Improving Supply Chain Management in a Competitive Environment under Uncertainty

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Abstract

The consideration of uncertainty is highly important in nowadays and there are lots of academic and industrial based studies that deal with uncertainty in the parameters of the problem to make decisions in production planning problems. This work aims to optimize the planning of Supply Chains (SCs) in competitive environments under demand and market competition uncertainty. The proposed model approach considers a two stage stochastic programming formulation to solve a MILP (Mixed integer linear programming) or a MINLP (Mixed Integer Non-Linear Programming) problem to improve the decision making on the operation of different Supply Chains; different optimization criteria are considered to deal with cooperative and non cooperative behavior between SCs.

Introduction

The problem of decision making in the chemical process industry becomes more complex as the scope covered by decisions is extended. This increasing complexity is additionally complicated by the need to consider a certain degree of uncertainty in the models used to forecast the events that should be considered in this decision making. But although some of the published works in this area explicitly address the problem associated with the uncertainty in the available data, very few of them put the issue in a realistic operational environment, taking into account that the SC of interest will have to compete with other Supply Chains which, logically, would also like to work as efficiently as possible to cover the same demands on the basis of raw materials obtained in the same (global) markets. But even an efficient behavior should be assumed for these third parties (competitors), their specific way to face demands, suppliers, etc. is, from the point of view of the own interest, a new uncertain element to be considered.

Within this scope, nowadays it is not enough to study the deterministic problems that the industry deals with. There are some works (Lababidi et al (2004), Gupta & Maranas (2003), You and Grossmann (2010), Pistikopoulos (2004), Wellons & Reklaitis (1989), etc.) that solve the SC planning under uncertainty in terms of demand and market prices, using tools like Model Predictive Control, Multi-parametric programming and stochastic programming. In order to deal with this more realistic problem (introduce uncertainty as market competition behavior this work proposes to introduce into the model information, the expected performance of the competing supply chains (including the SC of interest); such information is entered in form of scenarios to manage the uncertainty in the optimization model. Based on this information, it is possible to construct a mathematical model to solve the problem using stochastic programming considering different sources of uncertainty.

This paper addresses the SC planning problem (inventory, production and distribution tasks) for Supply Chains that work in a common scenario. As mention before it is necessary consider a greater degree of uncertainty, and develop more complex models to solve the same supply chain problems. In these sense, this work aims to develop a model that considers several scenarios for the demand satisfaction using stochastic programming to solve the problem. It is also important to consider a higher complexity in the models; e. g. considers uncertainty, non linear models, etc.

Problem Statement

Supply Chain Planning

The typical scope of a SC planning problem is to determine the optimal production, inventory and distribution levels in the organization network (production centers, distribution equipments, storage centers, and market places), taking care of the constraints of the raw materials, production and distribution limits. These problems are typically formulated as MILP problems and are solved using mathematical programming tools, heuristics rules, metaheuristics, etc.

The model originally proposed by Zamarripa et al 2011 (this model introduce the use of game theory as a decision technique to determine the optimal SC production, inventory and distribution levels in a competitive planning scenario, and model the competition behavior of several SC's as an uncertainty source) has been adopted as a basis for the formulation presented in this paper, and consists in a two stage stochastic programming. Also this work considers as organization network; several SC's (production sites, storage centers and distribution options) that should face the same market competition for multiple time periods, there are some availability of machine and man hours to limit the production and there is a fixed capacity to distribute the products to the nodes of the network, also there are some fixed cost associated to the production, distribution and the storage of the products.

SC Planning under Uncertainty

Since 1980 there is an important increase of optimization applications in the study of the uncertainty behavior in the chemical systems, production planning and scheduling systems. Dolgui et al 2002, identify different sources of uncertainties along the supply chain (supplying reliability, assembly and manufacturing random lead times; random level and customers demand), the oldest fashion solutions for this problems was the use of safety stocks. Due to this, the academy focuses its efforts to solve the demand uncertainty in the production problems.

Sahinidis 2004, makes an exhaustive revision of the state of the art of the optimization under uncertainty setting as a principal recourse the two stage stochastic programming; the first stage variables are those that have to be decided before known the uncertainty parameters, subsequently, the random scenarios have presented the policy of the model selects the values of the second stage variables.

This model approach sets the production as first stage variable, being the second stage variables the storage and distribution levels, to be fixed/optimized once the uncertain parameters mentioned before are revealed.

The problem consists in two criteria to improve the decision making:

- Minimize the total cost of the Supply Chain under consideration (production, inventory, distribution and backorder costs)

$$Min\ z1(g) = \sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} a_{in} Q_{inh} (1+e_b)^h + \sum_{sc} \frac{1}{sc} \left(\sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} c_{in} W_{scinh} (1+e_b)^h + \sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} d_{in} E_{scinh} (1+e_b)^h + \sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} \sum_{j} k_{inj} T_{scinhj} (1+e_b)^h \right)$$

- Minimize the expenses of the buyers.

$$Min\ CST(g) = \sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} \sum_{j} Ps_{inj} T_{scinhj}\ Prate + \sum_{sc} \frac{1}{sc} \left(\sum_{i \in I\_G(i,g)} \sum_{n} \sum_{h} \sum_{j} Ps_{inj} T_{scinhj}\ Disc_{sc} \right)$$

Several Constraints are introduced to manage:

- Material balances.
- Production capacity.
- Storage limit.
- Demand satisfaction.
- Law of demand elasticity.
- Distribution capacity.
- Budget capacity.

Parameters under uncertainty

- **Demand.** As mentioned before, different scenarios (sc) for the satisfaction of the consumers are usually defined to take into account the overall effect of all exogenous sources of uncertainty. This is usually modeled as a normal probability distribution curve in the products demand. Since all the exogenous sources of uncertainty are considered to be included in the "Demand uncertainty" model, only the Total Cost of the Supply Chain under consideration (*z1*) is needed to optimize the SC behavior.
- **Competence behavior.** Actually, the demand to be covered is the result of the uncertain market demand and the demand covered by the competitor SCs, which will depend on the uncertain competitors' behavior. One way to consider this competition is to assume that the markets get the products from the cheaper SC; then, the second criteria above ("minimize the expenses of the buyers") can be included in the model as a second objective to be optimized.
  In order to manage this specific source of uncertainty, the eventual discount in the price of the products has been introduced as a new "first stage" variable to be optimized.
  Obviously a new challenge appears, related to the evaluation of uncertain behavior of the competitor SCs.

Case study

These concepts have been applied to a supply chain case study adapted from Liang (2008). The factory's strategy is to maintain a constant work force level over the planning horizon, and supply as much product as possible (demanded), playing with inventories and backorders. Two products are considered (P1 and P2) with a market demand of 3 months horizon demanded from 4 distribution centers (Distr1 to Distr4). The information about the considered scenarios, production, etc. and the rest of problem conditions (initial storage levels, transport capacities, etc.) can be found at http://cepima.upc.edu/papers/Competitive_SCs.pdf (Tables 3-6).

The cooperative problem is solved as a MILP that minimize the total cost z1 (sum of transportation, production and inventory costs). Also, the benefit is calculated (difference between sales and total cost) of each SC is estimated to highlight the results (cooperative/competitive). The competitive problem is solved as a MINLP that minimize the expense of the buyers CST. Figure 1 shows the considered SCs basic configuration, composed by 2 SCs (2+2 plants, Plant1/Plant2 and Plant3/Plant4) which collaborate or compete to fulfill the global demand from the 4 distribution centers.

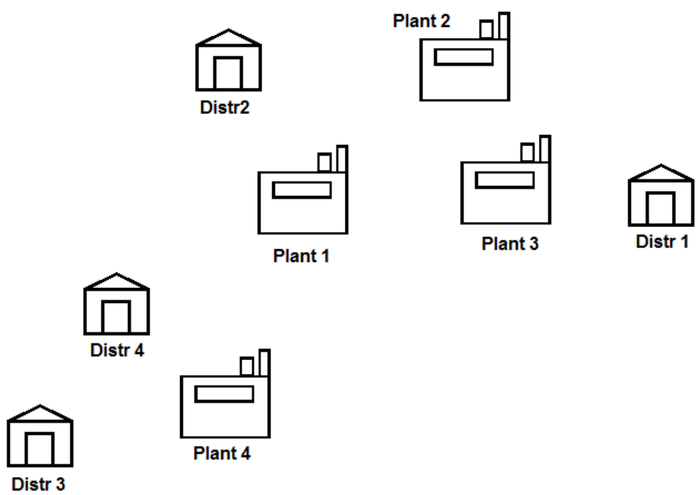

Figure 1 Description of the problem. Plant1-4 serves D1-4.

Results

Demand Uncertainty

This paper considers 3 different scenarios for the product demand (table 1). The deterministic solution for each scenario are presented in table 2.

From figure 2 it can be observed the inventory levels when the deterministic problem is solved for each scenario considered in the stochastic problem, after solving the deterministic cases proceed to resolve the stochastic programming model.

Table 1. Products demand for each distribution centers (D1-D4) for each scenario (sc1-3).

Destiny-Scenario		D1			D2			D3			D4		
Product	time	sc1	sc2	sc3	sc1	sc2	sc3	sc1	sc2	sc3	sc1	sc2	sc3
P1	t1	750	1000	1250	615	820	1025	375	500	625	923	1230	1538
	t2	2250	3000	3750	173	230	288	900	1200	1500	2550	3400	4250
	t3	375	500	625	3000	4000	5000	1800	2400	3000	3975	5300	6625
P2	t1	488	650	813	375	500	625	225	300	375	533	710	888
	t2	683	910	1138	540	720	900	300	400	500	5288	7050	8813
	t3	2250	3000	3750	1800	2400	3000	863	1150	1438	2325	3100	3875

Table 2. Solution for the deterministic cases

	Scenario 1		Scenario 2		Scenario 3	
	SC1	SC2	SC1	SC2	SC1	SC2
Cost	382081	210663	532941	269572	649097	363342
Total cost	592744		802513		1012439	
Benefit	1744418	1036129	2384058	1311079	2894902	1714612

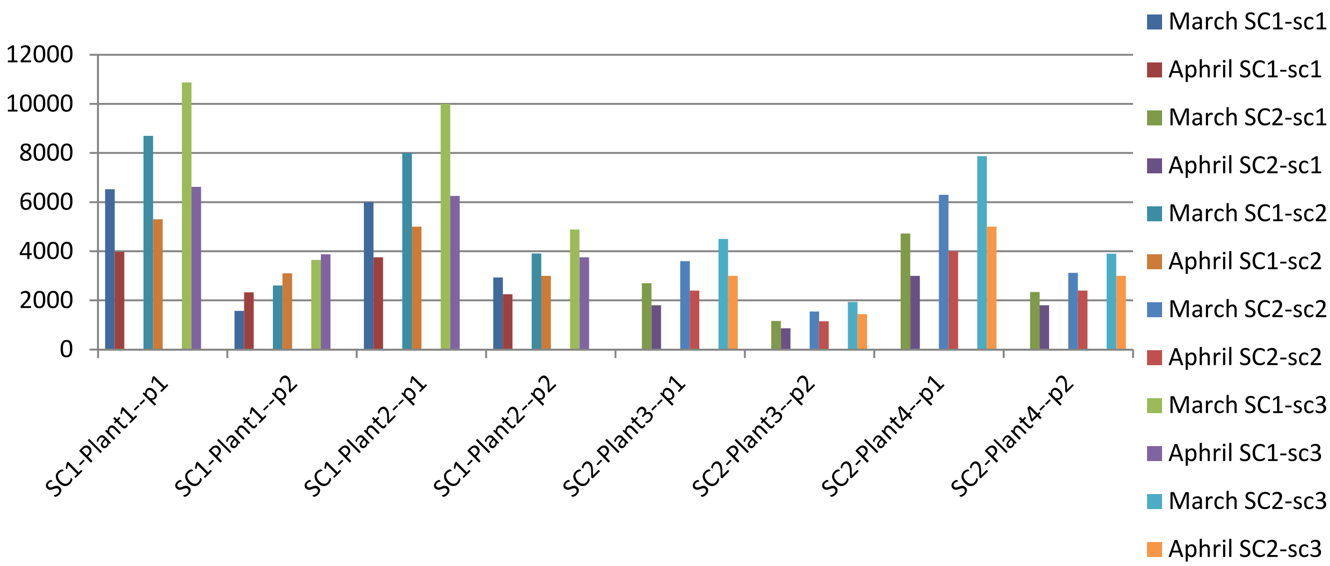

Figure 2. Optimal Inventory levels for the different Supply Chains (SC1 and SC2) at the different scenarios

Using the same case study, the proposed approach intends to obtain the production level necessary to achieve the different demands for the products (3 scenarios). The two stage stochastic programming model consists: the first stage variables which are the production and raw materials, and the second stage variables are the inventory and distribution tasks (equation 1). Some considerations are made in the problem: since the consumers in this case are the distribution centers of the Supply Chain suppose that the production centers can deliver more than the demanded in each time; because the problem needs to produce to satisfy the higher demand of the scenarios and can't storage the product at the end of the time horizon.

The solution for the stochastic model is given in tables 3-5; in the table 3 can be found the distribution tasks for the different scenarios of the problem, the table 4 contains the different inventory levels, and the production level is shown in Table 5. The solution of production levels is the same for all three scenarios, due to the need to set production levels before knowing the demand.

Table 3. Distribution tasks for each scenario.

Plant/product		Destiny	D1			D2			D3			D4		
	time\scenario		sc1	sc2	sc3	sc1	sc2	sc3	sc1	sc2	sc3	sc1	sc2	sc3
Plant 1	P1	April	0	0	0	4975	2493	10	0	0	0	923	1230	1538
		March	0	0	0	0	0	0	0	0	0	2550	3400	4250
		May	0	0	0	0	0	0	0	0	0	3975	5300	6625
	P2	April	0	0	0	2440	1226	10	0	0	0	533	710	888
		March	0	0	0	0	0	0	0	0	0	788	1050	1313
		May	0	0	0	0	0	0	0	0	0	2325	3100	3875
Plant 2	P1	April	5250	3250	1250	0	0	0	0	0	0	0	0	0
		March	2250	3000	3750	0	0	0	0	0	0	0	0	0
		May	3750	5000	6250	0	0	0	0	0	0	0	0	0
	P2	April	2749	1772	794	0	0	0	0	0	0	0	0	0
		March	683	910	1138	0	0	0	0	0	0	0	0	0
		May	2250	3000	3750	0	0	0	0	0	0	0	0	0
Plant 3	P1	April	0	0	0	0	0	0	2425	1525	625	0	0	0
		March	0	0	0	0	0	0	900	1200	1500	0	0	0
		May	0	0	0	0	0	0	1800	2400	3000	0	0	0
	P2	April	0	0	0	0	0	0	1140	753	365	0	0	0
		March	0	0	0	0	0	0	300	400	500	0	0	0
		May	0	0	0	0	0	0	863	1150	1438	0	0	0
Plant 4	P1	April	0	0	0	4165	2590	1015	0	0	0	0	0	0
		March	0	0	0	1725	2300	2875	0	0	0	0	0	0
		May	0	0	0	3000	4000	5000	0	0	0	0	0	0
	P2	April	10	10	19	1567	1095	615	627	319	10	0	0	0
		March	0	0	0	540	720	900	0	0	0	0	0	0
		May	0	0	0	1800	2400	3000	0	0	0	0	0	0

Table 4. Inventory levels.

Plant/product		sc1 (scenario 1)			sc2 (scenario 2)			sc3 (scenario 3)		
		April	March	May	April	March	May	April	March	May
PLANT 1	P1	6523	3975	0	8698	5300	0	10873	6625	0
	P2	1575	2325	0	2612	3100	0	3650	3875	0
PLANT 2	P1	6000	3750	0	8000	5000	0	10000	6250	0
	P2	2933	3350	0	3910	3000	0	4888	3750	0
PLANT 3	P1	2700	1800	0	3600	2400	0	4500	3000	0

	P2	1163	863	0	1550	1150	0	1938	1438	0
PLANT 4	P1	4725	3000	0	6300	4000	0	7875	5000	0
	P2	2340	1800	0	3120	2400	0	3900	3000	0

Table 5. Production level

PRODUCTION		April	March	May
PLANT 1	P1	120221	2	0
	P2	4348	1538	0
PLANT 2	P1	10950	0	0
	P2	5482	0	0
PLANT 3	P1	4725	0	0
	P2	2103	0	0
PLANT 4	P1	8590	0	0
	P2	4344	0	0

Market Competition Uncertainty

The proposed approach to model the SCs competition has been used to solve the same case study presented before, considering a fixed demand. This work looks for the best discount rate in the price for the products of Supply Chain 1 (Plant 1 and Plant 2), considering 4 scenarios of discount (percent) of the prices for the Supply Chain 2 (Plant 3 and Plant 4) sc1=0.1, sc2=0.2, sc3=0.3, sc4=0.4. As mentioned above this work uses the solution of the deterministic cases when the competition chooses the optimum discount rates. The best solution for the SC1is summarized by the discount rates shown in Table 6. The corresponding payoff matrix can be found in: http://cepima.upc.edu/papers/Competitive_SCs.pdf.

Table 6. Deterministic solutions for the different scenarios of the discount rate.

	Scenario SC2			
	sc1	sc2	sc3	sc4
Best solution of SC1	0.3	0.4	0.4	0.3

The solutions for the stochastic non linear model are given considering the different scenarios (tables 7-9), also this model choose the discount in the price for the Supply Chain 1 (discount of 0.3%).

Table 7. Production levels

Production Plant/product		sc1 (scenario 1)			sc2 (scenario 2)			sc3 (scenario 3)			sc4 (scenario 4)		
		April	March	May	April	March	May	April	March	May	April	March	May
PLANT 1	P1	14852	1498	0	12650	0	0	10350	0	0	9530	0	0
	P2	810	7270	0	3562	4518	0	5160	0	0	4660	0	0
PLANT 2	P1	8700	0	0	8700	0	0	8700	0	0	8700	0	0
	P2	4360	0	0	4360	0	0	4360	0	0	4360	0	0
PLANT 3	P1	3700	0	0	3700	0	0	3700	0	0	3700	0	0
	P2	1650	0	0	1650	0	0	1650	0	0	1650	0	0

	P1	0	0	0	3700	0	0	6000	0	0	6820	0	0
PLANT 4	P2	0	0	0	0	0	0	2920	0	0	3420	0	0

Table 8. Distribution tasks.

Plant/product		Destiny	D1				D2				D3				D4			
	time\scenario		sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4
Plant 1	P1	april	0	0	0	0	820	820	820	0	0	0	0	0	1230	1230	1230	1230
		March	0	0	0	0	2300	2300	0	0	0	0	0	0	3400	3400	3400	3400
		May	0	0	0	0	3700	0	0	0	0	0	0	0	5300	5300	5300	5300
	P2	april	0	0	0	0	300	500	500	0	0	0	0	0	710	710	710	710
		March	0	0	0	0	720	720	0	0	0	0	0	0	1050	1050	1050	1050
		May	0	0	0	0	2400	2200	0	0	0	0	0	0	3100	3100	3100	3100
Plant 2	P1	april	1000	1000	1000	0	0	0	0	0	0	0	0	0	0	0	0	0
		March	3000	3000	3000	0	0	0	0	0	0	0	0	0	0	0	0	0
		May	5000	5000	5000	0	0	0	0	0	0	0	0	0	0	0	0	0
	P2	april	650	650	650	0	0	0	0	0	0	0	0	0	0	0	0	0
		March	910	910	910	0	0	0	0	0	0	0	0	0	0	0	0	0
		May	3000	3000	3000	0	0	0	0	0	0	0	0	0	0	0	0	0
Plant 3	P1	april	0	0	0	0	0	0	0	0	500	500	500	500	0	0	0	0
		March	0	0	0	0	0	0	0	0	1200	1200	1200	1200	0	0	0	0
		May	0	0	0	0	0	0	0	0	2400	2400	2400	2400	0	0	0	0
	P2	april	0	0	0	0	0	0	0	0	300	300	300	300	0	0	0	0
		March	0	0	0	0	0	0	0	0	400	400	400	400	0	0	0	0
		May	0	0	0	0	0	0	0	0	1150	1150	1150	1150	0	0	0	0
Plant 4	P1	april	0	0	0	0	0	0	0	820	0	0	0	0	0	0	0	0
		March	0	0	0	0	0	0	2300	2300	0	0	0	0	0	0	0	0
		May	0	0	0	0	300	4000	4000	4000	0	0	0	0	0	0	0	0
	P2	april	0	0	0	0	200	0	0	500	0	0	0	0	0	0	0	0
		March	0	0	0	0	0	0	720	720	0	0	0	0	0	0	0	0
		May	0	0	0	0	0	200	2400	2400	0	0	0	0	0	0	0	0

The table 6 shows that in 2 deterministic cases the discount rate will be 0.4% but the global solution of the nonlinear stochastic model determines that there is better to set the discount rate in 0.3%.

The optimal solution of the SC1 (0.3 % of discount) for several scenarios of SC2 is driven by its capacity to adapt the prices, the model takes into account the global demand, and the budget capacity of the production plants. This budget capacity acts as the bottleneck of the problem, since there is a point in which don't care how much discount in the price there isn't more production capacity.

Table 9. Inventory levels.

Inventory Plant/product		sc1 (scenario 1)			sc2 (scenario 2)			sc3 (scenario 3)			sc4 (scenario 4)		
		April	March	May	April	March	May	April	March	May	April	March	May
PLANT 1	P1	13202	9000	0	11000	53000	0	8700	5300	0	8700	5300	0
	P2	0	5500	0	2552	5300	0	4150	3100	0	4150	3100	0
PLANT 2	P1	8000	5000	0	8000	5000	0	8000	5000	0	8000	5000	0
	P2	3910	3000	0	3910	3000	0	3910	3000	0	3910	3000	0
PLANT 3	P1	3600	2400	0	3600	2400	0	3600	2400	0	3600	2400	0
	P2	1550	1150	0	1550	1150	0	1550	1150	0	1550	1150	0
PLANT 4	P1	300	300	0	4000	4000	0	6300	4000	0	6300	4000	0
	P2	0	0	0	200	200	0	3120	2400	0	3120	2400	0

Finally the total cost and the benefit for the competitive case for several scenarios are shown in the next table (table 10). The preferences of the consumers have been modeled as just based on service (due date's maintenance) and customers cost, these elements have been introduced in the final objective function as previously indicated. A nominal selling price has been also introduced to maintain data integrity.

Table 10. Costs summary.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2
Total Cost	702559	100734	621159	181684	538423	264089	515516	286997
Benefit	3144863	544265	2857373	831285	2419675	1268299	2310978	1375326

CONCLUSIONS

This work introduces the use of the SC competition behavior as a specific source of uncertainty in order to optimize the management of a certain SC, proposing a stochastic non-linear programming model that jointly determines the price discount rates and the production, inventory and distribution decisions to be made in order to optimize the expected performance of this SC.

The obtained solution can be compared with the one resulting from other approaches considering that the effect of the competition can be model as part of the "SC demand uncertainty". Even this approach results in a more easy to solve two stage MILP stochastic model, the obtained results are clearly different, since the approach proposed in this contribution allows the SC manager to consider a new "control parameter" (prices or discount rates) to directly manage this source of uncertainty, obtaining improved solutions at the tactical decision level for real Supply Chain industrial problems.

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