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Abstract

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Keywords

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Stochastic Modeling and Optimization of Multi-plant Capacity Planning Problem

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Abstract: In this paper the problem of capacity planning under risk from demand and price/cost uncertainty of the finished products is addressed. The deterministic model is extended into a two-stage stochastic model with fixed recourse by means of various expected levels of demand as random. A recourse penalty is also included in the objective for both shortage and surplus in the finished products. The model is analyzed to quantify the risk using Markowitz mean-variance model.

Keywords: Capacity planning, stochastic optimization, AMPL/CPLEX, Markowitz-mean variance

1. Introduction

In general, capacity planning problems are always difficult to solve when considering multiple plants and customer locations worldwide (i.e. selling products overseas). Due to the current era of globalization & multi-national companies, it becomes even more crucial than before to develop robust approaches to deal with capacity planning problems.

In order to deal with the life cycle dynamics and demand uncertainty, flexibility provisions and long term capacity are the main challenges in manufacturing. Largely, these challenges leads to lower capacity utilizations as there is increased competition on stagnating markets, high product differentiation, and shortened product life cycles (Francas *et al.* 2009). Traditionally, majority of the state-of-the-art approaches in capacity planning approaches are based on the two-stage stochastic programming paradigm (Bertrand 2003; Van Mieghem 2003). In first stage, decisions on choice of technology, capacity plans, and manufacturing flexibility provisions is made under uncertainty. Then, in next stage (recourse stage), manufacturing decisions take place where all uncertainties are known. This approach has been used by Fine and Freund (1990) and Van Mieghem (1998) for capacity planning and investments. Another set of approaches in this area tried to increase the process flexibility by producing products at various plants in the network. Jordan and Graves (1995) developed chaining principles, through simulation and analytical methods, where several plants and products are connected by a chain structure. They argued that such manufacturing networks are fully flexible. Further, Francas et al. (2009) showed that this approach is robust in a dynamic setting with fluctuating demands along product life cycles. Following this, various studies such as Mak and Shen (2009), Santoso et al. (2005) have been done in the area of capacity & flexibility planning. Most these approaches are based on deterministic models and optimisation, which are least useful when considering real planning problems which are coupled with stochastic behaviours and uncertainties.

These planning problems always accompanied by some uncertainties in terms of demand, selling price and cost of the raw material owing to forecasting error, market fluctuation and currency exchange etc. Solution obtained from deterministic models may not be reliable and can cause big loss to the concerned

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company. In the literature, stochastic optimization has been widely used to solve such kind of problems to get better and robust solutions. In the present paper, the importance of stochastic optimization problems has been realized in a global multi-plant capacity planning problems.

2. Problem Background

ABC Incorporated is a producer of printed circuit boards used in custom computer assembly. ABC produces three types of boards, which we will refer to as boards A, B and C. Demand for ABC's products has been steadily increasing and management recognizes that total demand for its boards will soon exceed production capacity.

Because of increasing demand for its products, ABC Inc. is currently facing a decision of how to increase capacity while minimizing the risk associated. ABC has two existing plants in Austin and Paris and seven locations are being considered for a new plant. These consist of two cities in the United States (Charleston, S.C. and Mobile, AL) and five other locations currently simply defined by country (Australia, India, Malaysia, South Africa, and Spain). The company's customers have been aggregated to eight customers' zones (i.e. Malaysia, China, France, Brazil, US Northeast, US Southeast, US Midwest, and US West). Customers are paying good amount for the products because of increasing requirement of PCB. Considering this company ABC will give the customers a good discount if it cannot meet the desired demand (considered as a shortage cost). Also, over production will increase the inventory, thereby increasing the storage cost (considered as surplus cost). The data available for analysis of this problem is contained in given in appendix. Following parameters are used.

- *Duty- This contains the duty rate charged from each plant to each customer. This rate is multiplied by the selling price to get the cost per unit paid in duty to ship into one country from another.*
- *Fixed Cost- This contains the fixed cost of plant operation including capital costs, insurance, management etc. These costs depend on the capacity level of the plant (given in thousands of units).*
- *Forecast- This contains forecasted demand for each product by customer. Volume is in thousands of units.*
- *F&WH Cost- This contains freight & warehousing cost per unit from each plant to each customer (which are independent of product type).*
- *Price- It contains the selling price of each product for each customer.*
- *Variable Cost - It contains the variable cost of each product at each plant.*
- *Shortage Cost: It contains the cost associated with not meeting the demand.*
- *Surplus Cost: It contains the cost of overproducing the products.*

The aim is to maximize the profit, while minimizing the risk associated with it. Cost namely, shortage cost and surplus cots are the recourse penalty, incurred by the company in second stage. A deterministic model is developed first, which is the base for the analysis. It is followed by, a 2 stage stochastic optimization model. Later, results obtained in the analysis are presented. Finally, conclusion of the current work is shown with some topics on future scope.

2.1. A Deterministic model:

Let $p \in P$ represents the set of plants, $j \in J$ index the set of customers, and $k \in K$ index, the set of finished products. These products are produced n period of time indexed by $t \in T$ to meet the pre-specified demand during each time period. A typical capacity planning problem will consists of following objective and constraints set. The problem is formulated as mixed integer linear programming model.

Indices:

i: index of existing plants.

j=index of customers

k=index of products
l= index of prospective plant locations
p=index of total plants (includes existing and prospective both)
c1=index of current capacity for existing plant
c2=index of capacity for prospective plant locations

The set of parameters used in the study includes

FC_{lc2}=Fixed cost for setting up a new plant of capacity c2 in location l.
FC_exp_i= Fixed expansion cost of existing plant i.
x_{ij}=Number of product sold from existing plant I to customer j.
x_{lj}= Number of product sold from prospective plant location l to customer j.
x_{pj}=Number of product sold from all plants (existing and prospective both) p to customer j.
fwh_{pj}=freight and warehousing charge from plant p to customer j.
$duty_{pj}$=duty rate from plant p to customer j
$prod_{pjk}$=number of k product sold from plant p to customer j.
$prod_{ljk}$=number of k product sold from plant location l to customer j.
$prod_{ijk}$=number of k product sold from existing plant i to customer j.
VC_{pk}=Variable cost of product k to plant p.
SP_{jk}= Sales price of product k to customer j.
Cap_{lc2}= Capacity c2 of plant location l (i.e. prospective plant l).
Cap_upper_i=Upper limit of capacity for existing plant i (12000000 units)
Cap_lower_i=Lower limit of capacity for existing plant i (1,000 units)
Dem_{jk}=Demand of product k from customer j.

Following decision variables are used in the formulation

$$z_{lc2} = \begin{cases} 1, \text{if plant of capacity c2 is setup at location l} \\ 0, \text{otherwise} \end{cases}$$

$$y_{pj} = \begin{cases} 1, \text{ if there is a shipment from plant p to customer j} \\ 0, \text{otherwise} \end{cases}$$

$$w_{ic1} = \begin{cases} 1, \text{if } \sum_{j=1}^{J} x_{ij} > Cap_i \quad \forall i \in I \\ 0, \text{otherwise} \end{cases}$$

The mathematical models for the components of the objective function is given as

a. Fixed cost:

$$TFC = \sum_{l=1}^{L} \sum_{c2=1}^{C2} FC_{lc2} \times Z_{lc2} \tag{1}$$

b. Expansion cost:

$$TFC\_\exp = \sum_{i=1}^{I} FC\_\exp_i \times w_{ic1} \tag{2}$$

c. Freight and Warehousing cost:

$$TFWH = \sum_{p=1}^{P} \sum_{j=1}^{J} fwh_{pj} \times x_{pj} \times y_{pj} \tag{3}$$

d. Duty cost:

$$TDC = \sum_{p=1}^{P}\sum_{j=1}^{J} duty_{pj} \times x_{pj} \times y_{pj} \tag{4}$$

e. Variable cost (i.e. raw material cost)

$$TVC_k = \sum_{p=1}^{P}\sum_{j=1}^{J} prod_{pjk} \times y_{pj} \times VC_{pk} \quad \forall k \in K \tag{5}$$

f. Sales price

$$TSP_k = \sum_{p=1}^{P}\sum_{j=1}^{J} prod_{pjk} \times y_{pj} \times SP_{jk} \quad \forall k \in K \tag{6}$$

Whereas,

$$x_{pj} = \sum_{k=1}^{K} prod_{pkj}\ ,\ x_{lj} = \sum_{k=1}^{K} prod_{lkj} \text{ and } x_{ij} = \sum_{k=1}^{K} prod_{ikj}$$

The above objective is subjected to following set of constraints

1. Plant capacity constraints (prospective plants)

$$\sum_{j=1}^{J} x_{lj} <= \sum_{c2=1}^{C2} Cap_{lc2} \times z_{lc2} \quad \forall l \in L \tag{7}$$

2. Plant capacity constraints (existing plant for expansion)

$$Cap\_lower_i \le \sum_{j=1}^{J} x_{ij} \le Cap\_upper_i \quad \forall i \in I \tag{8}$$

3. Demand Constraints

$$\sum_{p=1}^{P} prod_{pjk} \ge dem_{jk} \quad \forall j \in J, \forall k \in K \tag{9}$$

4. Single plant constraints

$$\sum_{l=1}^{L}\sum_{c2=1}^{C} z_{lc2} = 1 \tag{10}$$

Objective function: A profit maximization objective function is considered as the difference between revenue from product sales and the cost incurred. The various cost components are: Fixed cost (both due to expansion of existing plants and setting up a new plant), Raw material cost, and Freight and Warehousing charge, Duty rate, given as;

$$Max\ Obj_0 = \sum_{k=1}^{K} (TSP_k - TVC_k) - TDC - TFWH - TFC\_\exp - TFC \tag{11}$$

2.2. A Stochastic model

In this section, a stochastic method based upon scenario analysis has been used to provide reliable and practical results for the optimization. Various related literature are reviewed to determine the structure of scenario tree, where, a collection of scenarios is generated that best captures and describes the trend of product prices of the raw materials and the sales values (prices) of the saleable products for a representative period of time based on available historical data. A total of three scenarios namely good, average and bad are found most of the time in global capacity planning problems. Thus, the same approach has been utilized in this paper. In order to collect data across random parameters namely demand and price/cost, a deviation of (+10%) from the average scenario and a deviation of (-10%) from the average scenario is assigned to both good and bad scenario. All scenarios are assumed to be equally probable i.e.

$$p_s = 1/3, \sum_{s \in S} p_s = 1 \tag{12}$$

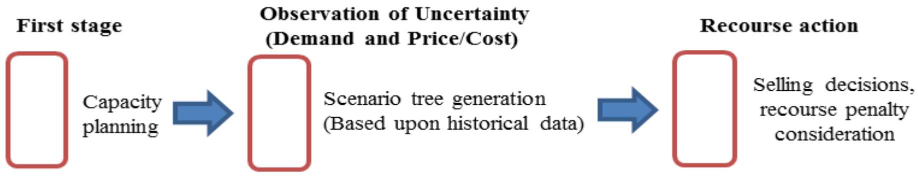

Figure 1: Framework for two stage stochastic model

2.2.1. Scenario tree structure

In the present analysis, two random parameters namely price/cost and demand constitutes the scenario tree. All three scenarios of the parameter price are checked against each individual demand scenario, and the best demand and price scenario is used with the introduction of a decision variable. A scenario tree will look like (figure 2)

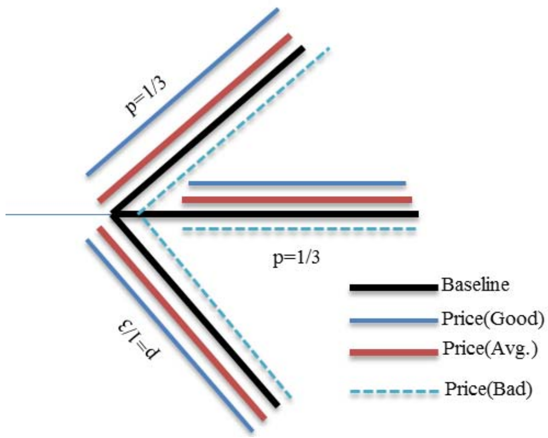

Figure 2 Scenario tree structure

2.2.1.1. Risk model 1

The approach adopts the classical Markowitz mean-variance model to handle randomness in the objective function coefficients and constraints. The expected profit is maximized, whereas the magnitude of operational risk due to variation in price/cost is minimized.

2.2.1.2. Expectation of the objective function

To represent the different scenarios accounting for uncertainty in prices, the price-related random objective function coefficients comprising: (1) TSP_{ks} for the sales price of k^{th} product in scenario s. (2)TVC_{ks} for the variable cost (i.e. raw material cost) for the product *k* in scenario s with an associated probability p_s (see equation 5 and 6). Since the objective function given by Eq. (10) is linear, it is straightforward to show that the expectation of the random objective function with random price coefficients is given by:

$$Max\ E\left[Obj^0\right] = \sum_{s=1}^{S}\sum_{k=1}^{K} p_s (TSP_{ks} - TVC_{ks}) - TDC - TFWH - TFC\_\exp - TFC \quad (13)$$

Variance in the objective function: Sticking with the concept of variability calculation by Markowitz, the variance in the objective function is given by:

$$Var(Obj^0) = \sum_{s=1}^{S} p_s \left(Obj_s^0 - E\left[Obj^0\right]\right)^2 \quad (14)$$

In equation (13) Obj_s^0 is the objective function corresponding to the scenario s and E [Obj[1]] is calculated from equation (13). Thus, the overall objective function will look like

$$Max\ \ obj^1 = E\left[Obj^0\right] - \Theta \times Var\left(Obj^0\right) \tag{15}$$

The objective function (15) is solved subjected to constraints (7-10), with Θ as the risk tradeoff parameter (to reduce the risk for expected profit). Θ can take the value in range (0, inf).

2.2.2 Modeling demand uncertainty:

Uncertainty in price/cost will reflect in the objective function; however demand uncertainty will affect both problem constraints and objective function. Uncertainty in market demand introduces randomness in constraints for production requirements of intermediates and saleable products as given by Eq. (4). The sampling methodology employed for scenario construction is similar to the case of price uncertainty. Compensating slack variables accounting for shortfall and/or surplus in production are introduced in the stochastic constraints with the following results: (1) inequality constraints (equation 9) are replaced with equality constraints, and (2) penalties for feasibility violations are added to the objective function of equation 13. The recourse penalty due to demand is given by:

$$RP_{dem} = \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{s=1}^{S} p_s\left(prod_{pks}^{+} \times Cost_k^{+} - prod_{pks}^{-} \times Cost_k^{-}\right) \tag{16}$$

$$\sum_{p=1}^{P}\sum_{s=1}^{S} prod_{pjks} + \sum_{p=1}^{P}\sum_{s=1}^{S} prod_{pks}^{+} - \sum_{p=1}^{P}\sum_{s=1}^{S} prod_{pks}^{-} = dem_{jks} \quad \forall j \in J, \forall k \in K \tag{17}$$

In equation 16, RP_{dem} is the recourse penalty due to demand, which includes overproduction and underproduction penalty, $Cost^+$ and $Cost^-$ are the costs associated with overproduction and underproduction. Equation (17) is the stochastic demand constrains. Thus, combining equation (16) with the objective function shown in equation (15) will look like;

$$Max\ \ obj^2 = E\left[Obj^0\right] - \Theta \times Var\left(Obj^0\right) - RP_{dem} \tag{18}$$

The objective function is subjected to deterministic constraints shown in equation (7, 8, and 10) and stochastic constraint (16). The analysis is done by varying risk parameter.

<u>2.2Risk model 2</u>

In this model, another risk parameter has been introduced to minimize the variance associated expected recourse penalty. This can be considered as an operational risk minimization strategy. Let Var (RP_{dem}) be the variance of recourse penalty for the second stage cost, presented as.

$$Var(RP_{dem}) = \sum_{s \in S} p_s\left(\xi_s - E[RP]\right)^2 \tag{19}$$

In equation 19, ξ_s is the recourse penalty in scenario s.

$$Max\ \ Obj^3 = E\left[Obj^0\right] - \Theta \times Var\left(Obj^0\right) - E\left[RP\right] - \Psi \times Var\left(RP\right) \tag{20}$$

In above equation, parameter ψ denotes the operational risk factor, and the model is solved subject to constraints (7, 8, 10, and 17). Similar to risk parameter Θ, risk parameters ψ can take the values in range (0, INF.) The higher the value of Θ or ψ, the less is the variability in the solution but as the expense of reduced profit. There is always a trade-off between risk factor and expected profit.

3. Computational results

In capacity planning problem, robustness can be defined as the flexibility measure of the model to respond in the face of uncertainty and any unplanned events. Computational results obtained in the analysis are presented. A description of the underlying dataset is given below:

3.1. Analysis of the results:

Tables 1 tabulate the computational results for the implementation of Risk Model I over a range of values of risk parameter Θ alone. As, it can be seen from the figure the corresponding risk factor alone is not able to measure the risk properly. A plot showing the variation in expected profit by varying risk factor Θ is shown in figure. The extreme Θ values are selected for further analysis. Risk model 2 is analyzed over a range of values of the operational risk parameter ψ with respect to the recourse penalty costs, for three representative cases of Θ = 1.0E–07, 1E–10, and 1.0E–5, respectively. An example of the detailed results is presented in Table 6 for ψ= 2.95E-03 (Θ = 1.0E–07) of the first case. Starting values of the first-stage deterministic decision variables have been initialized to the optimal solutions of the deterministic model. Fig. 3 depicts the corresponding efficient frontier plot for Risk Model II while Fig. 4 provides the plot of the expected profit for different levels of risk. After optimizing the problem, it was found that the new plant should be set-up in South Africa with a capacity of 6000K. Also, the existing plants viz. Austin and Paris need to be expanded to the capacities of 12000K and 8000K respectively. A total of 331500 units of product was in surplus, whereas, 178300 units of product was in shortage. Analysis at all risk factors yields the maximum profit equal to $24565.9.

Table 1: Computational results for risk model 1

Sl.no	risk factor	optimal value	expected profit	recourse penalty
1	1.00E-10	31281.0	36376.6	5095.15
2	1.00E-09	32754.6	37719.5	4959.77
3	1.00E-08	31810.7	37045.9	5183.84
4	1.00E-07	32419.9	37858.1	4933.66
5	1.50E-07	30421.7	32222.9	4987.2
6	1.00E-06	27552.1	37775.3	5144.51
7	1.50E-06	24632.2	35944.6	5642.5
8	1.75E-06	24444.7	38326.5	5035.03
9	1.80E-06	23754.9	38023.7	5123.65
10	1.90E-06	22392.7	37067.4	4933.66
11	1.95E-06	23576.6	38450	5020.04
12	1.00E-05	2067.97	10177.8	7823.48
13	1.01E-05	1595.99	9893.76	7912.55
14	1.05E-05	1647.71	9829.88	7806.1
15	1.05E-05	1524.63	2815.42	8024.56
16	1.10E-05	1674.35	2711.32	7696.59
17	1.15E-05	1425.89	2685.32	8563.65

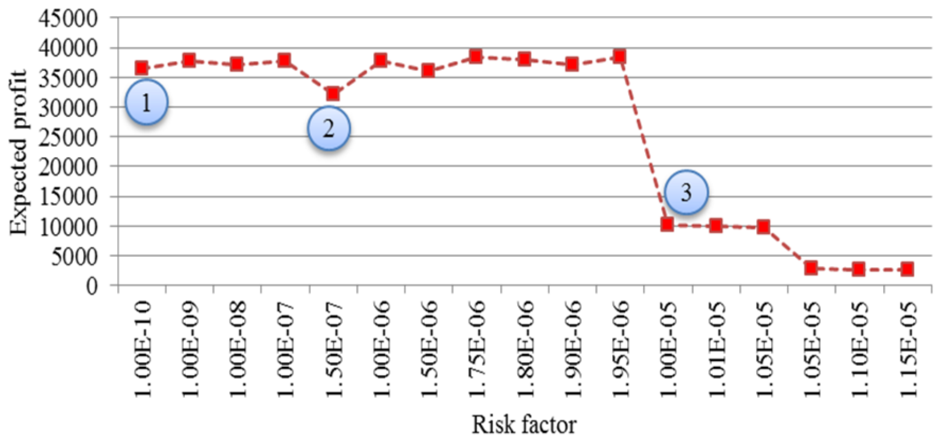

Figure 2 Plot of expected profit at different risk levels (Θ) in risk model 1 values represents the selected risk factor values for the analysis of risk model 2.

Table 2: Computational results for risk model 2 $\Theta = 1.0E-07$

Risk Factor ψ	Optimal Objective value	Expected Variation in profit (E+07)	Expected recourse penalty	Expected variation in recourse penalty	Expected profit E[Obj0]	μ	σ
1.00E-05	31863.5	5.78	4933.6	12151300	38514.2	33580.6	8363.69
1.00E-04	30638.6	5.74	4951.26	12240000	38330.6	33379.3	8345.06
1.50E-04	29853	4.78	4924.69	12106200	37891.5	32966.8	7739.91
1.00E-03	17932.9	4.78	4924.69	12106200	37790.1	32865.4	7739.91
1.50E-03	14463.9	4.72	4924.69	12106200	37570.8	32646.1	7701.05
1.75E-03	9201.26	4.72	4924.69	12106200	36297.2	31372.5	7701.05
2.00E-03	8222.19	4.72	4924.69	12106200	35952.2	31027.5	7701.05
2.50E-03	1598.54	3.95	4196.01	8952880	30598.4	26402.4	6960.81
2.60E-03	2516.37	3.95	4148.09	8770310	29315.7	25167.6	6947.68
2.70E-03	798.632	3.95	4098.82	8552460	29137.8	25039	6931.99
2.80E-03	1018.82	3.95	3914.7	7924960	28309.6	24394.9	6886.58
2.90E-03	327.881	3.95	3855.5	7722050	27777.6	23922.1	6871.83
1.00E-02	228.215	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.20E-02	228.215	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.30E-02	228.215	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.50E-02	228.215	1.95	3244.3	7208635	24565.9	21321.6	5168.04
2.00E-02	228.215	1.95	3244.3	7208635	24565.9	21321.6	5168.04

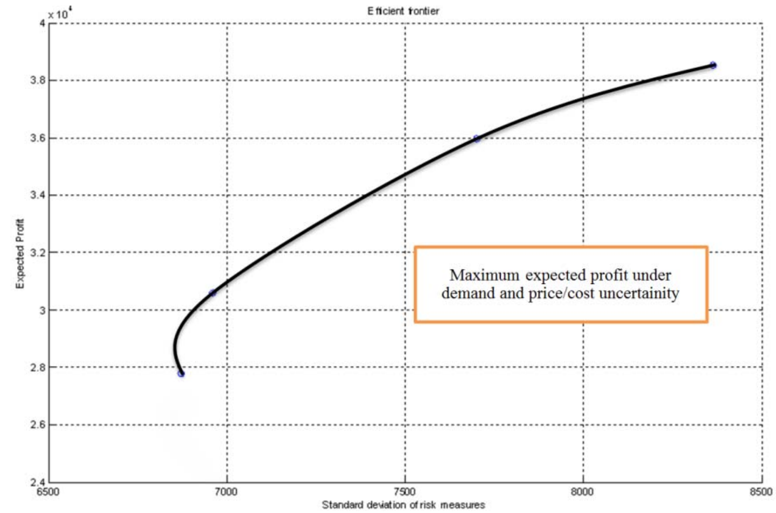

Figure 3: Efficient frontier of risk model 2 (Θ=1E-07). Reward is measured in terms of expected profit, whereas risk is measured in terms of standard deviation of initial objective and recourse penalty.

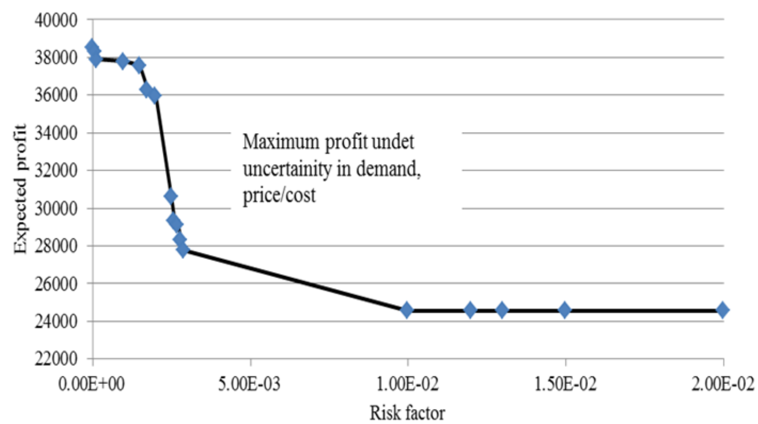

Figure 4. Plot of expected profit at different risk levels (ψ), economic risk factor (Θ=1.0E-07)

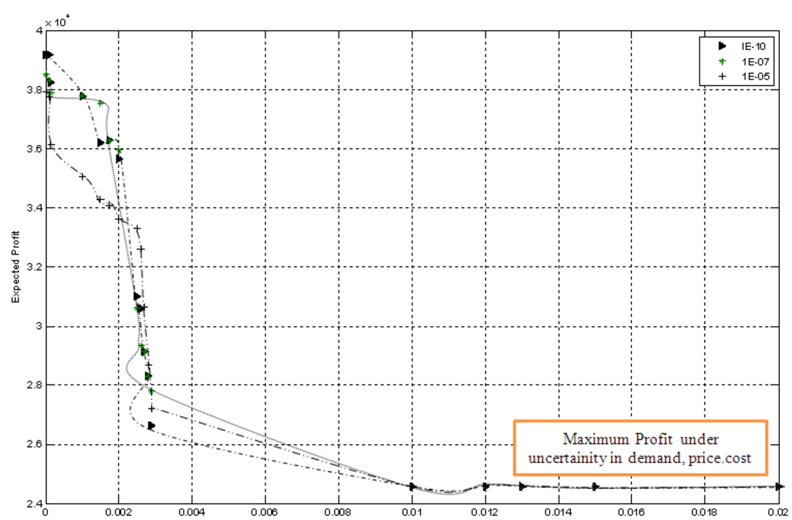

Figure 5. Plot of expected profit at different risk levels (ψ), economic risk factor (Θ=1.0E-10, 1.0E-07, 1.0E-05)

Table 3: Computational results for risk model 2 $\Theta = 1E-10$

Risk Factor	Optimal Objective value	Expected Variation in profit (E+07)	Expected recourse penalty	Expected variation in recourse penalty	Expected profit (E[Obj0])	μ	σ
1.00E-05	32353.984	5.78	4956.8	14151300	39185	34228.2	8482.41
1.00E-04	31687.399	5.76	4951.26	13240000	39178.2	34226.9	8416.65
1.50E-04	31492.126	4.78	4924.69	13106200	38242.1	33317.4	7804.24
1.00E-03	30879.727	4.78	4924.69	13106200	37790.1	32865.4	7804.24
1.50E-03	30758.065	4.75	4924.69	13106200	36214.1	31289.4	7785.00
1.75E-03	18256.45	4.72	4924.69	11106200	36297.2	31372.5	7635.85
2.00E-03	15698.52	4.72	4924.69	11106200	35661.9	30737.2	7635.85
2.50E-03	10876.32	3.95	4196.01	8456441	30998.4	26802.4	6925.06
2.60E-03	8565.27	3.95	4148.09	8456441	30598.4	26450.3	6925.06
2.70E-03	3569.56	3.92	4098.82	8378221	29137.8	25039	6897.70
2.80E-03	1685.48	3.92	3914.7	7924960	28309.6	24394.9	6864.76
2.90E-03	965.31	3.92	3855.5	7722050	26640.8	22785.3	6849.97
1.00E-02	798.21	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.20E-02	522.89	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.30E-02	522.89	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.50E-02	522.89	1.95	3244.3	7208635	24565.9	21321.6	5168.04
2.00E-02	522.89	1.95	3244.3	7208635	24565.9	21321.6	5168.04

Table 4: Computational results for risk model 2 $\Theta = 1E - 5$

Risk Factor	Optimal Objective value	Expected Variation in profit (E+07)	Expected recourse penalty	Expected variation in recourse penalty	Expected profit (E[Obj0])	μ	σ
1.00E-05	30654.3	5.78	4899.64	1.18E+07	37954.5	33054.9	8342.66
1.00E-04	29429.4	5.74	4855.02	1.18E+07	37762.9	32907.9	8318.65
1.50E-04	28643.8	4.78	4769.57	1.18E+07	36149.9	31380.3	7720.1
1.00E-03	16723.7	4.78	4614.76	1.18E+07	35068.3	30453.5	7720.1
1.50E-03	13254.7	4.72	4365.72	1.18E+07	34289.8	29924.1	7681.15
1.75E-03	8700.9	4.72	4314.62	1.18E+07	34091.4	29776.8	7681.15
2.00E-03	7721.83	4.72	4295.37	9012569	33626.5	29331.1	7497.5
2.50E-03	2016.01	3.95	4153.84	8598247	33326.2	29172.3	6935.29
2.60E-03	1098.18	3.95	3969.4	8339282	32618.1	28648.7	6916.59
2.70E-03	497.876	3.95	3955.96	8339282	30661	26705.1	6916.59
2.80E-03	718.064	3.95	3676.79	8339282	28685.9	25009.2	6916.59
2.90E-03	316.921	3.95	3638.76	8159832	27216.4	23577.7	6903.61
1.00E-02	217.255	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.20E-02	217.255	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.30E-02	217.255	1.95	3244.3	7208635	24565.9	21321.6	5168.04
1.50E-02	217.255	1.95	3244.3	7208635	24565.9	21321.6	5168.04
2.00E-02	217.255	1.95	3244.3	7208635	24565.9	21321.6	5168.04

Table 5. Detailed results (ψ=2.9E-03, Θ=1.0E-07)

Sl. no	Parameter	Value
1	Total fixed cost	$781000
2	Total fright and warehousing cost	$10218.5
3	Total duty charge	$4698.77
4	Total variable cost (A)	$22280.3
5	Total variable cost (B)	$23480.2
6	Total variable cost (B)	$36137.1
7	Total sales	$905592
8	Variance in Recourse	7722050
9	Variance in objective	3.95+07
10	Expected Profit	$27777.6
11	Expected Recourse penalty	3855.5
12	Surplus product	331500 units
13	Shortage product	178300 units

Table 6 (a): Results on number of products shipped from plant to customer

Plant	Customer	Scenario	x_A	x_B	x_C	x
AUSTIN	BRAZIL	AVG	0	0	0	0
AUSTIN	BRAZIL	BAD	0	0	0	0
AUSTIN	BRAZIL	GOOD	0	0	0	0
AUSTIN	CHINA	AVG	0	0	0	0
AUSTIN	CHINA	BAD	0	0	0	0
AUSTIN	CHINA	GOOD	0	0	0	0
AUSTIN	FRANCE	AVG	0	0	0	0
AUSTIN	FRANCE	BAD	0	0	0	0
AUSTIN	FRANCE	GOOD	0	0	0	0
AUSTIN	MALAYSIA	AVG	0	0	0	0
AUSTIN	MALAYSIA	BAD	88.8225	380.33	0	469.15
AUSTIN	MALAYSIA	GOOD	111.275	0	0	111.275
AUSTIN	USM	AVG	544.9	1723.5	2005.64	4274.03
AUSTIN	USM	BAD	0	1723.4	1995.75	3719.15
AUSTIN	USM	GOOD	528.696	1641.5	2439.25	4609.48
AUSTIN	USN	AVG	68.7	0	0	68.7
AUSTIN	USN	BAD	61.83	0	43.47	105.3
AUSTIN	USN	GOOD	4.87625	0	0	4.87625
AUSTIN	USS	AVG	999.7	684.49	0	1684.19
AUSTIN	USS	BAD	0	788.3	1370.07	2158.37
AUSTIN	USS	GOOD	1028.98	0	0	1028.98
AUSTIN	USW	AVG	1804	2925.5	1243.6	5973.09
AUSTIN	USW	BAD	1623.6	2805.2	1119.24	5548.04
AUSTIN	USW	GOOD	1913.71	2963.7	1367.96	6245.4
AUSTRALIA	BRAZIL	AVG	0	0	0	0
AUSTRALIA	BRAZIL	BAD	0	0	0	0
AUSTRALIA	BRAZIL	GOOD	0	0	0	0
AUSTRALIA	CHINA	AVG	0	0	0	0
AUSTRALIA	CHINA	BAD	0	0	0	0
AUSTRALIA	CHINA	GOOD	0	0	0	0
AUSTRALIA	FRANCE	AVG	0	0	0	0
AUSTRALIA	FRANCE	BAD	0	0	0	0
AUSTRALIA	FRANCE	GOOD	0	0	0	0
PARIS	BRAZIL	GOOD	0	13.75	0	13.75
PARIS	CHINA	AVG	0	0	1629.3	1629.3
PARIS	CHINA	BAD	0	446.411	0	446.411
PARIS	CHINA	GOOD	119.593	344.19	0	463.783
PARIS	FRANCE	AVG	655.275	292.987	1790.8	2739.062
PARIS	FRANCE	BAD	1265.4	435.947	1611.72	3313.067
PARIS	FRANCE	GOOD	1475.91	67.98	1969.88	3513.77
PARIS	MALAYSIA	AVG	0	231.187	1301.6	1532.787
PARIS	MALAYSIA	BAD	0	0	1171.44	1171.44
PARIS	MALAYSIA	GOOD	256.931	0	1431.76	1688.691
PARIS	USM	AVG	0	0	211.862	211.862
PARIS	USM	BAD	490.41	0	0	490.41
PARIS	USM	GOOD	0	0	0	0
PARIS	USN	AVG	0	316.387	48.3	364.687

Table 6 (b): Results on number of products shipped from plant to customer

Plant	Customer	Scenario	x_A	x_B	x_C	x
PARIS	USN	BAD	0	457.007	0	457.007
PARIS	USN	GOOD	0	93.72	53.13	146.85
PARIS	USS	AVG	0	0	1522.3	1522.3
PARIS	USS	BAD	899.73	0	0	899.73
PARIS	USS	GOOD	0	498.63	1674.53	2173.16
PARIS	USW	AVG	0	0	0	0
PARIS	USW	BAD	0	0	0	0
S_AFRICA	BRAZIL	AVG	163.5	243.687	740.7	1147.887
S_AFRICA	BRAZIL	BAD	147.15	391.577	666.63	1205.357
S_AFRICA	BRAZIL	GOOD	109.156	0	814.77	923.926
S_AFRICA	CHINA	AVG	3158.3	544.087	0	3702.387
S_AFRICA	CHINA	BAD	2842.47	215.526	1466.37	4524.366
S_AFRICA	CHINA	GOOD	3283.84	0	1792.23	5076.07
S_AFRICA	FRANCE	AVG	750.725	0	0	750.725
S_AFRICA	FRANCE	BAD	0	0	0	0
S_AFRICA	FRANCE	GOOD	0	0	0	0
S_AFRICA	MALAYSIA	AVG	399	0	0	399
S_AFRICA	MALAYSIA	BAD	270.278	0	0	270.278
S_AFRICA	MALAYSIA	GOOD	0	0	0	0
S_AFRICA	USM	AVG	0	0	0	0
S_AFRICA	USM	BAD	0	0	0	0
S_AFRICA	USM	GOOD	0	0	0	0
S_AFRICA	USN	AVG	0	0	0	0
S_AFRICA	USN	BAD	0	0	0	0
S_AFRICA	USN	GOOD	0	0	0	0
S_AFRICA	USS	AVG	0	0	0	0
S_AFRICA	USS	BAD	0	0	0	0
S_AFRICA	USS	GOOD	0	0	0	0
S_AFRICA	USW	AVG	0	0	0	0
S_AFRICA	USW	BAD	0	0	0	0
S_AFRICA	USW	GOOD	0	0	0	0
*0 value indicates the corresponding location is not selected to set up a new plant, or no shipment is done from the plant to customer location						

4. Conclusion and future scope

In this work, a systematic methodology for developing explicit yet robust stochastic programming models for capacity planning problems by simultaneously accounting for uncertainties in commodity prices and cost, product demands is analyzed. In addition, the importance of economic and operational risk in decision-making under uncertainty in used in form of economic and operational risk factors. The analysis was done on a randomly generated dataset. Analysis on real world problem such as energy planning etc. is a topic of future research. In addition, minimization of downside risk measures using semi-variance approach can be used instead to minimizing both upside and downside risk measures.

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Appendix:

Ampl code:

(Model file for risk 2 model)

```
set PRODUCT;        # number of products
set PLANT;          #exisitng+prospective locations
set LOCATION;       # prospective locations
set EXISTING;       #existing plants
set CUSTOMER;
set CAPACITY;
set SCENARIO;
set PEN;            # penalty type

param duty {PLANT,CUSTOMER}                        >= 0;
param fwh {PLANT,CUSTOMER}                         >= 0;
param selling_price {CUSTOMER,PRODUCT,SCENARIO}         >= 0;
param demand {CUSTOMER,PRODUCT,SCENARIO}                >= 0;
param variable_cost{PLANT,PRODUCT,SCENARIO}             >= 0;
param fixed_cost{LOCATION,CAPACITY}        >= 0;
#param fc_exp{EXISTING,CAPACITY}                    >= 0;
param over_cost{PRODUCT}      >=0;
param penalty{PRODUCT,PEN}    >=0;



var x_A {i in PLANT,j in CUSTOMER, s in SCENARIO}                 >= 0;
# Quantity of A shipped from Plant i to Customer j
var x_B {i in PLANT,j in CUSTOMER, s in SCENARIO}                 >= 0;
# Quantity of A shipped from Plant i to Customer j
var x_C {i in PLANT,j in CUSTOMER, s in SCENARIO}                 >= 0;
# Quantity of A shipped from Plant i to Customer j
var    x    {i    in    PLANT,j    in    CUSTOMER,s    in    SCENARIO}    =
x_A[i,j,s]+x_B[i,j,s]+x_C[i,j,s];         # Total Quantity shipped from Plant
i to Customer j
var y {PLANT,CUSTOMER}              binary;                  # If there exist
a shipment from Plant i to Customer j
var z {LOCATION,CAPACITY}           binary;                     # If Plant is
set-up at Location i
var cap {k in CAPACITY}                            >=0;                     #
Capacity of Plant at Location i
var dem_A {j in CUSTOMER,l in PRODUCT,s in SCENARIO}                  >=0;
# Demand of Pdt A by Customer j
var dem_B {j in CUSTOMER,l in PRODUCT,s in SCENARIO}                  >=0;
# Demand of Pdt B by Customer j
var dem_C {j in CUSTOMER,l in PRODUCT,s in SCENARIO}                  >=0;
# Demand of Pdt C by Customer j
var surplus {i in PLANT,l in PRODUCT, s in SCENARIO}            >= 0;
var short {i in PLANT,l in PRODUCT, s in SCENARIO}            >= 0;


var total_fc      = sum{i in LOCATION,k in CAPACITY} z[i,k]*fixed_cost[i,k];
var  total_fwh          =  sum{i  in  PLANT,j  in  CUSTOMER,s  in  SCENARIO}
x[i,j,s]*fwh[i,j];
var  total_duty       =  sum{i  in  PLANT,  j  in  CUSTOMER,s  in  SCENARIO}
x[i,j,s]*duty[i,j];
```

```
var  total_vc_A        =  sum{i  in  PLANT,j  in  CUSTOMER,s  in  SCENARIO}
variable_cost[i,'A',s]*x_A[i,j,s];
var  total_vc_B        =  sum{i  in  PLANT,j  in  CUSTOMER,s  in  SCENARIO}
variable_cost[i,'B',s]*x_B[i,j,s];
var  total_vc_C        =  sum{i  in  PLANT,j  in  CUSTOMER,s  in  SCENARIO}
variable_cost[i,'C',s]*x_C[i,j,s];

var total_fwh_1     = sum{i in PLANT,j in CUSTOMER} x[i,j,'GOOD']*fwh[i,j];
var total_duty_1    = sum{i in PLANT, j in CUSTOMER} x[i,j,'GOOD']*duty[i,j];
var   total_vc_A_1              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'A','GOOD']*x_A[i,j,'GOOD'];
var   total_vc_B_1              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'B','GOOD']*x_B[i,j,'GOOD'];
var   total_vc_C_1              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'C','GOOD']*x_C[i,j,'GOOD'];

var total_fwh_2     = sum{i in PLANT,j in CUSTOMER} x[i,j,'AVG']*fwh[i,j];
var total_duty_2    = sum{i in PLANT, j in CUSTOMER} x[i,j,'AVG']*duty[i,j];
var   total_vc_A_2              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'A','AVG']*x_A[i,j,'AVG'];
var   total_vc_B_2              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'B','AVG']*x_B[i,j,'AVG'];
var   total_vc_C_2              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'C','AVG']*x_C[i,j,'AVG'];

var total_fwh_3     = sum{i in PLANT,j in CUSTOMER} x[i,j,'BAD']*fwh[i,j];
var total_duty_3    = sum{i in PLANT, j in CUSTOMER} x[i,j,'BAD']*duty[i,j];
var   total_vc_A_3              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'A','BAD']*x_A[i,j,'BAD'];
var   total_vc_B_3              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'B','BAD']*x_B[i,j,'BAD'];
var   total_vc_C_3              =   sum{i   in   PLANT,j   in   CUSTOMER}
variable_cost[i,'C','BAD']*x_C[i,j,'BAD'];



var total_sales   = sum{i in PLANT,j in CUSTOMER, l in PRODUCT,s in SCENARIO}
(1/3)*selling_price[j,l,s]*(x_A[i,j,s]+x_B[i,j,s]+x_C[i,j,s]);
var sales_1       =sum{i   in   PLANT,j   in   CUSTOMER,   l   in   PRODUCT}
selling_price[j,l,'GOOD']*(x_A[i,j,'GOOD']+x_B[i,j,'GOOD']+x_C[i,j,'GOOD']);
var sales_2       =sum{i   in   PLANT,j   in   CUSTOMER,   l   in   PRODUCT}
selling_price[j,l,'AVG']*(x_A[i,j,'AVG']+x_B[i,j,'AVG']+x_C[i,j,'AVG']);
var sales_3       =sum{i   in   PLANT,j   in   CUSTOMER,   l   in   PRODUCT}
selling_price[j,l,'BAD']*(x_A[i,j,'BAD']+x_B[i,j,'BAD']+x_C[i,j,'BAD']);

var expected_recourse         = sum{i  in  PLANT,l  in  PRODUCT,s  in  SCENARIO}
((surplus[i,l,s]*penalty[l,'OVER'])+(short[i,l,s]*penalty[l,'UNDER']));
var        recourse_1=sum{i        in        PLANT,l        in        PRODUCT}
((surplus[i,l,'GOOD']*penalty[l,'OVER'])+(short[i,l,'GOOD']*penalty[l,'UNDER'
]));
var        recourse_2=sum{i        in        PLANT,l        in        PRODUCT}
((surplus[i,l,'AVG']*penalty[l,'OVER'])+(short[i,l,'AVG']*penalty[l,'UNDER'])
);
var        recourse_3=sum{i        in        PLANT,l        in        PRODUCT}
((surplus[i,l,'BAD']*penalty[l,'OVER'])+(short[i,l,'BAD']*penalty[l,'UNDER'])
);
```

```
var          variance_recourse=1/3*(recourse_1-expected_recourse)*(recourse_1-
expected_recourse)+1/3*(recourse_2-expected_recourse)*(recourse_2-
expected_recourse)+1/3*(recourse_3-expected_recourse)*(recourse_3-
expected_recourse);

var expected_profit     =  total_sales-(total_fc  +  total_fwh  +  total_duty  +
total_vc_A + total_vc_B + total_vc_C);
var  scen_1=sales_1-(total_fc+  total_fwh_1  +  total_duty_1  +  total_vc_A_1  +
total_vc_B_1 + total_vc_C_1);
var  scen_2=sales_2-(total_fc+  total_fwh_2  +  total_duty_2  +  total_vc_A_2  +
total_vc_B_2 + total_vc_C_2);
var  scen_3=sales_3-(total_fc+  total_fwh_3  +  total_duty_3  +  total_vc_A_3  +
total_vc_B_3 + total_vc_C_3);

var         variance_objective         =(1/3*(scen_1-expected_profit)*(scen_1-
expected_profit))+(1/3*(scen_2-expected_profit)*(scen_2-
expected_profit))+(1/3*(scen_3-expected_profit)*(scen_3-expected_profit));

maximize    total_profit        :    expected_profit-expected_recourse-1.00E-
7*variance_objective-2.9e-03*variance_recourse;

subject to total_capacity_1  {i in LOCATION}:
           sum   {j   in   CUSTOMER}   x[i,j,'GOOD']   <=   z[i,'L']*6000   +
z[i,'H']*12000;

subject to total_capacity_2  {i in LOCATION}:
           sum   {j   in   CUSTOMER}   x[i,j,'AVG']   <=   z[i,'L']*6000   +
z[i,'H']*12000;

subject to total_capacity_3  {i in LOCATION}:
           sum   {j   in   CUSTOMER}   x[i,j,'BAD']   <=   z[i,'L']*6000   +
z[i,'H']*12000;

subject to total_capacity_Austin_Max {s in SCENARIO}:
                  sum {j in CUSTOMER} x['AUSTIN',j,s] <= 12000;

subject to total_capacity_Austin_Min{s in SCENARIO}:
                  sum {j in CUSTOMER} x['AUSTIN',j,s] >= 1;

subject to total_capacity_Paris_Max{s in SCENARIO}:
                 sum {j in CUSTOMER} x['PARIS',j,s] <= 8000;

subject to total_capacity_Paris_Min{s in SCENARIO}:
                    sum {j in CUSTOMER} x['PARIS',j,s] >= 1;

subject to total_demand_A_1 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_A[i,j,'GOOD']+surplus[i,'A','GOOD']-
short[i,'A','GOOD'])== demand[j,'A','GOOD'];

subject to total_demand_A_2 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_A[i,j,'AVG']+    surplus[i,'A','AVG']-
short[i,'A','AVG'])== demand[j,'A','AVG'];

subject to total_demand_A_3 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_A[i,j,'BAD']+surplus[i,'A','BAD']-
short[i,'A','BAD'])== demand[j,'A','BAD'];
```

```
subject to total_demand_B_1 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_B[i,j,'GOOD']+surplus[i,'B','GOOD']-
short[i,'B','GOOD'])== demand[j,'B','GOOD'];

subject to total_demand_B_2 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_B[i,j,'AVG']    +surplus[i,'B','AVG']-
short[i,'B','AVG'])== demand[j,'B','AVG'];
subject to total_demand_B_3 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_B[i,j,'BAD']    +surplus[i,'B','BAD']-
short[i,'B','BAD'])== demand[j,'B','BAD'];

subject to total_demand_C_1 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_C[i,j,'GOOD']+surplus[i,'C','GOOD']-
short[i,'C','GOOD'])== demand[j,'C','GOOD'];
subject to total_demand_C_2 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_C[i,j,'AVG']    +surplus[i,'C','AVG']-
short[i,'C','AVG'])== demand[j,'C','AVG'];
subject to total_demand_C_3 {j in CUSTOMER}:
           sum    {i    in    PLANT}    (x_C[i,j,'BAD']    +surplus[i,'C','BAD']-
short[i,'C','BAD'])== demand[j,'C','BAD'];

subject to single_plant:
           sum {i in LOCATION,k in CAPACITY} z[i,k] == 1;
```

Ampl data file:

```
set PRODUCT := A B C;
set  PLANT     :=  AUSTIN  AUSTRALIA  CHARLESTON  INDIA  MALAYSIA  MOBILE  PARIS
S_AFRICA SPAIN;
set LOCATION:= AUSTRALIA CHARLESTON INDIA MALAYSIA MOBILE S_AFRICA SPAIN;
set EXISTING:= AUSTIN PARIS;
set CUSTOMER :=BRAZIL CHINA FRANCE MALAYSIA USM USN USS USW;
set CAPACITY := VL,L,M,H;
set SCENARIO := GOOD,AVG,BAD;
set PEN:= OVER,UNDER;

param duty :
            BRAZIL CHINA FRANCE MALAYSIA  USM   USN   USS   USW   :=
AUSTIN      0.12  0.3    0.09   0.22      0     0      0     0
AUSTRALIA   0.12  0.3    0.09   0.22      0.042 0.042  0.042 0.042
CHARLESTON  0.12  0.3   0.09    0.22      0      0     0     0
INDIA       0.12  0.3   0.063   0.22      0.042  0.042 0.042 0.042
MALAYSIA    0.12  0.3   0.063   0.22      0.042  0.042 0.042 0.042
MOBILE      0.12  0.3   0.09    0.22      0      0     0     0
PARIS       0.12  0.3   0       0.22      0.042  0.042 0.042 0.042
S_AFRICA    0.12  0.15  0.056   0.22      0.042  0.042 0.042 0.042
SPAIN       0.12  0.3   0       0.22      0.042  0.042 0.042 0.042 ;
```

```
param fwh:
            BRAZIL CHINA  FRANCE MALAYSIA USM    USN    USS    USW      :=
AUSTIN      0.2575 0.2454 0.2201 0.1365   0.0738 0.1134 0.0848 0.0793
AUSTRALIA   0.2289 0.1816 0.1981 0.1706   0.4093 0.3983 0.4005 0.4038
CHARLESTON  0.2399 0.2278 0.2025 0.1189   0.0562 0.0969 0.0672 0.0617
INDIA       0.318  0.197  0.175  0.131    0.285  0.274  0.274  0.274
MALAYSIA    0.3301 0.1266 0.1948 0.0859   0.2058 0.1948 0.1981 0.2003
MOBILE      0.2399 0.2278 0.2025 0.1189   0.0562 0.0969 0.0672 0.0617
PARIS       0.186  0.1299 0.0463 0.1585   0.186  0.1684 0.1684 0.2377
S_AFRICA    0.1244 0.3048 0.2267 0.2916   0.3994 0.3928 0.3928 0.406
SPAIN       0.1926 0.186  0.1244 0.1541   0.2509 0.2388 0.2388 0.2564;


param selling_price:=
[*,*,'GOOD']:A          B           C     :=
BRAZIL      12.672      12.408      12.969
CHINA       13.827      13.563      14.124
FRANCE      13.992      13.695      14.256
MALAYSIA    13.827      13.563      14.124
USM         12.243      12.012      12.54
USN         12.243      12.012      12.54
USS         12.243      12.012      12.54
USW         12.243      12.012      12.54

[*,*,'AVG']: A    B     C     :=
BRAZIL      11.52 11.28 11.79
CHINA       12.57 12.33 12.84
FRANCE      12.72 12.45 12.96
MALAYSIA    12.57 12.33 12.84
USM         11.13 10.92 11.4
USN         11.13 10.92 11.4
USS         11.13 10.92 11.4
USW         11.13 10.92 11.4

[*,*,'BAD']:A           B           C     :=
BRAZIL      10.368      10.152      10.611
CHINA       11.313      11.097      11.556
FRANCE      11.448      11.205      11.664
MALAYSIA    11.313      11.097      11.556
USM         10.017      9.828       10.26
USN         10.017      9.828       10.26
USS         10.017      9.828       10.26
USW         10.017      9.828       10.26;


param demand:= (# in 1000 units)
[*,*,'GOOD']:A          B           C     :=
BRAZIL      179.85      264.55      814.77
CHINA       3474.13     594.99      1792.23
FRANCE      1546.6      318.78      1969.88
MALAYSIA    438.9       250.8       1431.76
USM         599.39      1892.33     2439.25
USN         75.57       344.52      53.13
USS         1099.67     749.43      1674.53
USW         1984.4      3214.53     1367.96
```

```
[*,*,'AVG']:A           B           C     :=
BRAZIL      163.5       240.5       740.7
CHINA       3158.3      540.9       1629.3
FRANCE      1406        289.8       1790.8
MALAYSIA    399         228         1301.6
USM         544.9       1720.3      2217.5
USN         68.7        313.2       48.3
USS         999.7       681.3       1522.3
USW         1804        2922.3      1243.6

[*,*,'BAD']:A           B           C     :=
BRAZIL      147.15      216.45      666.63
CHINA       2842.47     486.81      1466.37
FRANCE      1265.4      260.82      1611.72
MALAYSIA    359.1       205.2       1171.44
USM         490.41      1548.27     1995.75
USN         61.83       281.88      43.47
USS         899.73      613.17      1370.07
USW         1623.6      2630.07     1119.24;


param fixed_cost:

            VL          L                 M           H     :=
AUSTRALIA   55555555    917000            55555555    1136000
CHARLESTON  55555555    962000            55555555    1180000
INDIA       55555555    840000            55555555    1059000
MALAYSIA    55555555    839000            55555555    1058000
MOBILE      55555555    937000            55555555    1156000
S_AFRICA    55555555    781000            55555555    1000000
SPAIN       55555555    874000            55555555    1093000;



param variable_cost:=
[*,*,'GOOD']:A    B     C     :=
AUSTIN      1.32  1.32  1.386
AUSTRALIA   0.495 0.671 0.649
CHARLESTON  0.462 0.627 0.605
INDIA       0.495 0.66  0.638
MALAYSIA    0.55  0.726 0.715
MOBILE      0.451 0.616 0.594
PARIS       1.386 1.397 1.375
S_AFRICA    0.506 0.682 0.66
SPAIN       0.528 0.704 0.693


[*,*,'AVG']:A     B     C     :=
AUSTIN      1.2   1.2   1.26
AUSTRALIA   .45   .61   .59
CHARLESTON  .42   .57   .55
INDIA       .45   .60   .58
MALAYSIA    .50   .66   .65
MOBILE      .41   .56   .54
PARIS       1.26  1.27  1.25
S_AFRICA    .46   .62   .60
SPAIN       .48   .64   .63
```

```
[*,*,'BAD']:A      B      C      :=
AUSTIN       1.08  1.08  1.134
AUSTRALIA    0.405 0.549 0.531
CHARLESTON   0.378 0.513 0.495
INDIA        0.405 0.54  0.522
MALAYSIA     0.45  0.594 0.585
MOBILE       0.369 0.504 0.486
PARIS        1.134 1.143 1.125
S_AFRICA     0.414 0.558 0.54
SPAIN        0.432 0.576 0.567;

param penalty:
             OVER UNDER :=
A            8.5   7.5
B            8.0   7.0
C            9.0   8.0;
```