Management of financial and consumer satisfaction risks in supply chain design

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Abstract

In this article the design of a supply chain consisting of several production plants, warehouses and distribution centers is considered introducing uncertainty and using a two stage stochastic model. The model takes into account profit over the time horizon and considers consumer satisfaction. Financial risk and the risk of not meeting the consumer satisfaction are considered and managed at the design stage. The result of the model is a set of pareto optimal curves that can be used for decision making.

1. Introduction

Supply Chains (SC), which started to be studied in the early 90s, include several decision variables: strategic, tactical and operational. Strategic decisions include the supply chain design, which consists of the determination of the optimal configuration of an entire SC network: number, location and capacity of plants, warehouses and distribution centers to be set up, the transportation links and the flows and production rates of materials.

In this work, we present a two-stage stochastic model for SC design with management of financial and consumer satisfaction risks. The model is presented next.

2. Deterministic Model

This model considers several production plants, warehouses and distribution centers. It is similar to previous SC models (Tsiakis et al., 2001). However, some modifications have been introduced. The NPV instead of the cost is used as objective function. In addition, the capacities of the plants/warehouses are considered in the determination of the capital investment and in the calculation of the operational associated costs.

2.1 Constraints

- *Mass balance:* the steady state is supposed through the SC

$$Q_{pit} = \sum_j X_{pijt} \qquad \forall\, p, j, t \tag{1}$$

$$\sum_i X_{pijt} = \sum_k Y_{pjkt} \qquad \forall\, p, j, t \tag{2}$$

$$\sum_j Y_{pjkt} \le Demand_{pkt} \qquad \forall\, p, k, t \tag{3}$$

- *Capacity constraints:* there are maximum and minimum capacity constraints for the plants and warehouses of the SC

$$\sum_p \sum_j X_{pijt} \cdot \alpha_{pi} = Cap_{it} \qquad \forall i, t \tag{4}$$

$$Cap_{it} \le \overline{Cap_i} \qquad \forall i, t \tag{5}$$

$$Cap_i^L \le \overline{Cap_i} \le Cap_i^U \qquad \forall i \tag{6}$$

$$2 \cdot \frac{\sum_p \sum_k Y_{pjkt} \cdot \beta_{pj}}{\lambda_j} \cdot SF_j = Cap_{jt} \qquad \forall\, j, t \tag{7}$$

$$Cap_{jt} \le \overline{Cap_j} \qquad \forall\, j, t \tag{8}$$

$$\sum_c B_{jc} \cdot Cap_{jc} = \overline{Cap_j} \qquad \forall\, j, t \tag{9}$$

2.2 Objective Function

The objective function is to maximize the NPV and the consumer satisfaction

$$\text{Max NPV} \quad \text{Max TCSat} \tag{10}$$

$$NPV = \sum_t \frac{CashFlow_t}{(1+ir)^{t-1}} \tag{11}$$

$$CashFlow_t = -CI = -(FCI + WC) \qquad t = 1 \tag{12}$$

$$CashFlow_1 = -\mathrm{Re}venues_t - DE_t - IE_t - Taxes_t \qquad t = 2...T \tag{13}$$

$$CashFlow_1 = -\mathrm{Re}venues_t - DE_t - IE_t - Taxes_t + WC \qquad t = T \tag{14}$$

$$FCI = \sum_i (FCI_i^L \cdot A_j + \overline{Cap_i} \cdot \gamma_i) + \sum_j \sum_c FCI_{jc} \cdot B_{jc} \tag{15}$$

$$revenues_t = \sum_p Sales_{pt} \cdot price_p \qquad \forall t, p \tag{16}$$

$$Sales_{pt} = \sum_i Q_{pit} \qquad \forall t, p \tag{17}$$

$$IE_t = \sum_i (IE_i^L \cdot A_i + \overline{Cap_i} \cdot \eta_i) + \sum_j \sum_c IE_{jc} \cdot B_{jc} \qquad \forall t \tag{18}$$

$$DE_t = \sum_i \sum_p Q_{pit} \cdot VC_{pi} + \sum_j \sum_p \sum_k Y_{pjkt} \cdot HC_{pj} + \sum_p \sum_i \sum_j X_{pijt} \cdot TC_{pij} + \tag{19}$$

$$+ \sum_p \sum_j \sum_k Y_{pjkt} \cdot TC_{pjk} + \sum_j \sum_p \sum_k \frac{\omega_j}{\lambda_j} \cdot Y_{pjkt} \cdot \beta_{pj} \qquad \forall t$$

$$Taxes_t = (revenues_t - Depreciation_t) \cdot tr \qquad \forall t \tag{20}$$

$$CSat_t = \frac{1}{n_p} \sum_p \frac{Sales_{pt}}{Demand_{pt}} \qquad \forall t \tag{21}$$

$$TCSat = \frac{1}{n} \sum_t CSat_t \qquad \forall t \tag{22}$$

3. Stochastic model

The stochastic problem is characterised by two essential features: the uncertainty in the problem data and the sequence of decisions. In our case, the demand is considered as a random variable with a certain probability distribution. The binary variables associated to the opening of a plant/warehouse as well as the continuous variables that represent the capacity of plants/warehouses are considered as first stage decisions. The fluxes of materials and the sales of products are taken as second stage or recourse variables. The objective functions are therefore the expected net present value and the expected consumer satisfaction.

4. Financial and Consumer Satisfaction Risk

The financial risk associated with a design project under uncertainty is defined as the probability of not meeting a certain target profit (Barbaro and Bagajewicz, 2002a,b). In this work, the risk of not meeting consumer satisfaction is defined in a similar way, that is, as the probability of not meeting a certain target consumer satisfaction.
A composite risk is defined using two aspiration levels or targets (a profit Ω and a consumer satisfaction Ω') as follows:

$$\text{Crisk}(x, \Omega, \Omega') = P(FO(x) < \Omega \wedge FO'(x) < \Omega') \tag{23}$$

In the case where the probabilities are independent, this risk results in the product of both risks. This is the assumption used in this article.

4.1 Risk Management

Three different objectives: NPV, consumer satisfaction and compounded risk are considered. If one uses a utility function, the compounded risk can be manipulated by changing the weights of the objectives for different aspiration levels Ω and Ω'. In order to avoid the use of binary variables the concept of downside risk (Drisk(x,Ω)), introduced by Eppen et al. (1989), is used, as explained by Barbaro and Bagajewicz (2002a,b).

5. Case Study

We considered a problem with two possible production plants locations, three warehouses and four markets. The aim of the problem is to determine the optimal SC configuration that maximises the *NPV* of the investment while maximise at the same time the consumer satisfaction.

Figure 1 shows the Pareto curve for the deterministic case. This curve was obtained maximizing the NPV and constraining the consumer satisfaction. The curve shows that only above a 66% consumer satisfaction level some trade off between the objectives exists. Below 66% of requested consumer satisfaction the solution is the same as that of the model without constraining consumer satisfaction and therefore all the pareto solutions accumulate at the end point on the left. Figure 2 shows the same curve for the stochastic model. Figures 3 and 4 show the corresponding consumer satisfaction and financial risk curves of the pareto solutions of the multiobjective stochastic problem. Unsupported solutions are suspected to exist, but this could also be the effect of the small number of scenarios (100) used. In future work this matter will be resolved.

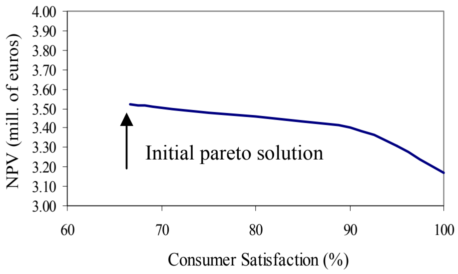

Figure 1. Deterministic Pareto Curve.

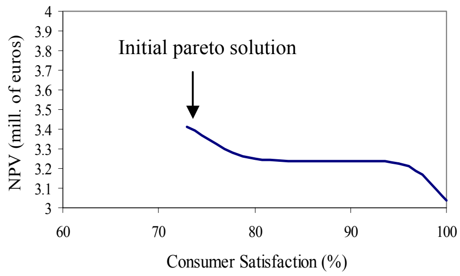

Figure 2. Stochastic Pareto Curve

Figures 4 depicts the financial risk curves associated with each point of the Pareto Optimal curve. For example the curve with no restriction on the consumer satisfaction (SP_E(CSAT)>0) is the one with largest expected NPV. As the consumer satisfaction is constrained the curves move to the left, thus reducing the expected net present value. The shape of the curves, however, remains fairly constant. The corresponding curves of consumer satisfaction risks are shown in Figure 3. The curves move to the right as the expected net present value is reduced. The shape in this case becomes steeper.

To reduce the risk associated to the consumer satisfaction the design was modified by limiting the downside risk at certain targets. In figure 5 the different risk curves associated to the penalisation of consumer satisfaction risk at 69%, 72% and 75%. When the risk is limited, the expected profit (figure 6) is reduced, that is the financial risk curves move to the left. One important thing to notice is that the consumer satisfaction risk curves do not intersect. This is because the consumer satisfaction is not maximised, but the expected net present value is. In addition, the resulting designs present a higher expected consumer satisfaction. Figure 7 shows the composite risk curves (the consumer satisfaction is not constrained). Figure 8 shows one composite risk pareto curve and another composite risk curve where the risk is constrained at a target of 75%.

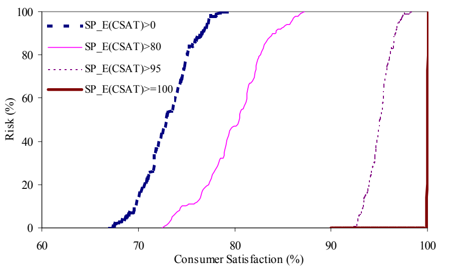

Figure 3. Consumer Sat. Pareto Risk Curves

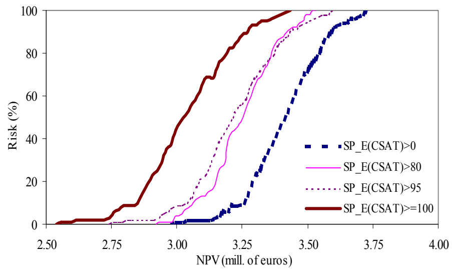

Figure 4. NPV Pareto Risk Curves

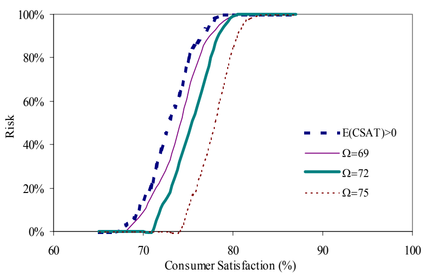

Figure 5. Consumer Sat. Risk Curves

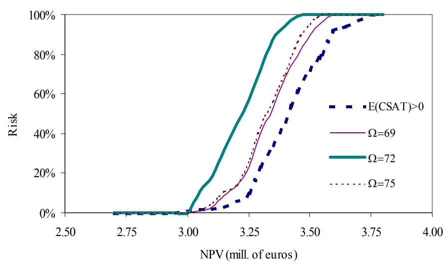

Figure 6. NPV Risk Curves

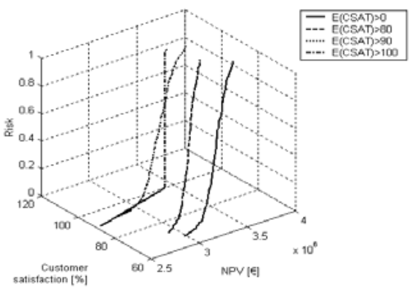

Figure 7. Composite Risk Pareto Curves

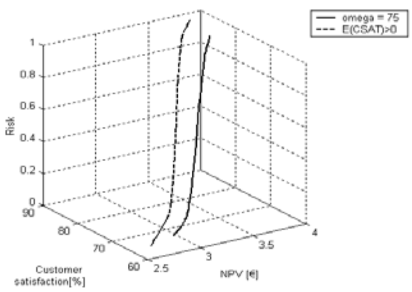

Figure 8. Composite Risk Curves

6. Conclusions

A definition of composite risk is presented and several pareto optimal curves have been obtained. A stochastic programming approach was used to manage financial and consumer satisfaction risks in the design of supply chains.

7. Nomenclature

p products
i plants
j warehouses
k markets
c discrete types
t interval times
CV_{pi} : Variable cost of *p* at *i*
CH_{pj} : Handling cost of *p* at *j*
CT_{ij}: Cost of transport between *i* and *j*
CT_{jk}: Cost of transport between *j* and *k*
ir: Interest rate
tr: Taxes rate
n: Useful plant life
n_p : Number of products
$FCI^L{}_i$, γ_i : Fixed cost coefficients at *i*
$IE^L{}_i$, η_i: Indirect expenses coefficients at *i*
IE_{jc}: Indirect expenses at *j* of *c*
$CSat_t$: Consumer satisfaction in *t*
TCSat: Total consumer satisfaction
A_i: Binary variable
(A_i =1 if i is opened, A_i =0 otherwise)
B_{jc}: Binary variable
(B_{ic} =1 if j of c is opened, B_{ic} =0 otherwise).
α_{pj}: Production capacity factor of *p* at *i*
β_{pj}: Handling capacity factor of *p* at *j*
ω_j: Inventory cost at *j*
λ_j: Turnover inventory rate at *j*
SF_j: Security design factor of *j*
$Demand_{pkt}$: Demand of *p* at *k* in *t*
$Price_p$: Price of *p*
Cap_{jc}: Capacity of *j* of *c*
Cap_{it}: Capacity of *i* in *t*
Cap_{jt}: Capacity of *j* in *t*
Cap_i: Capacity of plant *i*
Cap_j: Capacity of warehouse *j*
Q_{pit}: Amount of *p* fabricated at *i* in *t*
X_{pijt}: Amount of *p* transported from *i* to *j* in *t*
Y_{pjkt}: Amount of *p* transported from *j* to *k* in *t*

8. References

Barbaro, A.F. and M. Bagajewicz, 2002a. Managing Financial Risk in Planning under Uncertainty, Part I: Theory, AIChE Journal, Submitted.

Barbaro, A.F. and M. Bagajewicz, 2002b. Managing Financial Risk in Planning under Uncertainty, Part II: Applications, AIChE Journal, Submitted.

P. Tsiakis, N. Shah, and C. C. Pantelides, 2001; Design of Multi-echelon Supply Chain Networks under Demand Uncertainty. Ind. Eng. Chem. Res. 40, 3585-3604.

Simchi-Levi, D.; Kamisky, P.; Simchi-Levi, E., 2000; Designing and Managing the Supply Chain. Concepts, Strategies, and Case Studies. Irwin McGraw-Hill.

9. Acknowledgements

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