Firms often must make production planning decisions without exact knowledge of demand for their products. Most firms also face some degree of uncertainty in their product supply. This could be due to risk of machine malfunction, variability in ocean shipping schedules, or some other unpredictable supplier or processing related issue. The combined uncertainties in both demand and supply make production planning exceptionally difficult, particularly when customer service is an important performance metric.

A two-stage approach to production planning

A two-stage planning approach, involving optimization and simulation, is developed to aid production managers make the most profitable production plans, while considering all the inherent supply chain uncertainties. The core of the approach is recognizing the existing supply chain uncertainties and quantifying them by estimates of their probability distributions. This could be as simple as identifying the average demand and expected standard deviation of demand, compared to using the point estimates from the sales forecasts. Likewise, instead of assuming supply to be a single predictable number, it may be more realistic to estimate an average and standard deviation of supply, using historical data.
The first stage of the planning approach is to find an optimal production plan for one set of assumptions. These assumptions would traditionally be the average values of demand and supply. By definition, however, the average values have only a 50 percent chance of occurrence. Production managers would be equally well off to fly to Vegas and bet on red. Another common approach is for production managers to adjust their assumptions to be “conservative” or look at a “worst-case” scenario.

Alternatively, a more systematic approach to developing supply and demand assumptions is to start by choosing a point on the estimated probability distributions of these random numbers that corresponds to a given level of certainty (Figure 1). For example, historical data or best guesses can be used to estimate that “95 percent of the time supply will never fall below 20 units a day.”

![Figure 1: Example of choosing a certainty level on the estimated distribution of yield](image)
Using certainty levels to define each of the random inputs is essentially scenario planning, and allows an optimal production plan to be found with a mathematical model, such as a linear program or a mixed integer linear program.

In the second stage of the planning approach, the optimal solution from stage one is a fixed input into a simulation model. The simulation incorporates the truly random nature of demand and supply, as quantified earlier. The observed distribution of outcomes from the stage two simulation indicates the robustness of the stage one solution. Specifically, if the desired levels of customer service or profitability are not reached, the stage one model can then be re-optimized with different certainty levels, to give a better solution. This process is repeated until the minimum service level or profit requirements are reached (Figure 2).

Figure 2: Overview of two-stage planning approach
The two-stage planning approach is designed to improve the precision of production planning by recognizing the inherent uncertainties in the system and compensating for them in the most economically efficient manner. To test the approach against current risk management practices, the two-stage approach was applied to a premium fresh produce supply chain.

Background on premium fresh produce

Trends in consumer preferences and production innovations are changing the agriculture and food marketplace. There are an increasing number of differentiated food products that appeal to specific consumer values, such as environmental-friendliness or locally grown. Furthermore the success of specialty retailers, such as Trader Joe’s® and Whole Foods Market®, demonstrates that high-quality high-margin agriculture can be sustainable and successful in mainstream grocery retail.

The growth of successful niche agriculture markets brings both opportunities and risks to agriculture and food supply chains. The opportunity to differentiate agriculture produce and earn price premiums provides a welcome alternative to producers who lack the scale to compete effectively in commodity markets. On the other hand, high product value and limited market demand creates greater incentives to avoid under or over-supply situations. These premium fresh produce supply chains must balance customer service requirements against costly agriculture production investment. Targeting a specific quantity of demand makes production planning particularly challenging, given the inherent biological and environmental uncertainties in agriculture.

1 Trader Joe’s® and Whole Foods Market ® are registered trademarks of the respective companies
The case of a premium tomato

The suggested two-stage planning approach is applied to a U.S. based premium-branded tomato production and marketing venture, forthwith referred to as “MaterCo.” The tomatoes marketed by MaterCo are grown under strict controls and protocols, segmented through the supply chain, and only sold at select retail locations. The value offering from MaterCo to the grocery retailer is consistent high quality, including superior taste, full traceability, environmental stewardship, good agricultural practices employed on the farm, and retail-merchandising support. The premium-branded tomatoes from MaterCo are referred to as “SuperT”.

The suggested two-stage approach is used to improve the matching of supply to demand by MaterCo’s production managers, by focusing on the following supply decisions:

- How many acres to plant
- Where to plant
- What times to plant.

In this case, the two-stage planning approach uses a mixed integer linear programming and Monte Carlo simulation to develop a production plan. Output from the optimization model is sequentially input into the simulation to provide management with information on expected profit and customer service levels at the grocery retail distribution centers. The models are formulated to incorporate uncertainty in demand, yield, and harvest failure (inability to harvest in a given week due to environmental or logistical constraints).
The outcome of the approach is an annual production plan for tomato production that meets minimum customer service requirements, while optimizing profit.

By recognizing customer service as a planning goal, the suggested two-stage planning approach takes a unique holistic supply chain view for agriculture production planning. Increasingly, agricultural production managers must understand and consider the needs of their downstream customers. In addition, instead of trying to define a particular production manager’s optimal solution based on their perceived risk preferences, the suggested two-stage planning algorithm allows production managers to determine their own acceptable risk levels.

Testing the approach

To test the validity of the proposed approach, it is important to understand how current supply decisions, i.e., production plans, are made within MaterCo. Similar to other agriculture-based businesses, planning decisions are made primarily with industry accepted heuristics and knowledge based on past experience. Though risks are recognized and managed under the current decision-making systems, they are seldom quantified enough to be used in making even more effective decisions.

MaterCo currently uses point forecasts for sales and demand as base inputs into their production planning model. The SuperT sales forecasts are extracted from the business plan. The weekly yield forecasts are derived from the average yield of growing trials. To account for yield variability from week to week and the uncertainty of a large scale crop
failure because of unpredictable weather, a common heuristic used by production
managers is to plant redundant acreage.

In stage one of the approach, optimizations are run for various certainty levels of demand
and yield, as well as using the average yield and demand, to represent current practices.
The runs performed in the analysis are shown in Figure 3.

<table>
<thead>
<tr>
<th>Run</th>
<th>Demand and Yield Certainty Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Avg Yield and Demand (DCL = 50%, PCL = 50%)</td>
</tr>
<tr>
<td>A2</td>
<td>Same inputs as A (with acreage output doubled)</td>
</tr>
<tr>
<td>B</td>
<td>DCL = 70%, PCL = 70%</td>
</tr>
<tr>
<td>C</td>
<td>DCL = 75%, PCL = 75%</td>
</tr>
<tr>
<td>D</td>
<td>DCL = 80%, PCL = 80%</td>
</tr>
<tr>
<td>E</td>
<td>DCL = 85%, PCL = 85%</td>
</tr>
<tr>
<td>F</td>
<td>DCL = 86%, PCL = 86%</td>
</tr>
<tr>
<td>G</td>
<td>DCL = 87%, PCL = 87%</td>
</tr>
<tr>
<td>H</td>
<td>DCL = 88%, PCL = 88%</td>
</tr>
</tbody>
</table>

Figure 3: Optimization runs tested

The solutions from the stage one optimization are run through a simulation where they
can be evaluated on two primary dimensions: profit to MaterCo and Type I Customer
Service Level (percentage of weeks where demand is met in full at the grocery retail
distribution center). To represent the doubling heuristic (A2), the planted acreage
suggested in Run A is doubled before simulation.

Results

The more sophisticated two-stage risk-incorporating approach demonstrates significant
saving to MaterCo, when compared to the doubling heuristic. An acceptable level of
customer service, defined as 90 percent, is achieved with 20 percent less planted acres, and almost three times as much profit than the industry heuristic of doubling the acreage (Figure 4).

![Mean Profit vs. Mean Type I CSL](image)

**Figure 4: Results of simulation**

Figure 4 shows how the mean profit decreases as mean customer service levels are increased. The highest profits are observed for the lowest customer service levels. The graph also illustrates the gap in service levels and profitability between the production plan based on expected (average) demand and yield and the risk-inclusive optimizations. Though the profitability is most attractive when no risk measures are taken, the customer service levels are not realistically acceptable.

Intuitively, the risk of poor service to the customer decreases as the planted acreage base increases. Nevertheless, as the customer service level increases, the profitability
decreases because a higher level of production is required to service the tails of the demand distribution and to compensate for the tails of the yield distribution. This reinforces the importance of finding the right balance between customer service and profitability.

Given a minimum customer service level of 90 percent, the optimal production plan suggested from the two-stage approach is from Optimization Run H. This production plan achieves at least 90 percent customer service with the least amount of acres. Compared to the doubling heuristic, the mean profit from Optimization Run H is approximately $40,000 more (almost three times as much). Therefore, higher profitability can be achieved in this instance using the suggested production planning approach and models, versus the simple doubling heuristic.

Summary
The research presented demonstrates that MaterCo, or similar firms, can save unnecessary production expenses by using the suggested two-stage planning approach while still providing acceptable service to their retail customers. With better understanding of the trade-off between profitability and customer service, MaterCo can also make more informed promises to customers.

The suggested two-stage planning approach is simple enough that production managers can easily scale their models to include more uncertainties, or more decisions, without
complex statistics. It is an approach that is capable of widespread application in agriculture supply chains, as well as other situations of uncertain supply and demand.