

OPTIMIZING MONSANTO'S SUPPLY CHAIN UNDER UNCERTAIN DEMAND

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Introduction

Every production company's desire is to produce at a competitive cost while capturing a significant share of market demand, so that reasonable profits are obtained. The industry where Monsanto's Crop Protection business unit competes has faced a rapidly changing market environment in the last few years. Although gross margins remain significant, it is becoming very clear that solely making product available for sale will not be good enough to compete in the future. In the agricultural inputs business, channel and end-use customers are becoming less and less willing to accept costs of doing business that result from inadequate supply chain practices. Monsanto's past and present successes result from technology and market development, but recently there has developed the realization that changing market supply conditions could foster new competitive advantages and threats. As a market leader, introducing new products, creating unique marketing programs as well as developing new distribution have been part of the Monsanto's strategy in recent years.

This paper analyzes changes in Monsanto's supply chain that are occurring as Monsanto services the present and prepares for the future. An optimization model was created in collaboration with Massachusetts Institute of Technology (MIT) and was undertaken to understand how current production, distribution and marketing practices should be adapted to take full advantage of new channel configurations. To analyze the impact of these changes, production, distribution and demand have been modeled using a linear programming model. A personal computer based model was developed to explore how changes in distribution affect manufacturing and vice versa.

Monsanto Crop Protection

Monsanto Co. is a large multi-national with headquarters in the USA. One of the main engines of the concern is the Crop Protection business. Although quite profitable, it became clear in the 1990's that a well integrated supply chain was becoming crucial for effective operation of the business. Consolidation within the channel could eventually lead to more power in the hands of the buyers who would likely demand products at the lowest prices. Obviously, the cost lever would become critical in later product life cycle stages.

At the same time, the MIT Integrated Supply Chain Management consortium was looking for an opportunity to learn about key operational challenges in process industries and to develop new approaches to deal with the challenges. Therefore, the match between Monsanto's need and MIT's concern led to the birth of this project.

Monsanto's Crop Protection business is very successful. It is considered the industry leader particularly in profitability margins. The main products are herbicides for corn, soybeans and wheat. Monsanto has products in three families of active ingredients:

glyphosate, found in Roundup Ultra^R
acetanilides (acetochlor, alachlor and propachlor) found in Harness^R and Lasso^R
triallate, found in Fargo^R and Avadex^R.

There are three major manufacturing facilities in the USA. Two of these produce glyphosate products, while in the third, acetanilide and triallate products are manufactured. In each of the plants, most of the capital is dedicated to the manufacture of the Crop Protection products, that is Monsanto does not produce products for its other business units using this equipment. Another philosophy of operation is level production. This is dictated in some measure by the fact that the season for several of the products is about 2 months long. The capital investment to manufacture all needed product during a 2 month period would be prohibitive.

Most of the products are formulations of the active ingredients. The majority of the end-use product volume is liquid. Product is sold as either bulk liquid or is packaged in several different sized containers. These container sizes range from 1 to 120 gallons. The bulk liquid is moved to retailers who have tanks with capacities of 1000-5000 gallons. These retailers then repackage product for their end-use customers.

Supply Chain Issues

Products are sold by Monsanto to the channel which in turn sells product to the end-use customers. The end-use customers are farmers, industrial users and government agencies (such as highway departments). The channel is composed of a mixture of distributors, wholesalers and retailers. Many of the distributors now own their own retailers and also service independent retailers in a wholesaling function. For the most part, the movement of the herbicide products is very seasonal. This reflects the use patterns for the products which are usually applied immediately before or during cropping seasons.

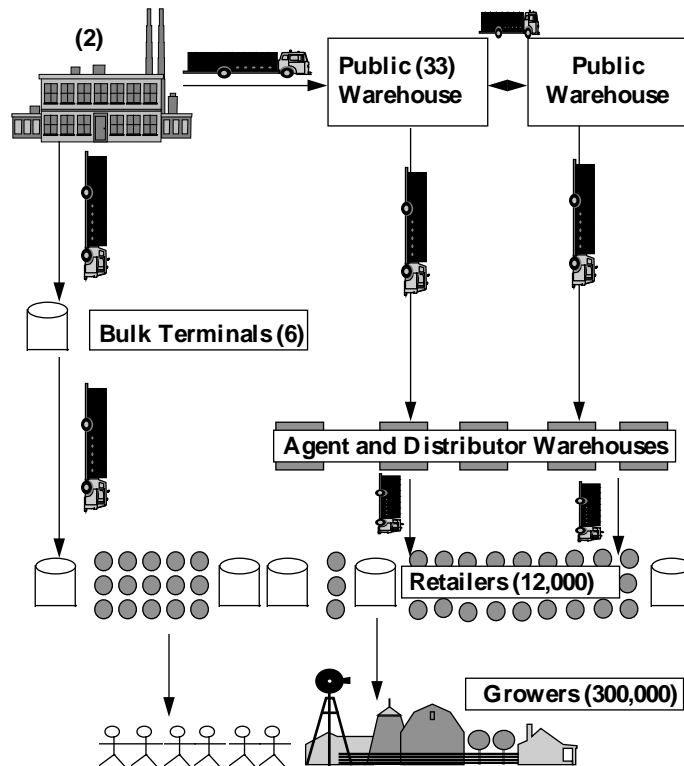
Package product is produced at the plants and then shipped to several different types of storage or redistribution locations. The plants have very little finished goods storage capability. This results from an old operating philosophy in which it was deemed necessary to produce and push product into regional storage locations. Recently, several solutions were formulated to deal with the lack of plant storage. For example, distributors have been enlisted to use storage space at their warehouses for seasonal storage of products. The product is consigned and the "Trade Partners" are paid for use of underutilized space. Another benefit to the Trade Partners is that they have product available "instantaneously".

Another solution to the level production problem was to ship directly from the plant to retailers. Retailers participating in this program were compensated for their efforts. Thus, a portion of the overall cost savings was passed into the channel in the hope that this would help to make the products more price competitive.

Bulk product has been moved directly to retailers for years. In this situation, product is shipped to the retailer's bulk tank under consignment in the off-season. Billing occurs in the season and refills to the retailers can be shipped directly from plant production (if in progress) or from storage at terminals. Many of the products can be stored over the winter in the cold climates, so this program generally works quite well and reduces the amount of three step distribution dramatically.

When the project started in 1994, the supply chain was executing many non-value added activities (see Scheme 1). The plant produced product and needed to ship almost all finished goods immediately to a storage point. The storage point was either terminals for bulk product or public warehouses for package product. Although a significant amount of bulk product has always flowed directly to retailers, virtually no package product moved directly from the plants to retailers. Instead, the product was shipped from the public warehouses to an agent/distributor warehouse. The agent/distributor then transacted with the retailer, so there were not only several cost-adding steps, but there was a loss of inventory information to Monsanto very early in the process.

SCHEME 1



The products made by Crop Protection are sold into highly competitive markets. With maturation, consolidation and the advent of the biotechnology era, the number of input options available to the end-user is increasing. This adds to the complexity of the business. The markets have always been weather dependent in terms of timing. For example, planting time might vary by several weeks in a specific geography, but the number of acres planted usually didn't vary by more than a few percent. Therefore, the only important issue for Monsanto or its competitors was ensuring that enough product was available. Now with a multitude of products and new techniques, it is possible to pick and choose; price can become a very large factor in the decision-making process. Therefore, the convolution of weather and market effects makes this a very difficult business to forecast, especially at the SKU level. Since many of the products are produced well in advance of the season, the complexity is compounded since as in any business, early forecasts contain a tremendous amount of variability. From the vantage point of the sales function, all products are important to customers and all margins are very healthy, so it is not acceptable to run out of any brand or SKU.

Another compounding factor at the time the project started was introduction of the acetochlor products, Harness, Harness Xtra and Harness Xtra 5.6L. These products are members of the acetanilides product family and are in many cases direct substitutes for alachlor products, Lasso, MicroTech, Bullet, etc. Both sets of products are manufactured at the same plant using common equipment, so supply chain complexity increased again.

Previously, forecasts were developed in headquarters and then used as gospel throughout the production and sales season. The entire supply chain effort was geared toward making successful a marketing forecast plan that may have been formulated six to nine months ahead of actual sales. The plan usually only changed for SKU's that were produced in season and then only if there was anecdotal information that might influence this process. At the same time, the manufacturing schedule for finished goods was largely driven by the production plan for active ingredients. The active ingredients are produced year around. Although some of this production is used to fulfill worldwide demand needs, finished goods for the USA business were usually produced simultaneously with the active ingredient production. Since there were minimal storage capabilities at the plants, the distribution function used a loose process in which product was shipped to any and all points near where the product might be sold.

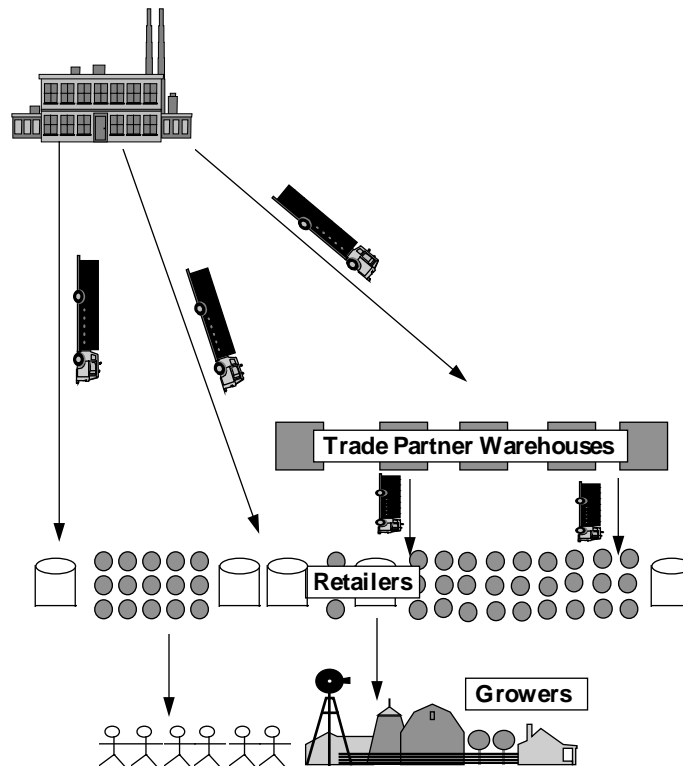
Excess product might be produced because it was campaigned early. Worse, not enough product was produced, because the forecast failed to estimate a market effect that occurred in season. Then distribution might send the product to what would become the "wrong" site and a costly redistribution of product needed to occur.

Recent Developments

In the last year, a new business process and system was developed and installed that allows the sales force to develop forecasts at a local market level. Although the process is new, early results indicate that it will be very beneficial for operating an integrated supply chain. The uncertainty of demand is and will always be an issue, but the timeliness (weekly) of disaggregated reports of demand changes allows the supply chain to be run more effectively. Indeed one of the major results is that the manufacturing function works with the distribution function in integrating the production and distribution plans to forecast demand on a weekly basis. This results in a much more credible business approach.

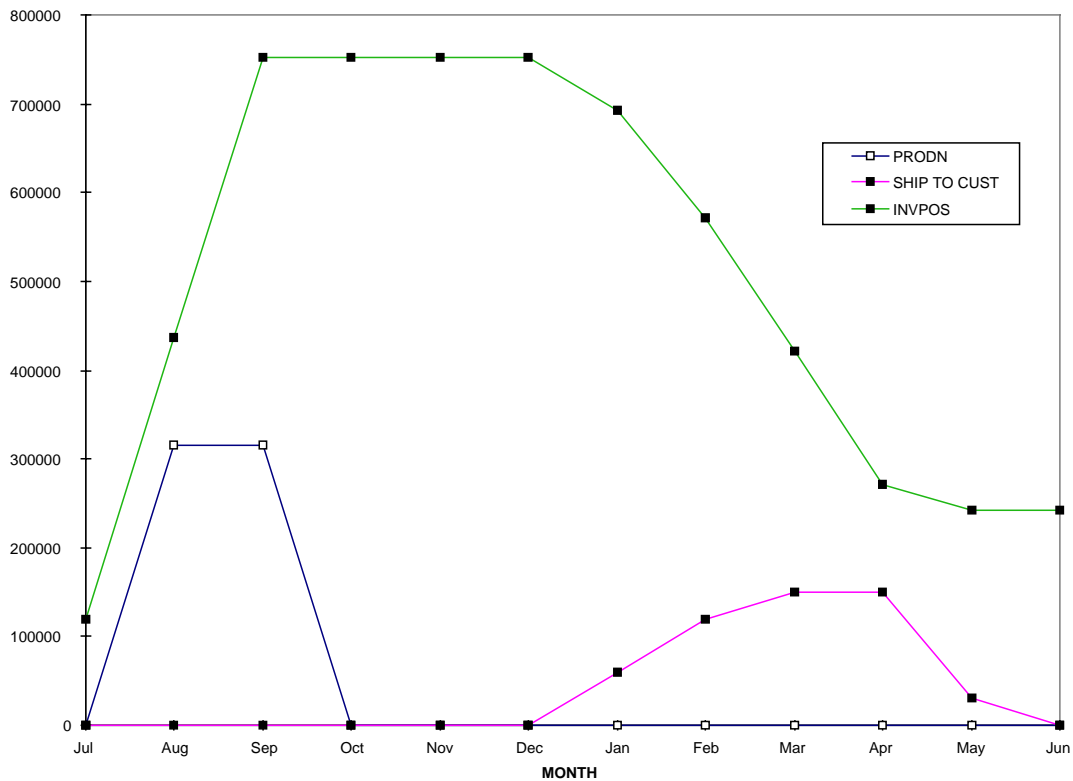
In distribution, one of the ways that the company and the channel could improve is via direct shipments to Trade Partners and retailers. Increases in direct flow (avoiding excessive use of public storage) could result in cost savings of \$0.03-0.06 per pound of shipped product. Some of these cost savings will be passed along to the end user, so the improvement in supply chain management will result in a more competitive market position. This system is depicted in Scheme 2. It should be clear that this is a simplistic representation of the future state. There will always be a need for buffer stocks to be held at intermediate storage areas. Reasons for this are manufacturing constraints in line-time that cause pre-building, safety stocks accumulation, etc.

SCHEME 2



The paradigm that allowed many products to be manufactured early and only once was also examined. If the selling season occurred in the Spring of Year 2, a specific product might be manufactured 8 months earlier in the Fall of Year 1. This was the result of line time constraints and the need for level production vs. higher capital investment for instantaneous capacity. Although it was and is clear that additional capital investment is unwarranted, the resulting plan allowed very little flexibility downstream from production. There was very little postponed production and few changeovers between SKU's due to the functional need to reduce manufacturing costs. Consequently, a significant amount of product was pushed to the wrong place and had to be shifted as demand occurred months later. As shown in Chart 1, the consequences for the system could be even more traumatic than distribution costs.

CHART 1

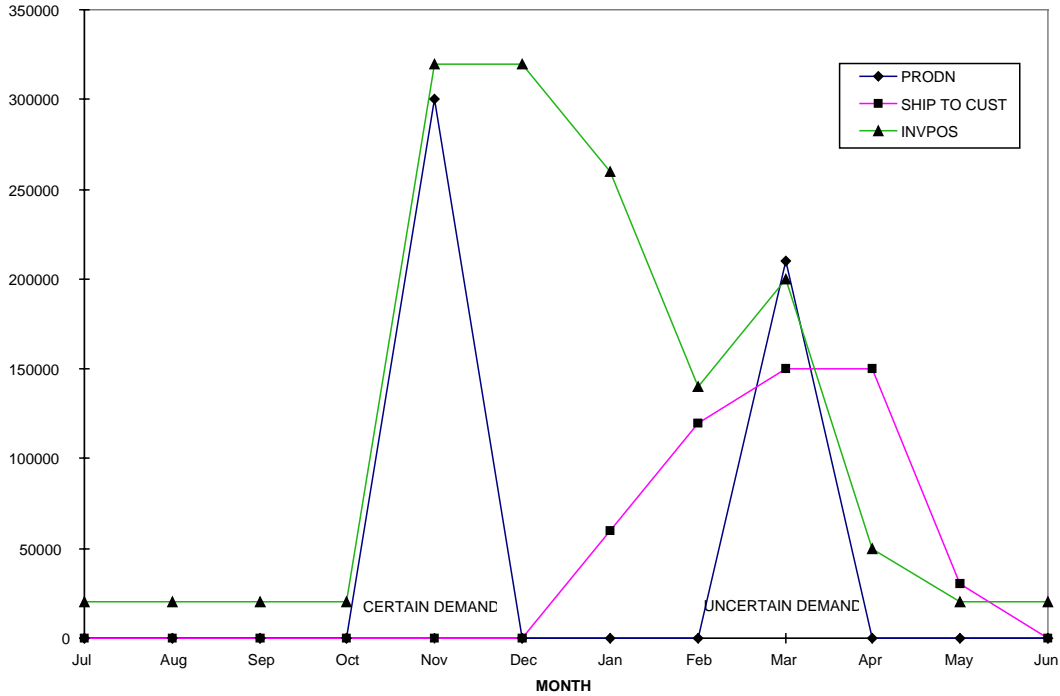


As shown, product along the SHIP TO CUST line moves with demand from December to June. However, product to support the demand is manufactured in July through October as shown on the line labeled PRODN. The implications of this are that managing working capital becomes an exercise fraught with luck and disaster. In Chart 1, the “season” starts with a significant amount of inventory shown on the line INVPOS, about 125,000 gallons. Worse, the season ends with about 250,000 gallons of inventory. In this case, there is overproduction presumably based on a high forecast number. This situation translates into a high working capital charge, particularly since in Monsanto’s business, the inventory needs to be carried for at least 15 months. The most catastrophic situation results when the forecast is too low. There are stock outs and it’s likely there may not be recourse to produce again in season. The cost for this problem is gross margin of each unsold gallon and this is never captured on the income statement or balance sheet.

A better proposition and one that Monsanto is moving towards is the concept of “postponing uncertain demand”. This concept is depicted in Chart 2. In this case, demand remains the same both in amount and timing. The difference is that production is cut into two portions. The first portion is product manufactured in October through November. The amount produced at this time is known as “certain demand”. It is demand volume that planners feel has a very high probability of being sold in the coming season. The

second portion of production occurs in the selling season. This production occurs from February through April. This portion fulfills the need for the “uncertain demand”, that is the demand volume that was forecasted in the original plan, but which planners feel may or may not be sold. In reality, this portion of demand becomes very real during the season when the sales force understands the market and weather dynamics better and sales orders are flowing from customers to Monsanto.

CHART 2



The latter proposition allows everyone’s needs to be satisfied. The customer gets a better deal in the long run, because prices reflect lower costs (due to reduced working capital and distribution charges). Also, there are significantly fewer stockouts, so the customer has a more reliable source of product. The manufacturing function prospers, because the reduction in working capital pays for additional costs due to increased changeovers. Since this is only one of many products that may be produced on this line, it can still be scheduled throughout the year thus filling the need for level production with low capital investment. Finally, the distribution function prospers, because there are more opportunities to ship product directly to customers and less probability that product will

have to be moved from warehouse to warehouse. This is the direction Monsanto is heading, particularly for the products that have but one selling season every year.

Project Overview

To implement some of these ideas effectively, it appeared that the problem was too difficult to tackle heuristically. There was a need to look at the entire supply chain and analytically determine when product should be made within the constraints and where it should be distributed based on the demand uncertainty. Thus, Monsanto embarked on this project with MIT to “solve the problem”.

The mission of this project was to develop and apply a model of the production, inventory and distribution network to guide strategic level decisions about Monsanto's Crop Protection business. The project was conducted by a cross-functional team from Monsanto and from MIT, under the auspices of the Integrated Supply Chain Management consortium at MIT. The project started in May 1995. In the initial phase we focused on modeling the production and distribution of two product families for the US market. Over the summer of 1995 we built and validated a model for this portion of the Crop Protection business; a series of analyses were performed with this model in the fall, 1995. Gutierrez (1996) provides documentation for both this model and its application. Based on the success of the initial phase, over the course of 1996, the model was extended and enlarged to encompass virtually all of the production and distribution for the North America Crop Protection business.

Goals of the Model

There are several goals for the model.

Create a robust tool to validate and/or challenge current production, distribution, and marketing practices, policies, and heuristics. As in many companies, decisions taken in production, distribution, and marketing are not always based on a system perspective. Cost-benefit analyses are generally performed within each department. But functional barriers do not encourage analysis beyond these departmental barriers. The model allows the firm to analyze current practices, policies, and heuristics, as well as identify new ones, from the perspective of the entire company.

Develop a model-based tool that will rationalize production cycles. Production has used a strategy of manufacturing each product once a year, where only a fraction of the products can be produced during the season. Given the forecasting uncertainty, the logical strategy is to overproduce those products manufactured ahead of the demand to diminish the risk of lost sales. A consequence of this manufacturing strategy is the risk of having high inventories at the end of the season, due to the forecast errors.

In this context, the model should help to understand the potential benefits of producing two batches instead of only one. With two batches, it may be possible to adjust production according to new information about demand so as better to balance the risk of

lost sales versus the risk of high end-of-season inventories. The model can also guide decisions on which products should be manufactured first and then stored.

Understand the best positioning of inventory across the supply chain. End-of-year and seasonal inventory has been placed in centralized (plant storage locations) and decentralized (public warehouses and terminals) storage locations. The model can help to understand the impact of centralizing versus decentralizing inventory.

Assess the impact of changes to the configuration of the supply chain. Changes in the distribution network have increased the need for a responsive production plan. The removal of several echelons in the supply chain has reduced overall storage capacity. The shift from storage space at public warehouses to trade partners is one example.

The model can help to understand the real need for intermediate storage locations, and the benefits from increased storage space at the plant.

Incorporate forecasting uncertainty. Forecasting in the Crop Protection business is a very complex process, and substantial forecast errors are a given. One of the model requirements is to optimize production considering several demand scenarios. The different demand scenarios would represent the anticipated range of forecast error. The model can define a single production plan that is the best for a given set of demand scenarios, i.e., for a given level of forecast uncertainty as captured by the demand scenarios.

Identify production bottlenecks. The model can be helpful in identifying production and storage bottlenecks, and especially in quantifying the impact of these bottlenecks on total costs. For instance, with the model we can readily explore how the production and distribution plan, and their costs, change as more capacity is added to the bottleneck. Understanding where the bottlenecks are, and their cost implications, can also help to develop tactics for better exploiting the limited capacity of a bottleneck.

Model Features

To develop a decision support model to address the stated goals requires that we capture the most relevant features of the Monsanto Crop Protection business into the model. However, as with any modeling exercise, there is a tradeoff as to the richness and realism of the model versus the size and complexity. We judged the following features to be essential to this application.

Network Representation of the Supply Chain: We represent the supply chain as a network, where Scheme 3 provides an example. As such, in the network representation we model the production facilities and the storage locations for raw material, WIP, and finished goods as nodes in the networks. The arcs in the network depict both the production process for families of products, as well as their distribution channels. As shown, a production process for a product can visit multiple production facilities, and a product can serve multiple distribution channels.

Multiple Products: The model must plan over multiple products. We characterize products by their raw materials, by their production process, and by their package. For each product we need its raw material requirements, its production rate and cost for each production facility in its process, its space requirements and storage cost, including inventory holding costs, and its transportation costs for each distribution channel.

Multiple Time Periods: The model must cover at least an annual planning horizon in order to capture the seasonal aspect of the business and the need to build inventory year round. Consistent with Monsanto's planning practices, we plan for a year at a time, divided into 12 month-long time periods.

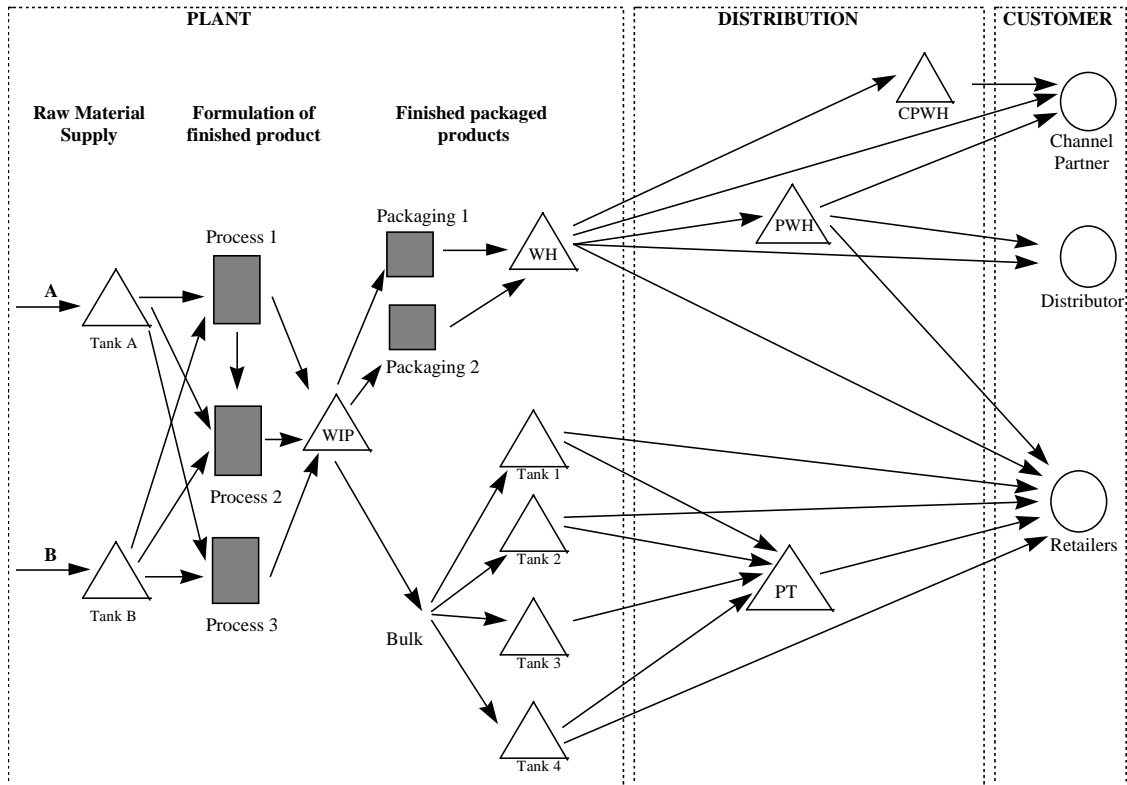
Limited Raw Material Supply: We limit the scope of the model to taking the active ingredient as the raw material for the supply chain. We do not include the scheduling of the production of these raw materials in the model. Rather, we are given as input in the model the schedules for the availability of these raw materials, i.e., for each active ingredient.

Shared Production and Packaging Facilities: A key limiting resource is the capacity for production and for packaging. These resources are shared by multiple products. Furthermore, the capacity level for each of these resources may vary over the year, and the unit cost for each facility may depend on its level of operation; for instance, a one-shift operation will have a different unit cost than a two-shift operation.

Limited Storage: There are a series of storage facilities at the plants and in the field as part of the distribution system. These facilities are characterized by their capacity and by the type of inventory to be stored there (raw, WIP or finished good). They can also be differentiated by the specific products allowed to be stored there.

Multiple Distribution Channels: As shown in Scheme 3, there can be several distribution channels for each product, targeted to a customer class. The transportation and storage costs can vary by channel, as well as the cost for not meeting demand (cost of lost sales).

SCHEME 3



Multiple Demand Scenarios: We require a demand forecast by month for each product for each channel. To capture the uncertainty in the demand forecasts, we allow multiple demand scenarios to be input to the planning model. For instance, there may be three scenarios representing our best guess at demand for the coming year, an optimistic forecast and a pessimistic forecast. Alternatively, the scenarios may depend upon a set of possible weather outcomes, which would influence the timing of the planting season in different parts of the country and hence the product demand. We have designed the model to consider simultaneously the set of scenarios, possibly weighted by their respective likelihood's; with the model we then find a single production plan that best serves the set of possible scenarios, given that we do not know which will occur.

Model Assumptions and Limitations

There are several key, simplifying assumptions required to develop the model. We have tried to set these assumptions so as to ease the implementation and the parameterization of the model without jeopardizing the model's applicability to the goals stated above.

We assume the model will be used for strategic analyses and tactical planning. We have not designed the model to be applicable to operational decisions like scheduling. As such we divide the planning horizon into monthly time buckets, and the output from the model does not have any greater specificity than a month by month plan.

Similarly, given the goals for the project, we do not model the distribution system in the detail that would typically be necessary for operational planning. Rather, in the model we consolidate the distribution system by a high-level aggregation of storage sites, transportation, and customers. We approximate the transportation costs for movements from plants to storage sites, and from storage sites to customers by a weighted average of the actual shipment costs. Whereas from this consolidation we lose the geographic and spatial details of the distribution system, we gain a great reduction in the complexity of the model.

We do not explicitly include the determination of production changeovers in the model. To do so would significantly increase the size of the model, and the effort required to solve it. Rather, in setting the inputs to the model, we must make an assumption about what the changeovers will be and how much capacity will be consumed by the changeovers. Due to the magnitude of the changeover times, this is a major limitation of the model. To overcome this, we need to run the model repeatedly, under different sets of assumptions about the changeover plan.

We do not explicitly represent production uncertainty in the model. To capture demand uncertainty, we have built the model so that it will optimize over a weighted set of demand scenarios. In this way, we can incorporate a range of likely outcomes for the demand over the next year that represents the uncertainty in the forecast. But the size of the model grows linearly with the number of scenarios.

Model Structure and Implementation

We formulated the model as a large linear program. For the initial phase of the project, we modeled the production and distribution of two product families for the US market; to model three demand scenarios entailed a linear program with about 10,000 constraints and 20,000 variables. In the second phase, we extended the model to all of the production and distribution for the North American Crop Protection business, requiring nearly 30,000 constraints and 80,000 variables for one demand scenario.

We have employed commercial optimization software to solve these linear programs. Substantial development effort went into building spreadsheet interfaces for the input and output for the linear program solver, and for developing the data base needed to parameterize the model. Indeed, these efforts were essential in order to produce a transferable application that could be run and maintained after the developers had moved on.

The optimization determines an annual production and distribution plan, detailed by product, month and channel. This plan optimizes a given objective function subject to a series of constraints on the plan, and subject to a given demand forecast or set of demand scenarios.

The objective function for the optimization is to minimize the annual costs to meet the demand for the supply chain. This includes the variable costs for production, the holding

costs for inventory of all forms, transportation and warehousing costs, and the cost of lost sales or unmet demand.

The constraints on the plan include the supply of raw material, production capacity for the various production facilities, and storage space at the various warehousing sites. Given a demand forecast (or alternatively a set of demand scenarios), the model finds a plan that fits within the constraints and that best satisfies the demand.

Gutierrez (1996) provides the specific formulation for the optimization model and details about the implementation.

Outcomes

The outcomes of the project were numerous. A few were qualitative and will be discussed later. Of those that were quantitative, the following are or will shortly be enacted as practices. Examples are:

- 1) Moved a portion of packaging of a brand from one plant to another resulting in a cost reduction of \$300,000.
- 2) Rearranged the production schedule to “find” additional time for production of an important brand. This resulted in an opportunity to service the highside sales volume.
- 3) Switched production timing for two products so that there would be less public storage. The product scheduled for Fall production freezes over winter when stored outdoors. Most retailers have outdoors storage, so shipping the product to them in the Fall was not an option. Another product that had been scheduled for Spring production (due to some relatively artificial constraints) was capable of being stored outside over the winter. Therefore, the two products were swapped within the production schedule resulting in a \$500,000 cost savings.

Lessons Learned

There have been many lessons learned in the performance of this project. Following are some of the important learnings:

- 1) There is tremendous value in defining the project well. It was very important that the goals be clearly defined. The scope was narrowly defined in the beginning so that it was possible to focus on the project process. The project then took an evolutionary route with each successive revision of the model incorporating a new piece of the business process.
- 2) Resources were committed by both MIT and Monsanto. This was clearly a complicated project; without the full-time commitment of people from both concerns, the project would not have achieved the high level of success. This seems obvious, but again, allowing several people to focus on the problem led to many fruitful and unequivocal results.
- 3) Data collection was combined with a business understanding. Had the MIT researchers not been able to explore the Monsanto Crop Protection business process, it is likely that debugging and disputing of the model would still be occurring. In fact, the MIT portion of the project team made some interesting and insightful suggestions about the Supply Chain business process that started several secondary initiatives.

- 4) Thinking about the problem caused a few constraints to be relieved without using the model. This is a key point. The model served as a tool to help analyze the Supply Chain. In the end, its analytical usefulness was key in decisions in which a solution was not apparent or where several solutions appeared almost equal. However, in thinking about certain aspects of Supply Chain and the integration points between functions, it became quite clear that the model was an excellent catalyst for discussions and problem solving sessions, which in the end yielded several solutions without the use of model analytics. The implicit neutrality of the model also allowed these discussions to occur from a company perspective rather than a functional perspective; that is, the model is non-judgmental.

Finally, the model has clearly been an excellent exercise in which Monsanto and MIT have learned a great deal from each other. Monsanto profited in that it was able to get a better understanding of the factors that could make its integrated supply chain more effective. The cost savings are apparent and as the market demands changing mixes of products, the model can be used to help plan for the most effective supply of the portfolio. MIT also benefited in that the researchers were able to provide methodology could successfully answer some very difficult questions in a complex operation.

Acknowledgment

The success of this project depended upon the contributions, hard work and team work from many people, both from Monsanto and from MIT. We would particularly want to acknowledge and thank Sandra Townsend, Sandra Griffith, David Kletter, John Ruark, Sean Willems and Michael Zhang for their help.

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