Global Journal of Advanced Engineering Technologies and Sciences

SUPPLIER SELECTION CRITERION IN UNCERTAIN PRODUCT COST: A DYNAMIC PROGRAMMING APPROACH

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Abstract

Supplier selection is very significant business problem for ensuring competitiveness on the market. A number of quantitative methods have been applied to solve this problem. In this paper a criterion to select a supplier is suggested in the cases where the product cost of the supplier varies with planned periods and is uncertain. The effect of variability on the optimal solution is illustrated with the help of a numerical example. The optimal cost for ten periods is estimated using forward dynamic programming approach. It is found that the optimal (minimum) cost increases with the variability in the product cost. One of the important finding of this study is that the supplier with less variability in product cost should be preferred.

Keywords:Supplier Selection, Inventory Lot Sizing, Dynamic Order Sizing, Optimal Ordering Cost.

Introduction

The problem with vendor selection and determining procurement quotas from selected vendor is the most important phase for a production company in the process of procurement of materials. Several studies addresses issues related to supplier selection. These studies have used different methods ranging from Analytic Hierarchy Process (AHP) (Nydic and Hill , 1992) and cost ratio method(Timmerman,1987) to total cost of ownership (ellram,1990;Gheidar Kheljani et al.,2009),linear programming(Ng,2008:Talluri and Narsimhan,2003), multi objective programming (Narsimhan et al.,2006) and DEA (Liu et al.,2000; Ramanathan ,2007;Weber,1996). Muralidharan et al., (2002) proposed an AHP based model in which nine criteria were used for ranking the suppliers. Furthermore, they take into account the opinions of experts from different departments such as purchasing and quality control in their model. Chan and Chan (2010) developed an AHP based model for supplier evaluation and selection as well as Muralidharan (2002) with a case in fashion industry.

In today's business environment, companies need to operate in a efficient and effective manner in order to survive. The purchasing management and inventory management are important decision making areas. Mathematical programming methods are important tools to find favorable decisions. Applications of inventory control and management have been extensibly studied in the related literature. Many researchers have studied the problem to consider the most appropriate suppliers ,a and to determine the optimal lot size for each product in each planning period to minimize the total inventory holding cost. Brahim et al. (2008) presented a comprehensive review of lot sizing problem in the case where demand of the product varies over different time periods. Heady and Zhu(1994) improved the solution procedure proposed by Wanger and Whitin (1958). The supplier selection problem without inventory consideration was studied by Current and Weber (1994).

The problem with multiple Suppliers with inventory considerations is studied by various workers. Aissaoui et al.(2007) developed a well known economic order quantity model to discuss the problem of multi suppliers. The lot sizing with single product with discount rate was solved by Tempelmeir (2002) with a heuristic method. Basnet and Leung (2005) considered the supplier selection and order lot sizing problem with multiple products each with different deterministic demand. M.M.Moqri et al. (2011) discussed a multi period integrated supplier selection and order lot sizing problem where a single buyer plans to purchase a single product in multiple periods from several suppliers. They developed a mathematical programming model and proposed a forward dynamic programming approach to obtain the optimal solution.

In this study, a supplier selection criterion is suggested in the case where marketing situation changes very rapidly. The cost of product varies with periods and is uncertain. The effect of uncertainty in the cost of vendor's product on the optimal solution is discussed .The product cost is supposed to follow the normal probability distribution. The effect of variability on optimal solution is illustrated by taking a numerical example. The various optimal solutions are obtained for different values of standard deviation. Different replicates of the solution are calculated and the average value of optimal solution is obtained.

Methodology

We assume that:

i) Products are shipped directly from supplier to the buyer (i.e., there is no intermediate distributor).
ii) Only one product is considered.
iii) Supplier's capacity is unlimited.
iv) Buyer's demand is deterministic and is known in advance.
v) Order lead time is zero.
vi) No product shortage is permitted.
vii) The planning horizon is finite.
viii) The lot size does not exceed the demand of the period.

The functional equation (Bellman, 1957, Karlin, 1955) representing the minimum cost policy for periods t through N, is given as:

$$\boldsymbol{f_t(I) = \min_{\substack{x_t \geq 0 \\ if\ x_t \geq d_t}} [i_{t-1}I + \delta(x_t)S_t + f_{t-1}(I + x_t - d_t)]} \qquad (1)$$

where

$$\delta(x_t) = \begin{cases} 0\ if x_t = 0 \\ 1\ if\ x_t > 0 \end{cases}$$

I=the inventory entering a period
I_0 =initial inventory
d_t= demand in period t
i_t=inventory holding cost per item
S_t=setup(ordering) cost
x_t= amount ordered (or manufactured)
t=1, 2 , 3 ………..,N

The alternate formulation to equation (1) proposed by Wanger and whitin (2004) is as follows:

$$\boldsymbol{F(t) = \min\left[\begin{matrix} \min_{1 \leq j < t}\left[s_{j+}\sum_{h=j}^{t-1}\sum_{k=h+1}^{t} i_h d_k + F(j-1)\right] \\ , s_t + F(t-1)\end{matrix}\right]} \qquad (2)$$

where *F(1) = S_1 and F(0) =0*

The equation (2) states that the minimum cost for first t periods comprise a setup(ordering) cost in period j ,plus charges for filling demand $d_k, k = j+1, \ldots, t$ by carrying inventory from period *j*, plus the cost of adopting an optimal policy in period *1* through *j-1* taken by themselves. In general if the product price varies in different periods, we have

$$\boldsymbol{F(t) = \min\left[\begin{matrix} \min_{1 \leq j < t}\left[s_{j+}\sum_{h=j}^{t-1}\sum_{k=h+1}^{t} i_h d_k + p_j\left(\sum_{i=j}^{t} d_j\right) + F(j-1)\right] \\ , s_t + F(t-1)\end{matrix}\right]} \qquad (3)$$

Equation (3) calculates the minimum total cost for the first t periods. Since the equation (3) is recursive we can use the dynamic programming approach to solve the problem. The solution procedure given by Wanger and Within (2004) is followed.

Their algorithm for calculation is given below in tabular form (Table 1).

Table 1: Procedure to calculate minimum ordering cost for N periods

Periods	1	2	3	-	N
1	1	(1)2	(1,2)3	-	(1,2,…..,N-1)N
2		12	(1)23	-	(1,2,…..,N-2)N-1,N
3			123	-	(1,2,…N-3)N-2,N-1,N
. . .					
N					
Minimum(Rs.)	**(1)**	**(1,2)**	**(1,2,3)**	-	**(1,2,3,………N)**

Row 1 and column 1 of the table represents number of order periods and minimum ordering cost for a particular order respectively. The tabular calculations shown in table 1 are as follows:

a) In the second column of Table 1,the order quantity must be equal to the demand of period 1, therefore ,the value of second and the last row of the column 2 is equal to the sum of the ordering and purchasing cost to meet the demand of the product in period 1 and is denoted by **(1).**
b) The second row of third column is a policy in which an order is placed in the second period; therefore, in both periods 1 and 2 , an order is placed and the cost of the policy is denoted by **(1, 2)**.
c) The third row of the third column represents a policy in which an order equal to the demands of both periods 1 and 2 is placed in period 1. The cost of this policy is denoted by **12.** The minimum cost for period 2 is given in the last row of third column and is denoted by **(12).** This includes the holding cost inventory which is carried from period 1 to 2.
d) For the column 4, there are three ordering options:
   (i) an order is placed in period 3 is equal to the demand in this period and demands of periods 1 and 2 are ordered optimally. The total cost of this policy is denoted by **(1, 2)3.**
   (ii) an order is placed in period 2 to satisfied demands of 2 and 3 and demand of period 1 is ordered optimally. The total cost of this policy is denoted by **(1)23**.
   (iii) an order s placed in period 1 to satisfied all the demands of periods 1 though 3. The total cost of this policy is denoted by **123.** The minimum cost for period 3 is denoted by **(123)**.

The similar procedure is adopted for the rest of periods.

The uncertain product cost is assumed to follow the normal probability distribution. The optimal solution for various variations (standard deviations) in the product cost is calculated. The average of various replicates of the optimal solution is obtained to represent the optimal solution.

Results And Discussion

The effect of uncertainty in product cost on optimal solution is illustrated with the help of the following numerical example:
The product demand per period =200.
The mean cost over the periods =Rs.2.
The inventory holding cost per product =Rs.1.
The ordering cost = Rs. 400.

The product cost is uncertain and follow the normal probability distribution with mean= μ and standard deviation =σ. Following the procedure described in methodology the optimal cost for ten periods have been calculated. The parameters of numerical example are given in Table 2.
Table 2: Parameters of numerical example (μ = Rs.2, σ =10)

Period	d_t	I_t**(Rs.)**	S_t **(Rs.)**	P_{it}**(Rs.)**
1	200	1	400	1.95
2	200	1	400	2.13
3	200	1	400	2.11
4	200	1	400	1.92
5	200	1	400	1.90

6	200	1	400	2.05
7	200	1	400	1.99
8	200	1	400	1.89
9	200	1	400	1-83
10	200	1	400	1.96

The minimum cost for each period for the numerical example given in Table 2 is found using forward dynamic programming approach described in methodology, and is shown in Table 3.
Table 3. Optimal (minimum) cost (Rs.) solution (μ=2, σ=10)

Periods	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	804	1619	2244	3048	3622	4400	4406	4770	5534	6268
2		1408	2388	2880	3684	3822	4978	4928	5734	6098
3			2212	3280	3716	3684	4906	5756	5650	6498
4				3216	4372	4652	5556	5848	6734	6572
5					4420	5664	5988	6792	6990	7912
6						5224	7156	7424	8228	8332
7							7428	8848	9060	9864
8								9232	10740	10896
9									11236	12832
10										13440
Minimum(Rs.)	804	1408	2212	2880	3622	3684	4406	4770	5534	6098

The two replicates of the solution given in table 3 are found and are given in table 4 and table 5 respectively. The average of the optimal (minimum) cost for tenth period of from three replicates is given in table 6.

Table 4. Replicate-2 of the solution presented in Table 3

Period	1	2	3	4	5	6	7	8	9	10
1	754	1594	2164	2854	3694	4214	4214	4496	5356	6204
2		1308	2234	2820	3446	3894	4782	4782	5378	6016
3			2062	3074	3676	3446	5242	5550	5550	6060
4				3016	4114	4732	5230	6316	6518	6518
5					4170	5354	5988	6422	7590	7686
6						5524	6794	7444	7814	9064
7							7078	8434	9100	9406
8								8832	10274	10956
9									10786	12314
10										12940
Minimum(Rs.)	754	1308	2062	2820	3446	3446	4214	4496	5356	6016

Table 5. Replicate-3 of the solution presented in Table 3

Peri0d	1	2	3	4	5	6	7	8	9	10
1	836	1642	2298	3040	3744	4402	4458	4886	5664	6444
2		1472	2248	2924	3632	3944	4972	5084	5914	6250
3			2308	3054	3750	3632	5184	5742	5910	6742
4				3344	4060	4776	5416	6204	6712	6936
5					4580	5266	6002	6608	7424	7882
6						6016	6672	7428	8000	8844
7							7652	8278	9054	9592
8								9488	10084	10880
9									11524	12090
10										13760

Minimum(Rs.)	836	1472	2248	2924	3632	3632	4458	4886	5668	6250

Table 6. Average minimum cost obtained from replicates of the solution for tenth period

Replicate	1	2	3
Minimum cost(Rs.)	6098	6016	6350
Average=Rs.6121			

In the next experiment the optimal solution is obtained with an increase in variability in product cost. The parameters of numerical example considered are same as previous numerical example except the standard deviation. The product cost distribution in ten periods is obtained using normal probability distribution with μ=2 and σ=20. Thus the columns of numerical example (Table 2) remain same except last column. The last column represents the large variability in product cost as compared to Table 2. The modified numerical example with σ=20 is not shown. The optimal cost for this experiment is shown in Table 7.

Table 7. Minimum cost (Rs.), μ =2, σ =20, dt =200, It =1 (Replicate-1)

Period	1	2	3	4	5	6	7	8	9	10
1	886	1714	2522	2978	3824	4210	4306	4768	5518	6280
2		1572	2342	3272	3414	4024	4806	4998	5830	6068
3			2458	3170	4222	3414	4932	5602	5890	6692
4				3544	4198	5372	4886	5786	6598	6982
5					4830	5426	6722	5922	6840	7794
6						6316	6854	8272	7158	8094
7							8002	8482	10022	8594
8								9888	10310	11972
9									11974	12338
10										14260
Minimum(Rs.)	886	1572	2342	3170	3414	3414	4306	4768	5518	6068

Table 8. Replicate-2 of the solution given in Table 7.

Period	1	2	3	4	5	6	7	8	9	10
1	728	1500	1930	2680	3266	3804	4060	4454	5384	6192
2		1256	2072	2404	3230	3466	4330	4690	5448	6114
3			1984	2844	3078	3230	4790	5056	5520	6242
4				2912	3816	3952	4930	5852	5982	6550
5					4040	4988	5026	6080	7114	7108
6						5368	6360	6300	7430	8576
7							6896	7932	7774	8980
8								8624	9704	9448
9									10552	11676
10										12680
Minimum(Rs.)	728	1256	1930	2404	3078	3230	4060	4454	5384	6114

Table 9. Replicate-3 of the solution given in Table 7.

Period	1	2	3	4	5	6	7	8	89	10
1	924	1770	2498	3082	3958	4370	4432	4904	5730	6604
2		1648	2416	3148	3548	4158	4992	5116	5976	6356
3			2572	3262	3998	3548	5378	5814	6000	6848
4				3696	4308	5048	5080	6388	6836	7084
5					5020	5554	629	6146	7598	8058
6						6544	7000	7748	7412	9008
7							8268	8646	9398	8878
8								10192	10492	11248
9									12316	12538
10										14604
Minimum(Rs.)	924	1648	2416	3148	3548	3548	4432	4904	5730	6356

The replicates of the solution presented in Table 7 are given in Tables 8 and 9 respectively.

The average minimum cost for tenth period is given in Table 10.

Table 10.The average minimum cost for period -10.

Replicates	1	2	3
Minimum cost(Rs.)	6068	6114	6356

Average = (608+6114+6356) / 3 = 6179

The third experiment is carried out with further increasing variability in the product cost. In this case the mean cost (μ) is same (Rs. = 2) but the standard deviation (σ) is taken equal to 40. All other parameters of the numerical example are same. The optimal cost solution with these parameters is given in Table 11.

Table 11. Minimum cost (Rs.), μ=2, σ=40, dt =200, It =1 (Replicate-1)

Period	1	2	3	4	5	6	7	8	9	10
1	760	1638	2082	2840	3386	4270	4222	4562	5376	6346
2		1320	2316	2644	3400	3586	4954	4844	5502	5990
3			2080	3194	3406	3400	4670	5838	5666	6242
4				3040	4272	4368	5120	5612	6922	6688
5					4200	5550	5530	6280	6754	8206
6						5560	7028	6892	7640	8096
7							7120	8706	8454	9200
8								8880	10584	10216
9									10840	12662
10										13000
Minimum cost(Rs.)	760	1320	2080	2644	3386	3400	4222	4562	5376	5990

Table 12. Replicate -2 of the optimal solution given in Table 11.

Period	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	*824*	*1696*	*2480*	*3358*	*4366*	*4994*	*4826*	*5134*	*5942*	*6880*
2		*1448*	*2368*	*3312*	*4244*	*4566*	*5544*	*5208*	*6042*	*6550*
3			*2272*	*3240*	*4344*	*4244*	*6418*	*6294*	*5790*	*6750*
4				*3296*	*4312*	*5576*	*6616*	*7744*	*7244*	*6572*
5					*4520*	*5584*	*7008*	*8102*	*927*	*8394*
6						*5944*	*7056*	*864*	*9788*	*10996*
7							*7568*	*8728*	*10472*	*11674*
8								*9392*	*10600*	*12504*
9									*11416*	*12672*
10										*13640*
Minimum(Rs.)	*824*	*1448*	*2272*	*3240*	*4244*	*4244*	*4826*	*5134*	*5942*	*6550*

Table 13. Replicate-3 of the solution given in Table 11.

Period	1	2	3	4	5	6	7	8	9	10
1	898	1624	2488	3056	3934	4322	4534	5096	5672	6510
2		1596	2150	3180	3762	4134	4682	5106	6258	6048
3			2494	2876	4072	3762	5850	5242	5878	7220
4				3592	3802	5164	5774	7108	6002	6850
5					4890	4928	6456	7080	8566	6962
6						6388	6254	7948	8586	10224
7							8086	7780	9640	10292
8								9984	9506	11532
9									12082	11432
10										14380

Minimum(Rs.)	898	1596	2150	2876	3762	3762	4534	5096	5672	6048

The replicates of the solution given in Table 11 are given in Tables 12 and 13. The average optimal solution in this case is given in table 14.

Table 14. The average Minimum cost (Rs.) from replicates.

Replicates	1	2	3
Minimum cost	5990	6550	6048

Average = (5990+6550+6048) / 3 = 6196

The results obtained from the numerical example illustrate that the uncertainty in product cost affects the optimal solution for the minimum cost. We found that as the variability in the product cost increases the minimum cost increases . The average optimal cost calculated from three experiments for last period for different values standard deviation is shown in Table 15.

Table 15. Variation of minimum cost for tenth period with variation in standard deviation.

σ	10	20	40
Average minimum cost(Rs.)	6121	6179	6196

The above Table shows that as the variation in product cost increases the minimum cost increase.

Conclusion

The forward dynamic programming approach is used to study the effect of uncertainty in the cost of the supplier product on the optimal cost solution. The cost of the product is different in each period and is uncertain. The cost is assumed to follow the Normal probability distribution .The effect of the uncertainty in the product cost on the optimal solution is illustrated by taking a numerical example.. The optimal solution is found for various values of the standard deviation of the product cost . It is found that as the standard deviation of product cost increases the optimal (minimum) cost for each period increases. One of the important conclusions of this study is that in case of uncertain variability in product cost, a supplier should be selected with less variability in product cost.

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