Supply Chain Planning Decisions under Demand Uncertainty

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Summary: This project developed a three-step approach to analyze and optimize supply chain designs under demand uncertainty. This approach adopts a Monte Carlo simulation and real option analysis method in conjunction with supply chain models. Its spreadsheet implementation was used to analyze ocean shipping plans and inland trucking plans.

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KEY INSIGHTS

1. Spreadsheet simulation can be used as an effective tool to analyze supply chain designs under demand uncertainty and to estimate the value of supply chain flexibility (real option).

2. The value of flexibility to use one ship in a two ship ocean shipping plan can significantly enhance the expected net income of the two ship plan.

3. Simulation and real option analysis can be performed in conjunction with optimization and sensitivity analysis to understand the key variables and to optimize supply chain design.

Introduction

Demand forecasts are typically associated with uncertainty. Deterministic planning models are not well suited for managing uncertainty. Such models may not expose the downside risk and fail to highlight the upside opportunities. Therefore, decision makers need to consider uncertainty explicitly in supply chain planning.

Researchers have also investigated ways of incorporating demand uncertainty in supply chain planning. For example, scenario-based approach models the outcome of each of the discrete scenarios based upon the probabilities of such scenarios’ occurrences. In practice, the probabilities are often the decision maker's expectation that each of the scenarios will occur. The problem of the scenarios approach is that foreseeing all possible scenarios is often difficult if not impossible.

It is well known that a flexible supply chain is better at handling demand uncertainty and disruptions. However, most decision makers found it a challenge to evaluate such flexibility quantitatively. Therefore, supply chain decision makers need a simple tool to evaluate supply chain design options under demand uncertainty and perform optimization under demand uncertainty.
Industry Case: Chiquita Brand International

Chiquita is a major distributor of fresh and packaged produce in Europe and North America. Many of its products are imported to the United States from tropical countries. Chiquita has an extensive transportation and logistics operation that plays an important role in the overall operation of the company. Ocean and surface transportation constitutes a significant part of Chiquita’s supply chain operation. For inland trucking, Chiquita has access to a large number of common carriers with varying availability and costs. Chiquita has also maintained a small dedicated fleet. Particularly for the dedicated fleet, Chiquita receives significant revenue through back haul.

In order to plan for market growth, Chiquita needs to understand the potential demands in the years ahead. However, future demands are affected by many factors and there are significant uncertainties associated with demand forecasts. Companies like Chiquita are interested in how to incorporate the estimated uncertainty of demand forecasts in the supply chain planning decision process.

Monte Carlo Simulation - Value at Risk and Gain Curve - Real Option Analysis using Spreadsheet

The research has applied an engineering evaluation approach developed at Professor de Neufville’s group to analyze demand uncertainty in supply chain planning. This approach was implemented in Microsoft® Excel and used to evaluate supply chain planning decisions for Chiquita. This approach and excel implementation should be useful for supply chain planners and managers.

The three part analysis approach is shown in Figure 1: 1) Estimating demand uncertainty and performing Monte Carlo Simulation to generate a large number of simulated demands; 2) estimating the outcomes of specific supply chain designs (for example, using common carrier versus using dedicated fleet) in terms of net income net present value (NPV), costs or other measures and plotting the outcomes in a cumulative distribution curve (also called Value at Risk and Gain Curve, VARG) for each supply chain design; and 3) performing optimization, sensitivity or other analysis.

Figure 1. Three-Part Analysis of Supply Chain Designs under Demand Uncertainty

Monte Carlo Simulation of Demands

Demand distributions can be estimated in a number of ways. In the case of Chiquita, the supply chain planner supplied estimated confidence of achieving specific levels of sales under conditions not constrained by supply chain (unconstrained demand). After converting the confidence levels to probability distributions, I found that these distributions generally follow normal distributions and therefore, the unconstrained demands can be simulated using Excel’s NORMINV function. Other distributions can also be simulated using Excel or specialized software packages.

Estimating Outcomes of Specific Supply Chain Designs

Models for various supply chain designs can be built using standard analysis approach such as Discount Cash Flow (DCF) analysis. The inputs to the models include the simulated demands. Economic or other measures such as net income NPV, costs, etc. are the outputs of the models. In the case of Chiquita Ocean shipping, this research considered several shipping plans listed in table 1.

<table>
<thead>
<tr>
<th>Table 1. Ocean Shipping Plans *</th>
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<td>Plan 1</td>
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<td>Plan 4</td>
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*Some Data in this thesis are masked to protect confidentiality of Chiquita Data.
For plans 2 and 4, there is the flexibility (or real option) of using one ship instead of 2 ships. Therefore, if the demand is low, Chiquita may decide to use one ship only and save fuel cost. This flexibility has values and therefore plan 2 or 4 with real option should have higher expected net income than plan 2 or 4 without the flexibility. The difference in expected net income of plan 2 versus plan 2 with real option, for example, is the value of the flexibility or real option. In this case, the real option for plan 2 is valued at $3 million on NPV basis.

The real option significantly shifted the VARG curve of Plan 2 to the right, particularly at the lower end, which improves net income. Comparing with Plan 2, the net income of Plan 2 with real option reduced the low end risk.

**Optimization under Demand Uncertainty**

The parameters of the supply chain models above can be easily optimized using Excel Solver. For example, Chiquita’s trucking plans (common carrier versus dedicated fleet) were also evaluated using the Monte Carlo simulation analysis. Figure 4 shows the distribution of trucking costs of various trucking plans. Dedicated fleet has a lower cost than common carrier, but a combination of a small dedicated fleet and the use of common carriers offer the lowest overall costs. This combination is optimized using Excel® solver.

**Sensitivity analysis: Effect of Fuel Cost**

One of the biggest downside risks for ocean shipping is the increase in fuel costs. Therefore, we conducted a sensitivity analysis with regard to fuel cost increases. Fuel cost has a major negative impact on net income. As fuel cost increases, the value of the real option increases significantly which makes Plan 2 much better than Plan 3 (Figure 5). Therefore, plan 2 with the ability to use one ship can be a good choice if Chiquita expects that there is significant risk of higher fuel cost in the future.

The outcomes are plotted in the form of distribution and cumulative distribution (CDF or VARG curve). Figure 2 shows the comparison of the distributions of net income under different shipping plans.

![Figure 2. Net Income Distribution](image)

Figure 3 focuses on the VARG comparison of Plan 2, Plan 2 with real option, and Plan 3.

![Figure 3. VARG curve for Ocean Shipping Plans 2 and 3](image)

![Figure 4. Trucking Costs](image)
Figure 5. Effect of Fuel Cost on Option Value of Plan 2

Conclusion

One core question of this research project is how estimated uncertainty of demand forecasts can be incorporated into the supply chain investment decision process. The result of this research illustrates that the Monte Carlo simulation, real option analysis and Value at Risk and Gain analysis approach developed by Professor de Neufville’s group at MIT can be an effective approach. Simulated demands according to the estimated uncertainty can be readily generated using spreadsheets that managers are familiar with. These simulated demands can be inputted to supply chain models to obtain output variables of interests, such as net income, costs and carbon emissions. Value at Risk and Gain curves (VARG) provide a graphic view of how these output variables behave. Supply chain designs and plans can be compared using VARG curves. Real options in the systems could be identified and their effects on the interested variables can be examined using this approach. Some parameters can be optimized based upon the simulation results as well.

Success of this approach in businesses will likely depend upon how managers of different functions view risk and uncertainty and whether they seek to actively manage uncertainty. Many of the parameters, particularly demand distributions, are estimated with many assumptions. To make this approach truly effectively, various corporate functions will need to collaborate extensively.