Financial Risk Management for Investment Planning of New Commodities Considering Plant Location and Budgeting

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The classical capacity planning problem considers the determination of the initial capacity for a particular network of processes and the timing and size of the future expansions. The data used for such a model are the forecasted demands and prices of raw material and products, as well as the utility costs. This paper expands the problem to also consider plant location, transportation of raw materials, and transportation of product to consumer markets. We also add budgeting constraints, which follow the cash flow through the life of the project and allow the project to finance the expansions. Finally, we add considerations about the price of the product in different markets. To illustrate the technique, we consider the case of ethyl lactate, a green solvent. The model was made stochastic, and financial risk is managed.

Introduction

Several researchers have introduced the planning of process capacity expansions. Old references have been surveyed by Luss.[1] More recently, the following work can be cited: Murphy et al.,[2] Sahinidis et al.,[3] Eppen et al.,[4] Berman and Ganz.[5] A formal two-stage stochastic model for capacity planning in the process industry was presented by Liu and Sahinidis[6] as an extension of the deterministic models developed by Sahinidis et al.[3] Ahmed and Sahinidis[7] presented a method to obtain robust solutions, and Eppen et al.[4] and Barbaro and Bagajewicz[8−10] discussed its financial risk management, contract, and inventory issues. Finally, Ahmed and Sahinidis[11] discussed solvability issues.

One of the limitations of the original formulation of the capacity planning problem is that location issues were not considered explicitly, or the facilities locations were predetermined. Thus, when considering operating costs, transportation of raw materials and products from and to their corresponding markets were not explicitly modeled. Nor were local labor cost, taxes, and other location dependent costs modeled explicitly. Not only one would want to locate a plant in a place that is optimal from the transportation of raw materials and products from and to markets point of view, but one would also want to take into account local conditions such as labor costs, taxes, and so forth, while at the same time picking the right markets from the demand and price point of view. Clearly, one cannot choose any of these independently. They need to be considered all together in one single integrated model. Finally, capacity planning models do not follow the cash flow of the project and consider capital as an external source for investments on expansions. In reality, many times such expansions are financed by the project itself. In this paper, we present an integrated model that considers all these aspects simultaneously and under uncertainty.

Capacity Planning Problem

We used the two-stage stochastic model presented by Liu and Sahinidis,[6] which is an extension of the deterministic mixed-integer linear programming formulation introduced by Sahinidis et al.[3] The complete set of equations corresponding to this model can be fetched from the original article.

To this model we have added the cost of transportation from the raw materials markets and to the final product markets. We model these proportionally to the amount transported, although fixed costs, as well as multilinear models, can be easily also added. We also considered a different set of locations for each plant, and we considered multiple plants producing the same product. These details are not a part of the original capacity planning problem.

Finally, we added budgeting constraints that follow the cash through the project life, and we use some of it to reinvest them.

Mathematical Formulation

The sets used are the following: (i) I, plants (including their locations); (ii) K, raw materials; (iii) J, markets; and (iv) T, time periods. The variables and parameters are introduced together with the equations.

Objective Function. The net present value (NPV) is maximized. NPV is constructed by counting proceeds of the project (i.e., cash effectively returned to investors each period; P_t) minus capital investment in each period (TCI_t), plus salvage value (V_S)-In this objective function, L_t is the discount factor for period t.

$$\max \mathrm{NPV} = \sum_{t\in T} L_t(P_t - \mathrm{TCI}_t) + L_{t_N} V_S \qquad (1)$$

TCI_t is the total capital invested using outside sources. We also consider reinvestment of cash obtained from revenues.

Constraints. Material Balance Equations. The material sent from the raw material location k to all plants i in period t ($\mathrm{Xm}_{k,i,t}$) is smaller than the maximum available in supply region k ($\mathrm{Xm}_{k,t}^{\max}$)

$$\sum_{i\in I} \mathrm{Xm}_{k,i,t} \le \mathrm{Xm}_{k,t}^{\max} \qquad k \in K;\quad t \in T \qquad (2)$$

The sum of all the final products sent to all markets ($\mathrm{Xp}_{i,j,t}$) from plant i is equal to all the raw material received. A conversion factor conv_k is used.

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$$\sum_{j\in J}\mathrm{Xp}_{i,j,t} \leq \sum_{k\in K}\mathrm{Xm}_{k,i,t}\mathrm{conv}_k \qquad i \in I; \quad t \in T \tag{3}$$

Material sent to all markets from plant i is smaller than the plant installed capacity ($Q_{i,t}$).

$$\sum_{j\in J}\mathrm{Xp}_{i,j,t} \leq Q_{i,t} \qquad i \in I; \quad t \in T \tag{4}$$

Material sent from all plants to market j is smaller than the demand of the market ($D_{j,t}$).

$$\sum_{i\in I}\mathrm{Xp}_{i,j,t} \leq D_{j,t} \qquad j \in J; \quad t \in T \tag{5}$$

Logical Constraints. The capacity is between the minimum ($Q^{\min}$) and the maximum ($Q^{\max}$) only when the plant has been constructed, which is controlled by the binary variable indicating the first installation, $Y_{i,t}$.

$$Q^{\min}\sum_{\substack{t'\leq t\\ t'\in T}} Y_{i,t'} \leq Q_{i,t} \leq Q^{\max}\sum_{\substack{t'\leq t\\ t'\in T}} Y_{i,t'} \qquad i \in I; \quad t \in T \tag{6}$$

Capacity can only increase in time

$$Q_{i,t-1} \leq Q_{i,t} \qquad i \in I; \quad t \in T \tag{7}$$

Capacity can only increase (through expansion) after two years have passed from the first installation.

$$Q_{i,t} - Q_{i,t-1} \leq \Omega(1 - Y_{i,t-1} - Y_{i,t-2}) \qquad i \in I; \quad t \in T \tag{8}$$

where Ω is a number greater than the maximum capacity ($Q^{\max}$) and is used to avoid conflict with eq 6.

There is no production in years one and two.

$$\mathrm{Xp}_{i,j,t_1} = \mathrm{Xp}_{i,j,t_2} = 0 \qquad i \in I; \quad j \in J \tag{9}$$

Plant i is built once or never.

$$\sum_{i\in I} Y_{i,t} \leq 1 \qquad t \in T \tag{10}$$

Capacity only increases when there is an expansion. We introduce a continuous variable $Y^{\mathrm{ext}}_{i,t}$ in the interval [0, 1] to control expansions.

$$(Q_{i,t} - Q_{i,t-1}) \leq \Delta Q^{\max} Y^{\mathrm{ext}}_{i,t} \qquad i \in I; \quad t \in T \tag{11}$$

When an expansion occurs, $Y^{\mathrm{ext}}_{i,t} = 1$; then, eq 11 sets a bound $\Delta Q^{\max}$ on the capacity increase, whereas, when there is no expansion, then $Y^{\mathrm{ext}}_{i,t} = 0$ and eq 11 together with eq 7 forces $Q_{i,t} - Q_{i,t-1} = 0$.

Expansions cannot be planned in consecutive years.

$$Y^{\mathrm{ext}}_{i,t} + Y^{\mathrm{ext}}_{i,t+1} \leq 1 \qquad i \in I; \quad t \in T \tag{12}$$

Expansions cannot be planned if the plant has not been first built.

$$Y^{\mathrm{ext}}_{i,t} \leq \sum_{\substack{t'\leq t\\ t\in T\\ t'\in T}} Y_{i,t'} \qquad i \in I; \quad t \in T \tag{13}$$

There are no expansions after year n^*. This is done to help convergence. In our example, we use 10.

$$Y^{\mathrm{ext}}_{i,t} = 0 \qquad i \in I; \quad t \geq n^* \tag{14}$$

No more than $n_{\exp}$ expansions are allowed. In our example, we use 4.

$$\sum_{t\in T} Y^{\mathrm{ext}}_{i,t} \leq n_{\exp} \qquad i \in I; \quad t \in T \tag{15}$$

Investment Equations. The total capital investment in period t ($\mathrm{TCI}_{i,t}$) is equal to the sum of the investments in the different sites ($\mathrm{FCI}_{i,t}$).

$$\mathrm{TCI}_t = \sum_{i\in I}\mathrm{FCI}_{i,t} \qquad t \in T \tag{16}$$

The total capital investment in the first two periods is limited by the maximum capital available (MaxCap)

$$\sum_{\substack{i\in I\\ t\in T\\ t\leq 2}}\mathrm{TCI}_{i,t} \leq \mathrm{MaxCap} \qquad t \in T \tag{17}$$

The model assumes that proceeds of the project are used to re-invest. Therefore, the re-investment total capital ($\mathrm{TCRI}^{\exp}_t$) is counted separately from the initial fixed capital investment (FCI) and is equal to the capital spent in the expansions ($\mathrm{CI}^{\exp}_{i,t}$)

$$\mathrm{TCRI}^{\exp}_t = \sum_{i\in I}\mathrm{CI}^{\exp}_{i,t} \qquad t \in T \tag{18}$$

The fixed capital investment ($\mathrm{FCI}_{i,t}$) is related to the binary variable defining new installation or not ($Y_{i,t}$). The fixed portion of investment ($\mathrm{PFCI}_{i,t}$) is spread over 2 years. The variable portion ($\mathrm{PVFCI}_{i,t}$) is also spread over 2 years using the variables $\alpha 1_{i,t}$ and $\alpha 2_{i,t}$, which are defined in the subsequent equations.

$$\mathrm{FCI}_{i,t} = \frac{\mathrm{PFCI}}{2}(Y_{i,t+1} + Y_{i,t+2}) + \frac{\mathrm{PVCI}}{2}(\alpha 1_{i,t} + \alpha 2_{i,t}) \qquad t \in T \tag{19}$$

The variable $\alpha 1_{i,t}$ is defined by the following set of equations:

$$\alpha 1_{i,t} - Y_{i,t+1}\Omega \leq 0 \qquad t \in T \tag{20a}$$

$$Q_{i,t+1} - \alpha 1_{i,t} - (1 - Y_{i,t+1})\Omega \leq 0 \qquad t \in T \tag{21a}$$

$$Q_{i,t+1} - \alpha 1_{i,t} \geq 0 \qquad t \in T \tag{22a}$$

$$\alpha 1_{i,t} \geq 0 \qquad t \in T \tag{23a}$$

When $Y_{i,t+1} = 0$, eq 21a is trivial and eq 22a together with eq 23a renders $\alpha 1_{i,t} = 0$. Conversely, when $Y_{i,t+2} = 1$, eq 20a is trivial and eq 21a together with eq 22a renders $\alpha 1_{i,t} = Q_{i,t+1}$. The equations for $\alpha 2_{i,t}$ are similar, but they are connected to $Y_{i,t+2} = 0$.

$$\alpha 2_{i,t} - Y_{i,t+2}\Omega \leq 0 \qquad t \in T \tag{20b}$$

$$Q_{i,t+2} - \alpha 2_{i,t} - (1 - Y_{i,t+2})\Omega \leq 0 \qquad t \in T \tag{21b}$$

$$Q_{i,t+2} - \alpha 2_{i,t} \geq 0 \qquad t \in T \tag{22b}$$

$$\alpha 2_{i,t} \geq 0 \qquad t \in T \tag{23b}$$

Different cost parameters are used for fixed capital investment in expansions. Expansions are additions of units on top of existing infrastructure. They are connected to the variable $Y_{i,t}$, which can happen only once.

$$\mathrm{CI}_{i,t}^{\exp} = \mathrm{VCI}^{\exp}\beta_{i,t} \qquad t \in T \tag{24}$$

where $\mathrm{VCI}^{\exp}$ is the variable capital investment for expansions. β_{it}, the plant i capacity expanded at time t, is defined as follows:

$$\beta_{i,t} = 0, \quad \text{if} \quad \begin{cases} \sum_{t' \le t} Y_{i,t'} = 0, & \text{or} \\ Y_{i,t} = 1, & \text{or} \\ Y_{i,t+1} = 1, & \text{or} \\ Q_{i,t+1} = Q_{i,t} \end{cases} \qquad t \in T \tag{25a}$$

$$\beta_{i,t} = (Q_{i,t+1} - Q_{i,t}), \quad \text{if} \quad \begin{cases} \sum_{t' \le t} Y_{i,t'} = 1, & \text{and} \\ Y_{i,t} = 0, & \text{and} \\ Y_{i,t+1} = 0 \end{cases} \qquad t \in T \tag{25b}$$

This is written in the form of equations as follows:

$$\beta_{i,t} - (1 - Y_{i,t} - Y_{i,t+1})\Omega \le 0 \qquad t \in T \tag{26}$$

$$\beta_{i,t} - \Omega \sum_{\substack{t' \le t+1 \\ t \in T}} Y_{i,t'} \le 0 \qquad t \in T \tag{27}$$

$$Q_{i,t+1} - Q_{i,t} - \beta_{i,t} - \Omega(1 + Y_{i,t} + Y_{i,t+1} - \sum_{\substack{t' \le t+1 \\ t' \in T}} Y_{i,t'}) \le 0 \qquad t \in T \tag{28}$$

$$Q_{i,t+1} - Q_{i,t} - \beta_{i,t} \ge 0 \qquad t \in T \tag{29}$$

$$\beta_{i,t} \ge 0 \qquad t \in T \tag{30}$$

When $Y_{i,t'} = 0$, $\forall\ t' \le t + 1$, then eqs 26 and 28 are trivial, because in this case, $Q_{i,t'} = 0$, $\forall\ t' \le t + 1$ due to prior constraints, and then eqs 27, 29, and 30 render $\beta_{i,t} = Q_{i,t+1} - Q_{i,t}$, which is zero when no expansions took place and is equal to the right value if they did. If $Y_{i,t} = 1$ (and, therefore, $Y_{i,t+1} = 0$), then based on eq 8, $Q_{i,t+1} = Q_{i,t}$ and eqs 26, 27, and 29 are trivial, and eqs 28 and 30 render $\beta_{it} = 0$. If $Y_{it+1} = 1$, eqs 26, 27, and 30 are trivial, and eqs 28 and 29 force $\beta_{it} = Q_{i,t+1} - Q_{i,t}$.

Operating Cost Equations. The total revenue (REV_t) is obtained from the sales in different markets. Sales tax ($\mathrm{saletax}_i$) is taken into account.

$$\mathrm{REV}_t = \sum_{i \in I} \sum_{j \in J} p_{i,t} \mathrm{XP}_{it,j}(1 - \mathrm{saletax}_i) \qquad t \in T \tag{31}$$

where $p_{i,t}$ is the sales price. The total transportation cost (TrC_t) is obtained from the amount delivered from each plant i to each market j.

$$\mathrm{TrC}_t = \sum_{i \in I} \sum_{j \in J} \mathrm{Tc}_{i,j,t} \mathrm{XP}_{i,t,j} \qquad t \in T \tag{32}$$

where $\mathrm{TC}_{i,j,t}$ is the transportation cost from plant i to sales market j during period t. The total raw material cost (RMC_t) is the sum of the raw material costs in all markets plus the transportation costs to all plants.

$$\mathrm{RMC}_t = \sum_{i \in I} \sum_{k \in K} \mathrm{Rmc}_{k,i,t} XM_{i,k,t} + \sum_{i \in I} \sum_{k \in K} Tc_{k,i,t} XM_{i,k,t} \quad t \in T \tag{33}$$

where $\mathrm{Rmc}_{k,i,t}$ is the cost of the raw material and $\mathrm{Tc}_{k,i,t}$ is the transportation cost from purchase market k to plant i at time t. The operating costs (OC_t) have two components, one fixed ($\mathrm{Foc}_{i,t}$, associated with the existence of the process) and another variable ($\mathrm{Voc}_{i,t}$).

$$\mathrm{OC}_t = \sum_{i \in I} \sum_{\substack{t' \in T \\ t' \le t}} \mathrm{Foc}_{i,t} Y_{i,t} + \sum_{i \in I} \sum_{j \in J} \mathrm{Voc}_{i,t} \mathrm{XP}_{i,j,t} \qquad t \in T \tag{34}$$

Profit Equations. The net profit before (NP_t) taxes is given by the revenues minus the operating costs

$$\mathrm{NP}_t = \mathrm{REV}_t - \mathrm{TRC}_t - \mathrm{RMC}_t - \mathrm{OC}_t \qquad t \in T \tag{35}$$

Taxes are related to net profit before taxes and depreciation (deprate).

$$\mathrm{Tax}_t = \mathrm{taxrate}^*(\mathrm{NP}_t - \mathrm{deprate} \sum_{\substack{t \in T \\ t' \ge t-11 \\ t' \le t}} \mathrm{TCI}_{t'}) \qquad t \in T; \quad t \ge 12 \tag{36}$$

$$\mathrm{Tax}_t = \mathrm{taxrate}^*(\mathrm{NP}_t - \mathrm{deprate} \sum_{\substack{t' \in T \\ t' \ge 3 \\ t' \le t}} \mathrm{TCI}_{t'}) \qquad t \in T; \quad t \le 11 \tag{37}$$

The net profit after taxes (NPAT_t) is given by

$$\mathrm{NPAT}_t = \mathrm{NP}_t - \mathrm{Tax}_t \qquad t \in T; \quad t \ge 4 \tag{38}$$

Budgeting Equations. These equation follow cash accumulated in different periods, which is increased by profit after taxes and reduced by investments on expansions and proceeds taken form the projects and returned to the investor.

$$B_t = B_{t-1} + \mathrm{NPAT}_t - \mathrm{TCI}_{i,t+1}^{\mathrm{ext}} - P_t \qquad t \in T; \quad t \ge 4 \tag{39}$$

$$B_t = B_{t-1} + \mathrm{NPAT}_t - P_t \qquad t \in T; \quad t = 3 \tag{40}$$

$$B_t = 0 \qquad t \in T; \quad t = 1; \quad t = 2 \tag{41}$$

where B_t is the budget at time t.

The above model is applied to a variety of source raw materials, aiming at the production of one commodity, which can be sold in different markets at different prices. Also, in our par-

Table 1. Market Locations Considered

CA	Los Angeles, San Jose	NC	Charlotte, Durham, Wilmington
CO	Denver	NM	Albuquerque
DE	Wilmington	NV	Reno
FL	Jacksonville	NY	Massena, Schenectady
GA	Atlanta	OH	Cincinnati, Dayton, Columbus, Toledo
IL	Chicago	OK	Oklahoma City
IN	Indianapolis, Fort Wayne, Bedford	OR	Portland
KY	Bowling Green, Madisonville	PA	Pittsburgh, Erie, Philadelphia
LA	Shreveport	SC	Greenville, Charleston
MA	Boston	TN	Memphis
MD	Baltimore	TX	Ft. Worth, Austin, Dallas, Houston
ME	Bangor	VA	Fredericksburg, Charlottesville
MI	Detroit, Lansing	VT	Rutland
MN	Minneapolis	WA	Seattle, Spokane
MO	St. Louis	WV	Martinsburg
MS	Jackson		

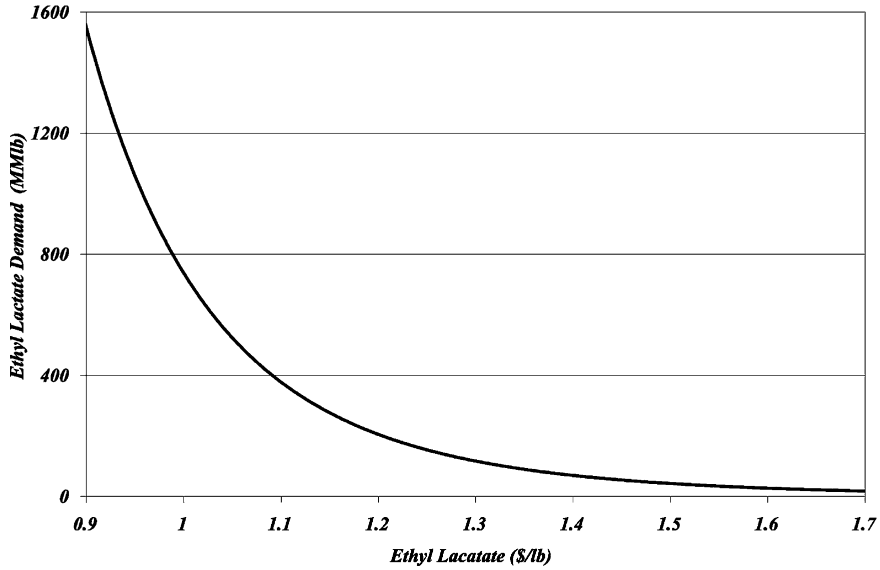

Figure 1. Domestic ethyl lactate demand (DOE).

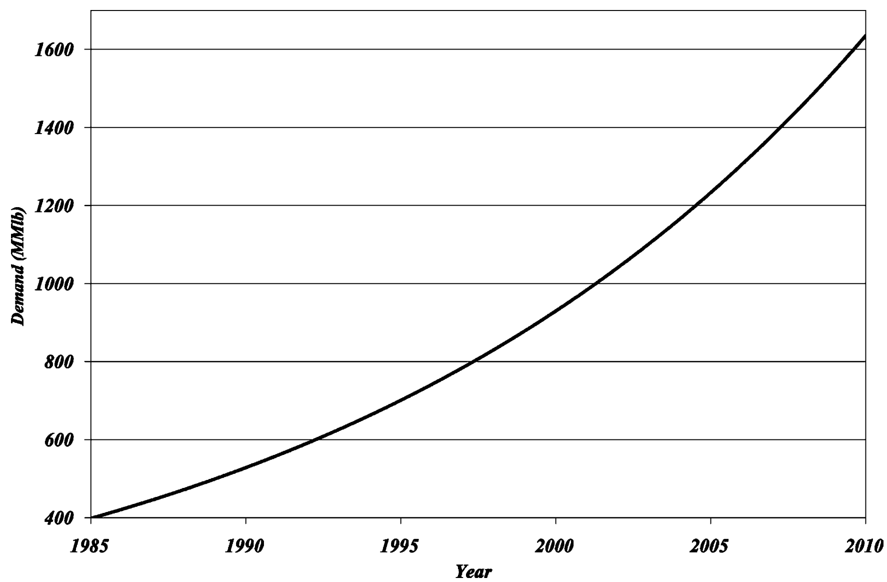

Figure 2. Demand for green solvents over time (Freedonia Institute).

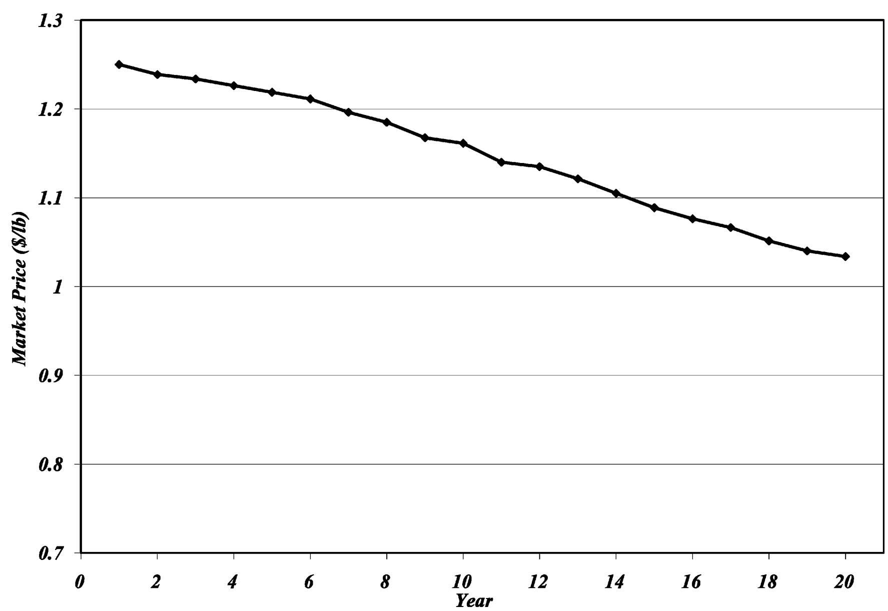

Figure 3. Ethyl lactate selling price prediction.

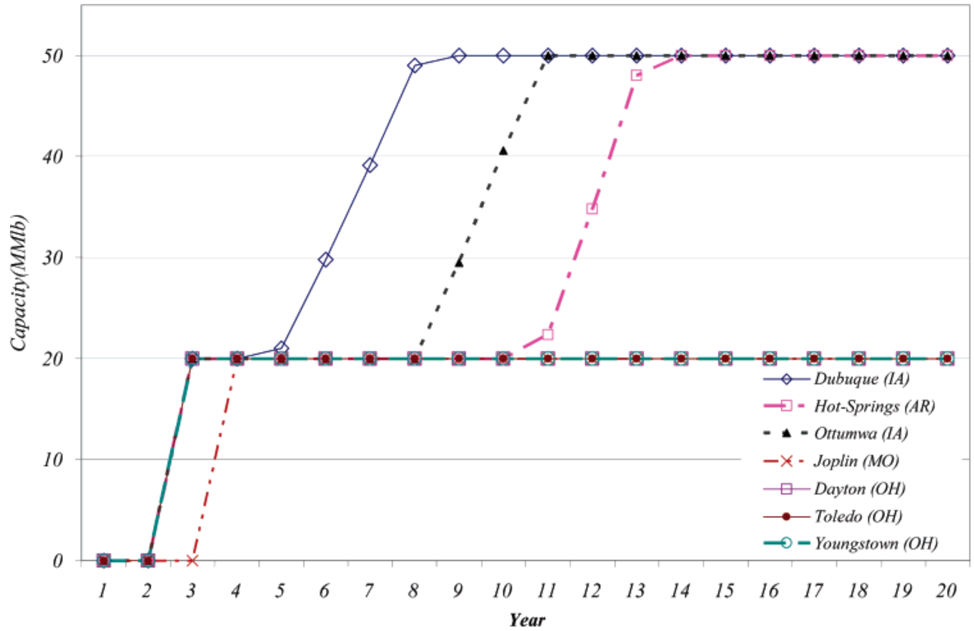

Figure 4. Plant capacity installed.

ticular case study, the expansion capacity is performed by adding fixed values of capacity. Raw material prices include the transportation costs from raw material sources to plant locations.

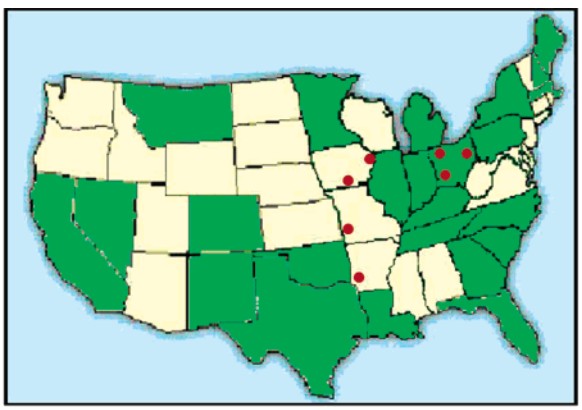

Figure 5. Location of plants.

We now illustrate the use of this model in a deterministic case, to later use a stochastic model.

Deterministic Problem

Product. We consider the production of ethyl lactate, which is an environmentally benign solvent, whose effectiveness can be compared to other petroleum-based chemicals. The worldwide solvent market is 33 billion lbs/year, of which approximately 11 billion lbs are used domestically in the United States.

Process. The process involves the esterification reaction of ethanol and lactic acid to form the desired product. Ethanol and lactic acid can be created from biomass raw materials through fermentation. These are traditional units.

Raw Material Markets. The selection for the best raw materials relates the type and quantity of raw material being produced, the specific location of the raw materials, and the

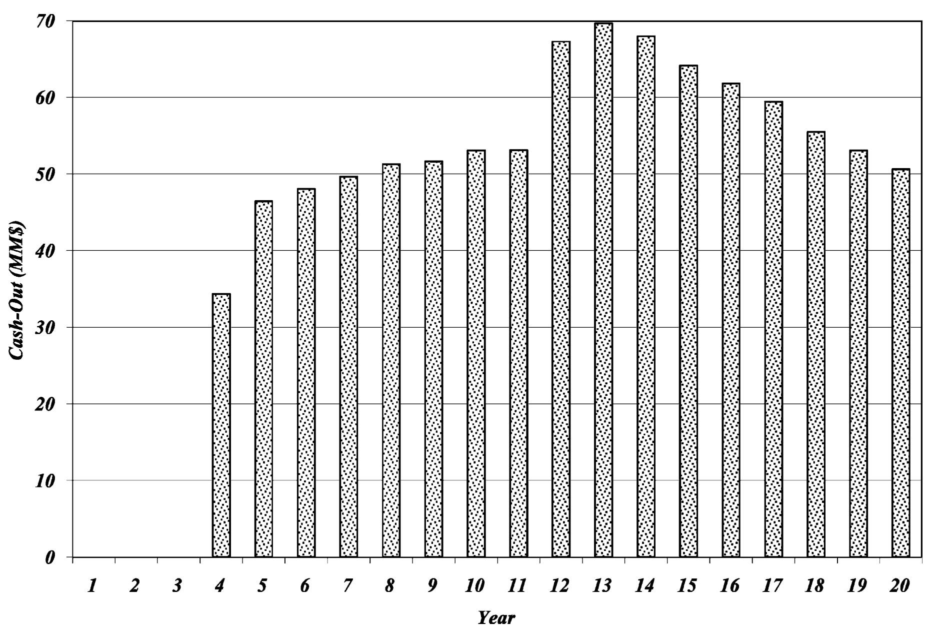

Figure 6. Net cash out.

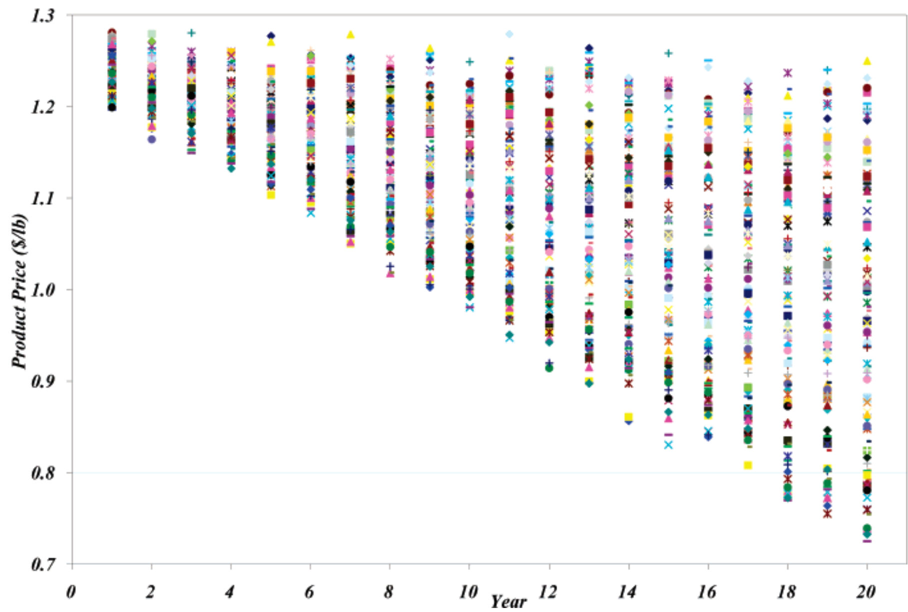

Figure 7. General price sampling for all the markets consisting of 100 scenarios.

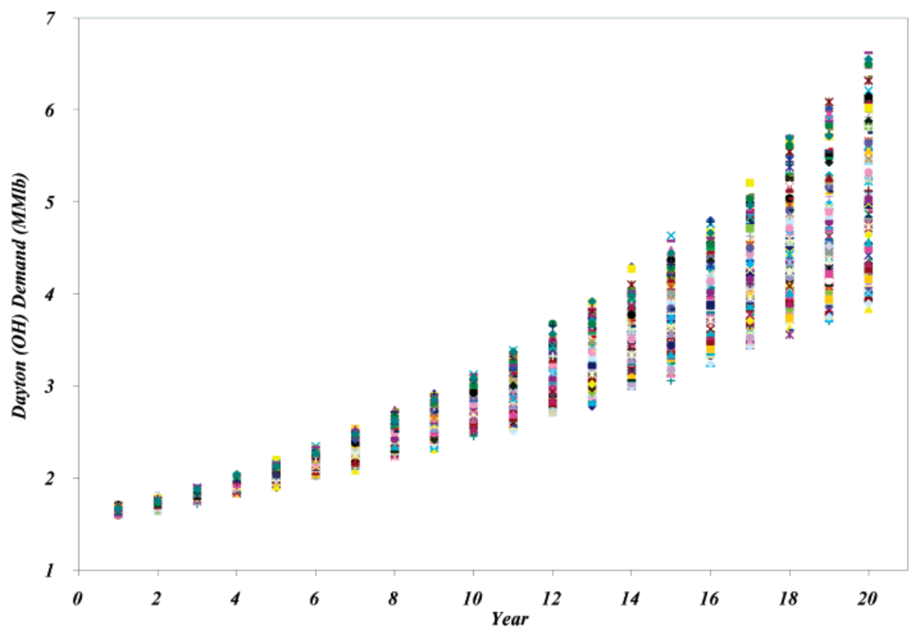

Figure 8. Dayton's (OH) demand sampling consisting of 100 scenarios.

local taxes associated with the raw materials. These values were converted into equivalent units for comparison. The type and quantity of raw material being produced in a particular area was determined through statistical analysis within the United States Department of Agriculture (USDA). Overall, eight raw materials were evaluated: rice, wheat, barley, corn, oats, rye, sugarcane, and sweet potatoes.

Consumer Markets. Locations for potential wholesale markets varied according to location and possible ethyl lactate demand. These locations were determined by locating companies that would purchase ethyl lactate as a degreaser. In particular, companies specializing in motor vehicles (and their parts), computer equipment, aircraft (and parts), and electronic equipment were considered for ethyl lactate purchasing. *Industry Week and Special Issues* listed information pertaining to wholesale markets. The cities where these types of companies were located were chosen for potential ethyl lactate wholesale markets. Overall, a total of 50 market locations within the United States were considered for the mathematical model (Table 1).

Potential Plant Locations. The process for determining potential plant locations varied as a result of the population of the city, taxes associated with land and plant holdings, and the amount of growth of new and pre-existing companies within that city. Much of the information regarding high labor market areas was obtained from a study done by the National Commission on Entrepreneurship (NCOE).[12] The statistics gathered by the NCOE represent the possibilities for growth based on the increased employment rates of new and pre-existing companies throughout the United States. The cities that were considered ranged in populations from over three million people to between 150 000 and 300 000 people. Also, values for growth in labor market areas were a reflection of the number of companies that grew amid the total number of companies for that particular city. Finally, cities that were considered to have high values for growth were chosen for potential plant locations. Overall, 46 possible plant locations were considered based on favorable analysis by NCOE, proximity to abundant raw materials, and proximity to several possible markets.

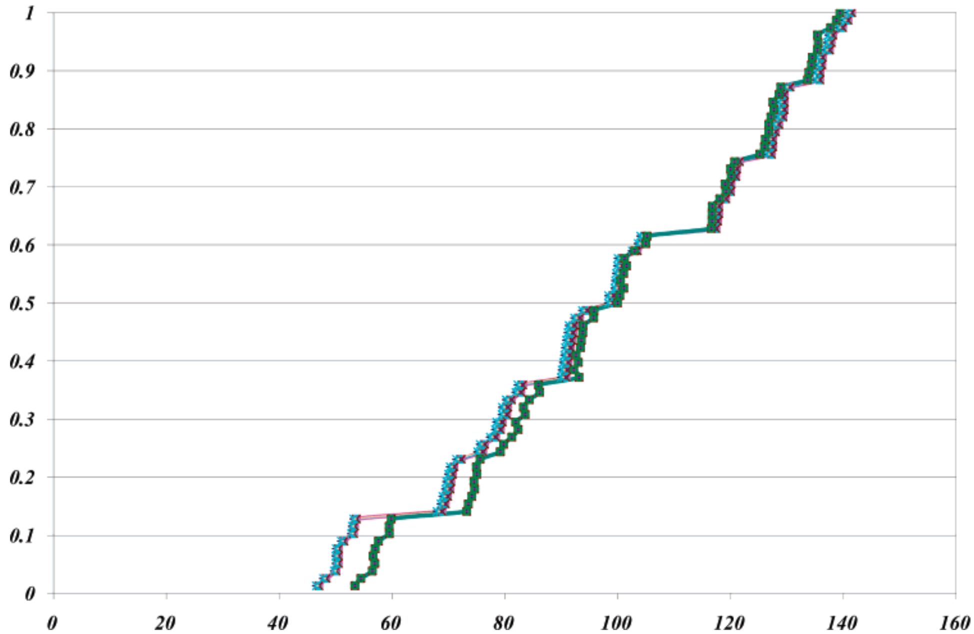

Figure 9. 100 risk curves obtained.

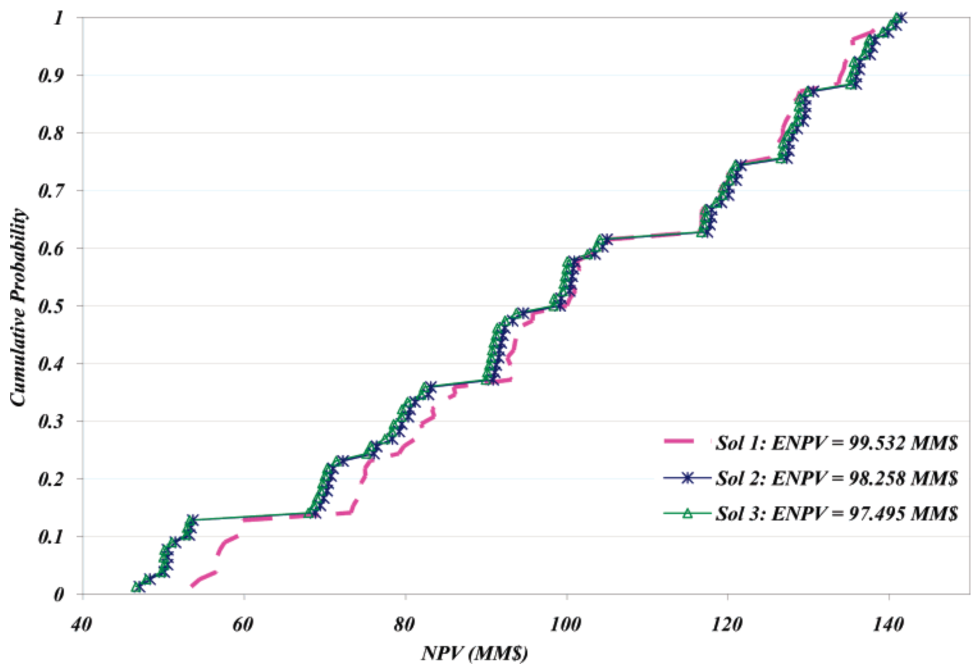

Figure 10. Best three risk curves.

Demands and Pricing. The projection for the product demand and selling price were based on literature information. We assumed that the domestic demand of ethyl lactate would grow as the price decreases as shown in Figure 1. Figure 2 shows the projections of the demand for green solvents done by the Freedonia Institute.[13]

The demand for each market location (j) was then calculated on the basis of the following equation:

$$\mathrm{Demand}_j = \frac{\mathrm{GSP}_{\mathrm{Manuf}_j}}{\mathrm{price}_{\mathrm{solvent}}} P_{\mathrm{Green}} P_{\mathrm{EthylLacate}} P_{\mathrm{EthLacMarket}} \quad (42)$$

where $\mathrm{GSP}_{\mathrm{Manuf}_j}$ = gross state product of solvent specific industries at market location j, $\mathrm{price}_{\mathrm{solvent}}$ = average price of commercial solvents, P_{Green} = percentage of solvent market occupied by green solvents, $P_{\mathrm{EthylLactate}}$ = percentage of green solvent market occupied by ethyl lactate, and $P_{\mathrm{EthLacMarket}}$ = percentage of ethyl lactate market occupied.

The selling price predictions were also calculated on the basis of the projections of the Freedonia Institute. The prediction is shown in Figure 3.

Results

The mathematical model was performed assuming a straight-line depreciation over 11 years for each individual fixed capital investment. The entire project was given a lifespan of 20 years beginning in 2005, and the initial investment was limited to \$20 million. The salvage value and the working capital were set at 10% and 15% of the fixed capital investment (FCI), respectively. During the first 2 years, the plants are built; therefore, there is no production.

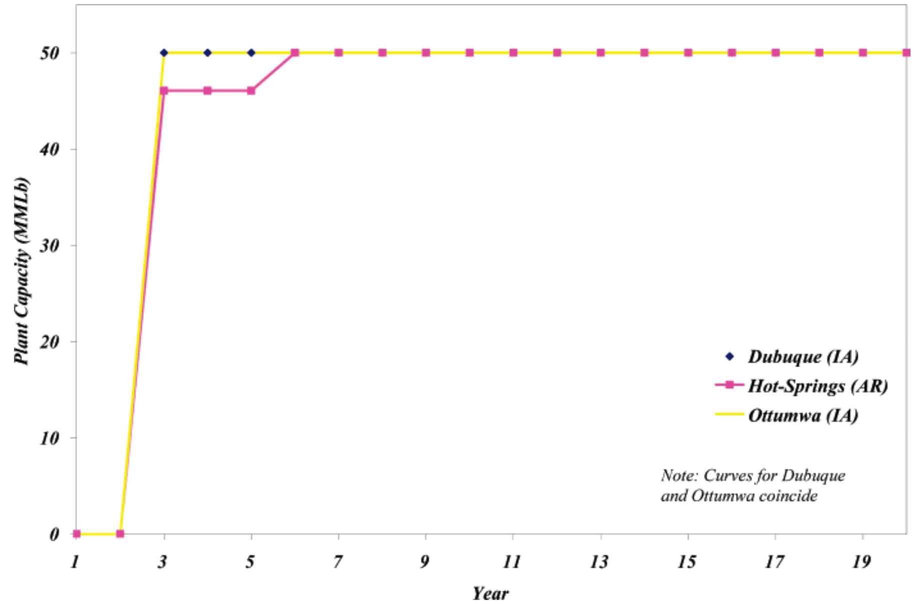

Figure 11. Plant capacity installed for solution 1 (deterministic).

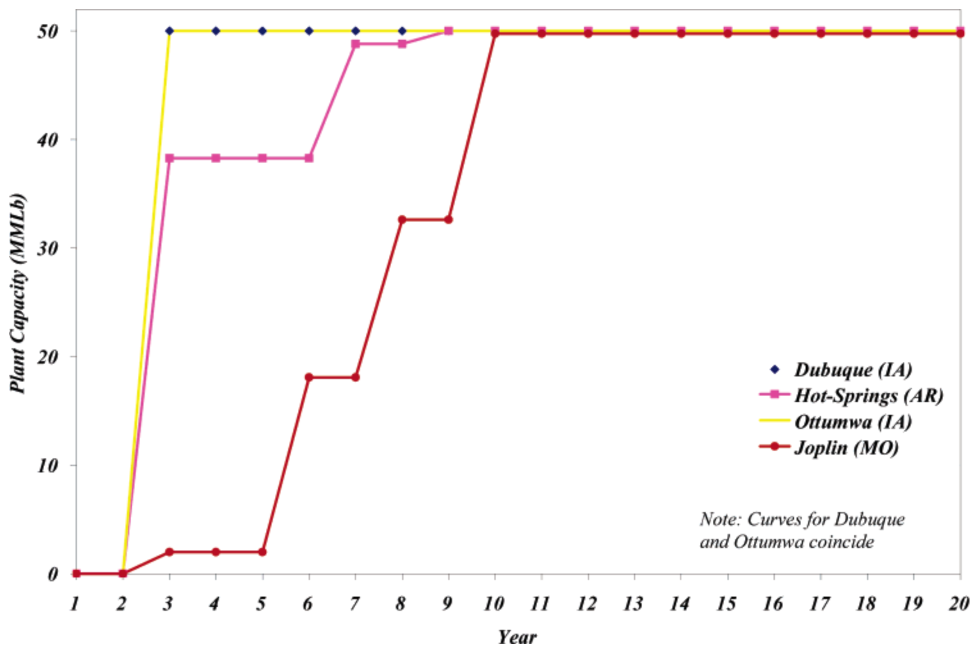

Figure 12. Plant capacity installed for solution 2 (deterministic).

All the input specifications helped make the mathematical more realistic and provided a practical amount of options. A total of 8 raw materials (and all possible locations associated with high production rates of that particular raw material), 50 market locations, and 46 plant locations were included in the model. Freight costs and sales taxes were also taken into account to make the considerations for raw materials and potential markets more realistic.

Figure 4 shows the resulting plants installed along with the capacity of each plant, throughout the time horizon. Figure 5 shows the distribution of the plants in the U.S. territory. The optimal solution is to install six plants at the beginning, starting operation at the third year, and one more at the fourth year. Some of them are then expanded throughout the project life. The NPW of the project is $202.7 million. The net cash flow through the life of the project is represented in Figure 6. The initial investment is $12.1 million for the six first plants installed, and there is a complementary investment of $391 332 to build a plant in Joplin the fourth year. The rest of the capital is available from the profit made the third year. The rest of the expansions are financed by revenues. The model has determined this to be more profitable than using a fresh investment.

Stochastic Problem

Uncertainty in the Market Price and Demand of the Product. On the basis of the deterministic correlations for the market price and demand, we then introduced uncertainty in these two parameters by considering 100 scenarios with equal probability of occurrence. Figure 7 shows the market price sampling, and Figure 8 shows the demand for the Dayton (OH) market. It was assumed that the price will be the same for all the markets, and each market demand is independent of the rest. However, the demand is correlated to the market price scenarios. The general price sampling was generated creating 10 random scenarios with normal distribution around 10 different base

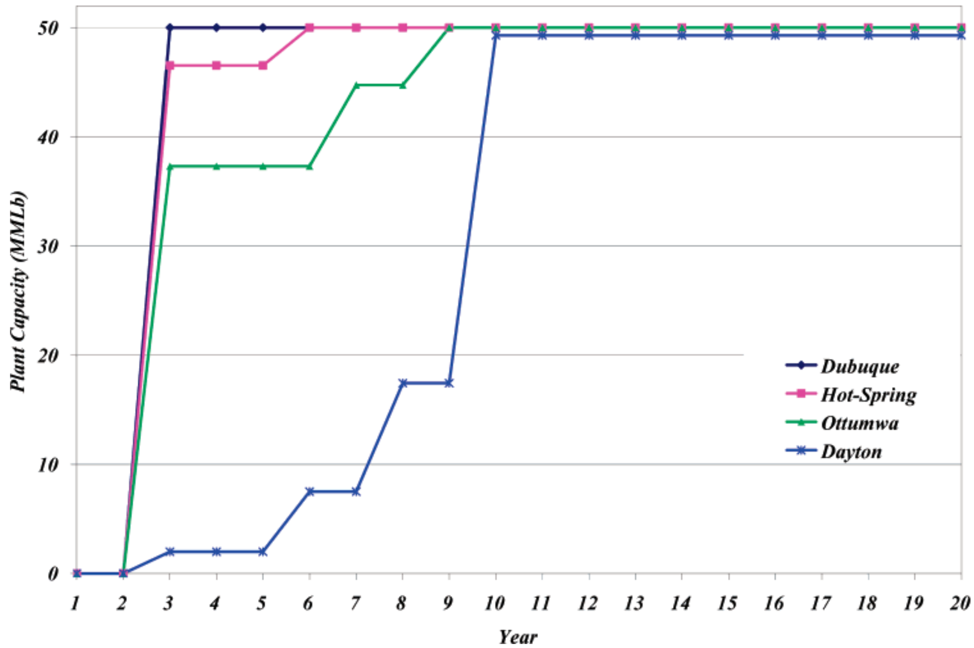

Figure 13. Plant capacity installed for solution 3 (deterministic).

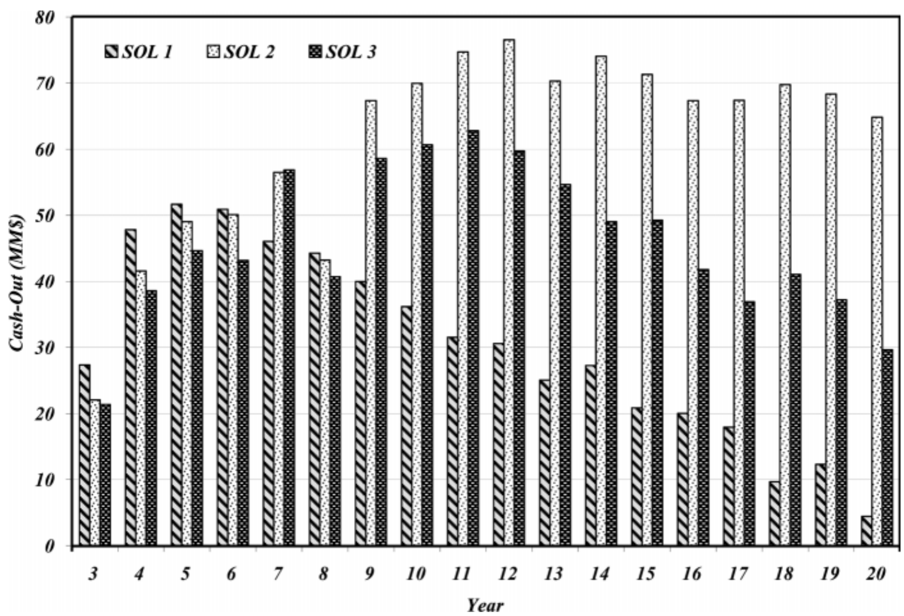

Figure 14. Cash out for the three best solutions.

curves. Doing so, we avoided having "chain saw" scenarios. The demand sampling for each market was based on the general price sampling along with the deterministic demands to correlate for each market separately.

The stochastic model was generated by applying the technique introduced by Aseeri and Bagajewicz.[14] This technique consists of solving each scenario independently. Then each solution is solved again with the first-stage variables fixed for all the scenarios to obtain all the risk curves for the rest of the scenarios. As result, 100 risk curves were obtained, each one conformed by the 100 values of NPV resulting from simulation for each scenario, fixing the deterministic solution obtained from one of the 100 scenarios. The first-stage decision variable was the binary variable of building or not building a plant at a certain location, at a certain point in the time. The binary variable of expanding or not expanding an existing plant was considered a second-stage variable, to give flexibility when solving with the first-stage variable fixed.

Figure 9 shows the 100 risk curves obtained. They are very close to each other at high cumulative probabilities and slightly separated into two groups as the cumulative decreases. Many of the curves that belong to the same group have almost the same ENPV.

Figure 10 shows the three curves representing the best three curves in terms of expected net present value (ENPV).

Figures 11−13 show the *deterministic* plant capacity installed for solutions 1−3, shown in Figure 10, respectively. The actual plant capacity installed and expansions obtained applying this solution might vary from one scenario to another, but the total number of plants installed in the time horizon is the same for all the scenarios, because this is determined by the first-stage decision variables. Figure 14 shows the *deterministic* cash out associated with these three solutions.

From Figures 11−13, it can be observed that solution 1, the best strategy under all the scenarios considered, is the most conservative of the three, because it only installs three plants.

At the same time, this strategy comes from a worst-case scenario, as can be observed from its cash out.

Conclusions

The model presented in this paper considers simultaneously plant location, transportation from raw materials markets, and transportation of product to consumer markets at once. It also includes budgeting constraints, which follow the cash flow through the life of the project and allow the project to finance the expansions. The example exposed shows that it could be advantageous to re-inject part of the profit to expand the plants initially installed and even to install new plants at certain points of the project life. Financial risk can be also addressed, determining which scenarios provide the best strategy to be applied.

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