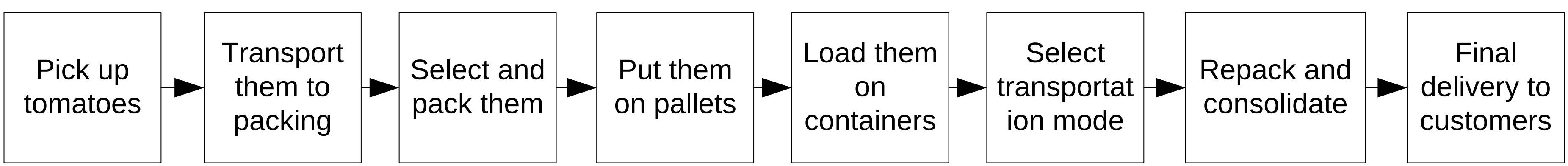


Production on Week 10



Operational Model





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Operational Model

<u>What we have available to make decisions</u>

- 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'