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A multiobjective approach to vendor selection taking into account transportation

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Aicha AGUEZZOUL, Pierre LADET

Automatic Laboratory of Grenoble.

BP 46, rue de la houille blanche, 38406, Saint martin d'Herès cedex, France

aicha.aguezzoul@inpg.fr, pierre.ladet@inpg.fr (+33)04 76 82 71 13 (+33) 04 76 82 63 88

Abstract: The analysis of the most researches related to the supplier selection shows that very little attention is given to transportation although its cost may be significant important to this selection. In this paper, we present a multiobjective approach of selecting suppliers and allocating the order quantity among them, taking into account transportation. The objectives to minimize in the model are the total cost and the lead-time. The total cost is the sum of transportation, inventory and ordering costs. The constraints related to suppliers, buyer and transportation are also considered in the model. The model is implemented in Matlab, software specialized in optimization. An evaluation of the model is presented under various scenarios.

Keywords: Multiobjective programming, Supplier selection, Transportation, Inventory

1. INTRODUCTION

In today's increasing competitive business world, the suppliers selection and evaluation is one of the most critical activities of a company and a strategic purchasing decision that commit significant resources (40% to 80% of total product cost) and impact the total performance of the firm. The studies in that field show that this decision is a complex process involving various criteria such as procurement cost, product quality, delivery performance, etc. These criteria may vary depending on the type of product considered and are often in conflict with one another. For example, low prices can be offset by poor quality or delivery reliability. Therefore, the supplier selection is an inherently multiobjective decision. In 1966, Dickson has identified at least 23 criteria in his empirical study in various vendor selection problems. Moreover, a review of 74 articles by Weber et al (1991) obtained similar results and also showed that several approaches have been suggested to take into account the multiobjective nature of the decision problem. These approaches may be grouped into three categories, which are: linear weighting models, mathematical programming models and statistical/probabilistic approaches. However, that study identified very few articles that have proposed mathematical programming techniques to analyze

supplier selection decision. Over the past few years, other techniques are suggested in the literature. We can mention: interpretive structural modeling (Mondal et Deshmukh, 1994), expert system (Vokurka et al, 1996), data envelopment analysis (Weber, 1996; Liu and al, 2000), multi-objective programming (Weber and al, 2000), etc. Other models have been examined by Youssef et al (1996). However, the transportation aspect is not considered explicitly in these techniques. This is a great limitation because splitting orders across multiple suppliers will lead to smaller transportation quantities which will likely imply larger transportation cost. Moreover, transportation and inventory elements are highly interrelated and contribute most to the total logistics costs: costs incurred in the suppliers while the products wait to be shipped, costs represented by the products in transit and costs incurred in the buyer while the products wait to be used. Finally, transportation has a direct impact on the lead-time, which affects the firm's total cycle time.

The most important articles that have addressed the problem of multi-sourcing, in particular dual sourcing and transportation are described bellow:

Hong and Hayya (1992) have discussed reducing lot size in the JIT purchasing environment with multiple vendors. A nonlinear programming problem is formulated and the objective function is to minimize the aggregate ordering and holding costs under delivered cost and quality constraints. Transportation cost is not formulated explicitly in the model. For multiple sourcing, the model gives the optimal selection of suppliers and the size of the split orders whereas, for the single sourcing, it determines the optimal number of deliveries.

Ganeshan et al (1999) examine the dynamics of a supply chain that has the option of using two suppliers: one reliable and other unreliable. The unreliable supplier is characterized with long lead-time. Although the use of that supplier might warrant higher inventory and transportation costs, it's attractive to the firm because he is willing to provide a discount on the purchase price.

In that study, the authors present a model, which minimize the sum of purchasing, ordering, holding and transportation costs. Holding cost includes cycle-stock, in-transit stock and safety stock carrying costs. The expected shortage per replenishment cycle is the only constraint of the model. A simple heuristic is used to determine the level of discount that needs to be offered and the portion of the order that should be placed with secondary supplier

More recently, Tyworth and Ruiz-Torres (2000) investigate the role of transportation in the sole versus dual sourcing decision. They present a model, which minimize the sum of purchasing, ordering, storage and transportation costs. No constraints are defined in the model. They demonstrated that dual supplier sourcing could yield savings under some conditions on supplier price, annual demand, lead-time performance and line-haul distance.

In these various researchs, stocks in all the transportation network (suppliers, transit, buyer) are not clarified and the constraints related to transportation policy are not considered. The contribution of our paper is the integration of all these elements in the multi-objective programming (MOP) approach that we propose. The MOP model was first introduced by Weber and Ellram (1993) as a technique for selecting vendors in procurement environment characterised by multiple conflicting criteria. In our case, the objectives to minimize in the model are total cost and lead-time criteria under suppliers, buyer and transportation constraints. Total cost includes transportation, ordering and inventory costs. Total purchasing cost is not considered here and we suppose that the product, which is purchased over a given horizon of time, has the same unit price from all the suppliers. The model simultaneously determines the optimal number of suppliers to employ and the order quantities to allocate to them, taking into account the transportation. The model is validated using a numerical example.

This paper is structured as follows. In the next section, we present the mathematical form of our model. In section 3, we give a solution methodology of the multiobjective model. Section 4

reports the results of computational experiments made using MATLAB, software specialized in optimization, to solve the model. The final section contains concluding remarks.

2. MODEL FORMULATION

The buyer must make a choice of a set of n potential suppliers, on the basis of criterion, which take into account transportation, namely total product cost and lead-time. The objectives to minimize simultaneously in the model are these two criteria. Total cost includes ordering, transportation and storage costs subject to lead-time and capacity of each supplier; lead-time imposed by the buyer and transportation mode used constraints. Moreover, we assume that the demand of the buyer is known and constant and that the transportation capacity is unlimited.

Let's define the following variables and formulas:

n = number of suppliers

D = unit time demand of buyer

Q = ordered quantity to all suppliers in each period

Q_i : ordered quantity to i^{th} supplier in each period

A_i = ordering cost per order, of i^{th} supplier

P_i = purchase price of i^{th} supplier

C_i = production capacity of i^{th} supplier

l_i = lead-time required by i^{th} supplier

T_i = average transit time from i^{th} supplier to buyer

L = lead-time imposed by the buyer

r = holding rate of the buyer

r_i = holding rate of i^{th} supplier

rt_i = in-transit holding rate of i^{th} supplier

Cf_i = fixed shipping cost of i^{th} supplier

Cv_i = variable shipping cost of i^{th} supplier

Decision variables:

X_i = fraction of Q allocated to i^{th} supplier

$Y_i = 1$ if $X_i > 0$ (i^{th} supplier is selected)

0 if $X_i = 0$

In addition, D/Q is the number of periods during the time considered.

The total cost (TC) can be written as:

$$TC = \sum_{i=1}^n [(D/Q)(Cf_i Y_i + QX_i Cv_i) + (D/Q)A_i Y_i + DX_i P_i (T r_i + (Q/2D)(r_i + r)X_i)]$$

The first term in this expression is the total transportation cost. We use the modeling $(Cf/Q + Cv)$ suggested by Hall (1985). The fixed shipping cost Cf is independent of a load and includes cost of stop and cost per unit distance. The variable shipping cost Cv is a cost per load and it's independent of the distance covered. The second term represents the total ordering cost. A_i is restricted to traditional (non-transportation) ordering and inspection cost elements. The last term is the total inventory cost. In a transportation network, inventory includes items waiting to be shipped from each supplier, items in transit to buyer and items waiting to be used by buyer. That supposes that each supplier produces items at a constant rate and the production planning is synchronized with that of transport. The average time required to i^{th} supplier to produce a shipment of size Q_i is Q_i/D . Each item in the load waits on average half of this time before being shipped $Q_i/2D$. After arriving, each item waits on average $Q_i/2D$ before being used. The average time spend by an item from i^{th} supplier to buyer is $Q_i/D + T_i$.

As Q is the optimum order quantity, it can be calculated by using the derivative of TC:

$$\frac{\partial TC}{\partial Q} = 0 \Rightarrow Q = \sqrt{2D(\sum_{i=1}^n (A_i + Cf_i)Y_i) / \sum_{i=1}^n P_i X_i^2 (r_i + r)}$$

By substituting for Q in TC, it becomes:

$$TC = \sqrt{2D\left(\sum_{i=1}^n (A_i + Cf_i)Y_i\right)\left(\sum_{i=1}^n P_i X_i^2 (r_i + r)\right)} + \sum_{i=1}^n DX_i (rt_i T_i P_i + Cv_i) \quad (1a)$$

An appropriate aggregate performance measure for delivery to the buyer is given in Pan (1989) in the expression (1b) below:

$$LD = \sum_{i=1}^n l_i X_i \quad (1b)$$

This expression must be less than the lead-time imposed by the buyer. This implies that the long lead-time of one supplier is compensated by the short lead-time of other suppliers.

The mathematical formulation of the nonlinear multi-objective program model (NMOP) is given as follows:

$$\text{Min } Z = (TC, LD) \quad (1)$$

S. T.

$$X_i D \leq C_i \quad i = 1, n \quad (2)$$

$$\sum_{i=1}^n l_i X_i \leq L \quad (3)$$

$$\sum_{i=1}^n X_i = 1 \quad (4)$$

$$\varepsilon Y_i \leq X_i \leq Y_i \quad i = 1, n \quad (5)$$

$$X_i \geq 0 \quad i = 1, n \quad (6)$$

$$Y_i = 0,1 \quad i = 1, n \quad (7)$$

Equation (1) specifies the multiobjective function whose components expressions are given by equations (1a) and (1b).

Constraints (2) represent the supplier production capacity restriction. Constraint (3) is an aggregate performance measure for delivery for all suppliers. Constraint (4) indicates that demand is placed with the set of n suppliers. Constraints (5) require that an order is placed with a supplier if only he is selected; ϵ is a positive number, slightly greater than zero. Constraints (6) enforce the non-negativity restriction on the decision variables X_i . Constraints (7) impose binary requirements on the Y_i variables.

3. SOLUTION METHODOLOGY

The multiobjective programming is often used to find a compromised solution, which simultaneously satisfy a number of design criteria. In solving the multiobjective programming problems, classical methods reduce them into a single objective of minimizing a weighted sum of deviations from goals. In our case and since the cost and time-time criteria have different orders in magnitude; we have normalized the objectives by using the absolute values of the relative variations of each objective compared to its goal. Thus, the multiobjective function (1) can be rewritten as:

$$\text{Min } Z = w \left[\sqrt{2D \sum_{i=1}^n (A + C_f) \left(\sum_{i=1}^n P X_i^2 (r + r) \right) + \sum_{i=1}^n D X_i (r T P + C_v)} - G_1 \right] / G_1 + (1-w) \left[\sum_{i=1}^n X_i - G_2 \right] / G_2$$

This equation is a single objective function and our NMOP can be solved as a single objective optimization problem subject to constraints (2)-(7).

G_1 , G_2 , w and $(1-w)$ respectively are the cost, lead-time goals and the weighting factors for the absolute values of the relative variations of each criterion.

To find G_1 , we solve the model in section 2 by considering the cost as the only objective function ($Z = TC$), even thing for G_2 ($Z = DL$).

The next section presents a numerical example to evaluate the model. All results presented are generated on a personal computer (Intel Pentium IV, 2,40 GHz) using Matlab version 6.5, a high-performance language that offers the optimization Toolbox which consists of functions that perform minimization (or maximization) on general nonlinear functions. One of these functions is *fmincon* which allows to find a constrained minimum of a scalar function of several variables starting at an initial estimate. This is generally referred to as constrained nonlinear optimization. *Fmincon* uses a Sequential Quadratic Programming (SQP) method. In this method and at each iteration, a Quadratic Programming (QP) subproblem is solved and an estimate of the Hessian of the Lagrangian is updated.

The model is solved several times, evaluating various scenarios. Each scenario depends on the type of shipment used to move the products from suppliers to buyer.

4. MODEL VALIDATION

In this section, we first study the performance of the model by representing the CPU time in function of the number of suppliers and then, present a case study of three suppliers who have capacities limited and according to five scenarios, each one depends on the type of shipment employed by each supplier, as follows:

- scenario 1 : each supplier uses a LTL,
- scenario 2 : each supplier uses a TL,
- scenario 3 : supplier 1 uses a TL while suppliers 2 and 3 use LTL each one,
- scenario 4 : supplier 2 uses a TL while suppliers 1 and 3 use LTL each one,
- scenario 5 : supplier 3 uses a TL while suppliers 1 and 2 use LTL each one

LTL and TL are respectively a truckload (TL) and a less than truckload (LTL) characterized respectively by the in-transit holding rate 10% and 12%. The demand of the buyer is 1000 per

week, $r=20\%$, the maximum accepted lead-time is 3 days, the ordering, the purchasing costs and the holding rate of each supplier are respectively 10\$, 5\$ and 20%.

Table 1 below contains information on the suppliers, according to whether they use one or the other type of shipment.

Table 1: Supplier information

		Supplier 1	Supplier 2	Supplier 3
Capacity		900	800	700
Distance to buyer (miles)		100	150	200
Lead time (days)	LTL	1.43	2.14	2.86
	TL	0.57	0.86	1.14
Transit time (week)	LTL	0.14	0.21	0.29
	TL	0.06	0.09	0.11
Fixed shipment cost	LTL	15.28	22.92	30.56
	TL	132	198	264
Variable shipment cost	LTL	0.05	0.05	0.05
	TL	0	0	0

Table 2 gives the CPU time which includes the generation, compilation and execution times in seconds, to provide an optimal solution for each value of n .

Table 2: Computational time in CPU seconds

n	CPU (seconds)
2	0.97
3	1.58
4	1.70
5	4.48
6	22.19
7	63.92
8	196.26
9	538.66
10	1827.61

This time appears to grow exponentially in the number of suppliers, especially for value 7 of n . In this case, CPU time varies from 1 minute for $n=7$ to 30 minutes for $n=10$. This increase is

attributed to the combinations of binary variables Y_i (2^n). But we can conclude that our model can be solved in a rather reasonable amount of time.

For each of the five scenarios referred to above, table 3 below respectively gives the values of G1, G2 and other computational results corresponding to each goal. LT* and TC* respectively represents lead-time and total cost for G1 and G2.

Table 3: Computational results

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
X1	0.54	0.90	0.51	0.90	0	0.90	0.58	0.20	0.54	0.30
X2	0.46	0.10	0.49	0.10	0.54	0.10	0	0.80	0.46	0
X3	0	0	0	0	0.46	0	0.42	0	0	0.70
Q	219	170	583	453	251	315	233	402	219	499
G1	662.69		1256.05		802.31		731.62		662.69	
LT*	1.76		0.71		2.47		2.03		1.76	
G2		1.50		0.60		0.73		0.97		1.23
TC*		796.73		1591.33		1171.25		1268.58		1307.96

By considering the values of G1 and G2 for each scenario, table 4 below summarizes the results of the NMOP. In our experiment, we vary the values of w from 0 to 1 with a step of 0.1. Usually, this factor is fixed by the decision maker, which makes the method subjective to the user.

Let us note that we did not represent the correspondents' results with scenarios 1 and 2 (when suppliers use all the same type of shipment) because the suppliers to be selected in this case remain 1 and 2.

Table 4: Computational results of the NMOP

Weight (w1)	X1	X2	X3	Q	Transportation cost	In transit inventory cost	Inventory cost of supplier 1	Inventory cost of supplier 2	Inventory cost of supplier 3	Inventory cost of buyer	Optimum total cost	Optimum total lead-time	Z*
Scenario 1													
1	0.54	0.46	0	219	224.55	172.20	63.81	46.31	0	110.12	662.69	1.757	0
0.9	0.56	0.44	0	218	225.25	170.79	68.39	42.17	0	110.56	663.04	1.742	0.016
0.8	0.59	0.41	0	216	226.54	169	74.24	37.13	0	111.37	664.49	1.724	0.032
0.7	0.62	0.38	0	214	228.91	166.62	81.99	30.88	0	112.87	668.12	1.700	0.046
0.6	0.67	0.33	0	208	233.51	163.27	92.78	23	0	115.78	676.37	1.666	0.057
0.5	0.74	0.26	0	197	243.43	158	108.97	13.06	0	122.03	696.14	1.613	0.063
0.4	0.89	0.11	0	173	270.77	147.67	137.20	2.08	0	139.28	754.78	1.508	0.059
0.3	0.90	0.10	0	171	272.82	147	138.86	1.72	0	140.58	759.31	1.501	0.044
0.2	0.90	0.10	0	171	272.82	147	138.86	1.72	0	140.58	759.31	1.501	0.030
0.1	0.90	0.10	0	171	272.82	147	138.86	1.72	0	140.58	759.31	1.501	0.015
0	0.90	0.10	0	226	354.26	147	183.05	2.26	0	185.31	938.26	1.501	0
Scenario 2													
1	0.51	0.49	0	583	566.01	89.72	150.29	141.29	0	291.58	1256.05	0.713	0
0.9	0.52	0.48	0	583	566.50	89.20	158.84	132.98	0	291.83	1256.54	0.709	0.018
0.8	0.54	0.46	0	581	567.79	88.55	169.71	122.78	0	292.49	1258.53	0.703	0.036
0.7	0.56	0.44	0	578	570.56	87.70	183.99	109.94	0	293.93	1263.40	0.696	0.052
0.6	0.60	0.40	0	573	576.33	86.54	203.54	93.36	0	296.90	1274.12	0.687	0.067
0.5	0.64	0.36	0	561	588.77	84.84	232.04	71.26	0	303.30	1298.05	0.673	0.078
0.4	0.72	0.28	0	533	619.23	82.01	277.82	41.18	0	319	1358.01	0.651	0.083
0.3	0.90	0.10	0	457	721.56	75.76	366.72	4.99	0	371.71	1562.62	0.600	0.074
0.2	0.90	0.10	0	457	722.33	75.72	367.22	4.89	0	372.11	1564.17	0.599	0.049
0.1	0.90	0.10	0	457	722.33	75.72	367.22	4.89	0	372.11	1564.165	0.599	0.025
0	0.898	0.100	0.002	611	972.73	75.71	492.488	6.155	0.001	498.645	2070.288	0.60	0
Scenario 3													
1	0	0.54	0.46	251	262.93	246.81	0	73.19	53.19	126.38	802.31	2.471	0
0.9	0	0.58	0.42	248	265.27	243.24	0	84.87	42.89	127.76	804.29	2.44	0.236
0.8	0.71	0.29	0	375	427.34	112.54	187.24	32.40	0	219.64	1005.80	1.03	0.285
0.7	0.85	0.15	0	333	472.28	93.01	239.60	7.73	0	247.33	1089.95	0.81	0.283
0.6	0.90	0.10	0	318	492.71	86.07	256.25	3.30	0	259.55	1129.3449	0.73	0.245
0.5	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.351	0.73	0.204
0.4	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.3548	0.73	0.163
0.3	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.3547	0.73	0.122

0.2	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.3552	0.73	0.082
0.1	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.3555	0.729	0.041
0	0.90	0.10	0	318	492.72	86.06	256.25	3.30	0	259.55	1129.3552	0.73	0
Scenario 4													
1	0.58	0	0.42	233	246.48	202.95	78.58	0	41.08	119.67	731.62	2.03	0
0.9	0.65	0	0.35	227	252.41	192.66	95.37	0	27.91	123.28	735.79	1.93	0.104
0.8	0.75	0	0.25	212	266.49	177.84	118.38	0	13.48	131.86	755.28	1.79	0.195
0.7	0.90	0	0.10	185	298.42	155	149.46	0	1.85	151.31	810.24	1.57	0.262
0.6	0.90	0	0.10	185	298.42	155	149.46	0	1.85	151.31	810.24	1.57	0.313
0.5	0.36	0.64	0	455	486.85	119.50	58.72	186.71	0	245.44	1119.21	1.06	0.314
0.4	0.29	0.71	0	436	503.55	117.33	37.11	218.83	0	255.95	1155.70	1.03	0.267
0.3	0.20	0.80	0	405	536.37	114.40	16.21	259.32	0	275.53	1226.51	0.97	0.206
0.2	0.20	0.80	0	405	536.37	114.40	16.21	259.32	0	275.53	1226.51	0.97	0.139
0.1	0.20	0.80	0	405	536.37	114.40	16.21	259.32	0	275.53	1226.51	0.97	0.071
0	0.20	0.80	0	402	545.23	143.40	16.09	257.43	0	273.52	1226.51	0.97	0
Scenario 5													
1	0.54	0.46	0	219	224.55	172.20	63.81	46.31	0	110.12	662.69	1.76	0
0.9	0.56	0.44	0	218	225.44	170.48	69.40	41.28	0	110.68	663.22	1.74	0.042
0.8	0.60	0.40	0	216	227.17	168.28	76.59	35.19	0	111.78	665.39	1.72	0.082
0.7	0.64	0.36	0	212	230.52	165.33	86.19	27.70	0	113.89	670.88	1.69	0.120
0.6	0.70	0.30	0	204	237.29	161.06	99.71	18.46	0	118.16	683.71	1.64	0.153
0.5	0.80	0.20	0	188	253.03	153.96	120.61	7.48	0	128.09	716.30	1.57	0.179
0.4	0.90	0.10	0	171	272.82	147	138.86	1.71	0	140.57	759.31	1.50	0.191
0.3	0.90	0.10	0	171	272.82	147	138.86	1.71	0	140.57	759.31	1.50	0.198
0.2	0.33	0	0.67	510	564.21	134.66	56.42	0	227.17	283.59	1285.66	1.24	0.192
0.1	0.30	0	0.69	499	574.25	134.40	44.94	0	244.70	289.64	1307.96	1.227	0.10
0	0.30	0.003	0.697	532	584.47	134.61	47.71	0.005	258.59	306.32	1343.66	1.230	0

- Table 4 illustrates that varying the weights of the criteria will result in different suppliers being selected with varying order quantities. Indeed, for scenario 3, the buyer will choose suppliers 2 and 3 if w takes values 1 or 0.9 and suppliers 1 and 2 if w takes other values. For scenario 4, the choice will relate to suppliers 1 and 3 if w varies from 0.6 to 1 and suppliers 1 and 2 if w varies from 0 to 0.5. Finally, for scenario 5, the buyer will select suppliers 1 and 2 if w varies from 0.3 to 1 and suppliers 1 and 3 if w varies from 0 to 0.2. Thus, supplier selection depends well on transport.

- For a given value of w , example $w=0.5$, the minimum of all the Z is reached for scenarios 1 and 5. The buyer will choose suppliers 1 and 2. In both scenarios, suppliers use a LTL transportation type, which gives a minimum transportation cost (253.03) with a percentage of 35.32% of the total cost. The optimum order allocations assigned to each supplier are respectively, in proportion 0.80 and 0.20. The optimum order quantity is 188 and the order quantities, which should be purchased from suppliers, respectively are 150 and 38 for each of the five periods because there are $D/Q (=5.32)$ periods. At the 6th period, the buyer may order the rest of quantities to buyer 1 (60) to satisfy the demand (see fig. 1)
- Always for $w=0.5$, the in-transit inventory cost is maximum for selected suppliers (case 2 of scenarios 1 and 5) whereas it's minimum for the same case, for the other scenarios and especially for scenario 2. Indeed, a TL is faster and thus the products remain less longer in the road. This cost is also less significant if one of the two suppliers uses a TL (scenarios 4 and 3). Conversely, the inventory cost of buyer is minimum for scenarios 1 and 5 whereas it's significant for scenario 3, then for scenario 4 and more significant for scenario 2. The use of a TL implies that the products arrive quickly to the buyer and its stock is maximum.

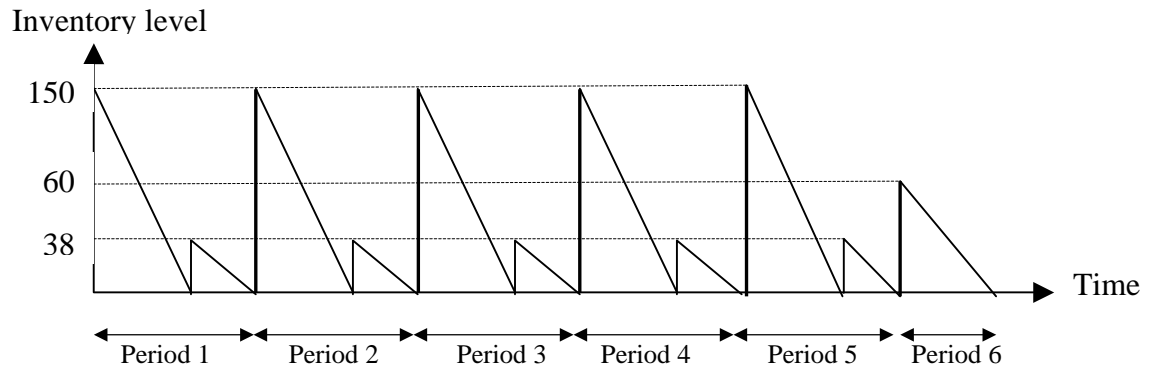


Fig. 1. Inventory level of the buyer

5. CONCLUSIONS

In reviewing the literature on the supplier selection problem, we note that there has been very little work that comprehensively examines the role of the transportation in this selection.

In this research, we have developed and demonstrated the use of a multiobjective programming approach for improving the impact of transportation in supplier selection problem. Our model can assist the buyer in selecting the appropriate suppliers and determining the size of the split orders.

The proposed approach is likely to find multiple solutions to the problem, each corresponding to a different setting of the weight factors. This makes this approach independent from the user. Solving five test scenarios has showed the efficacy of this approach.

Usually, this factor is fixed by the decision maker, which makes the method subjective to the user. Moreover, the solution of the problem largely depends on the value chosen for this factor.

The results of the numerical example demonstrated that transportation is likely to play a pivotal role in the supplier selection decision but also in the inventory system of the suppliers, in transit and of the buyer.

The perspective of this research is to study the combined transport, which is generally regarded as the most promising market for external logistics suppliers.

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