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A Multi-objective Mathematical Model for Sustainable Supplier Selection and Order Lot-sizing under Inflation

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ABSTRACT

Recently, scholars and practitioners have shown an increased interest in the field of sustainable supplier selection and order lot-sizing. While several studies have recently been carried out on this field, far too little attention has been given to formulating a multi-objective model for the integrated problem of multi-period multi-product order lot-sizing and sustainable supplier selection under inflationary conditions. In this study, a mathematical model for multi-period multi-product lot-sizing and sustainable supplier selection under the effects of inflation is developed. The proposed model includes four objective functions which minimize total cost and maximize total social, total environmental, and total economic qualitative scores. The model attempts to simultaneously balance different costs under inflationary conditions to optimize the total cost of purchasing and other objective functions. The applicability of the proposed model is shown by an illustrative example. The results show that the proposed model can provide an effective purchasing plan for the company while monitoring the effect of inflation and assuaging its concerns regarding sustainability issues.

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NOMENCLATURE

I	Number of products;	z	Discount rate
J	Number of suppliers	R	Effective inflation rate (r-z)
T	Number of periods	C_{ij}	Available capacity of supplier j for product i
D_{it}	Demand of product iat time t	V_i	Storage space needed for product i
P_{ijt}	Price of product i from supplier j at time t	S	Maximum storage space
O_{jt}	Ordering cost of supplier j at time t	E_{ij}	Score of supplier j for product i in environmental criteria achieved through fuzzy Inference system
φ_{jt}	Transportation cost from supplier j per kg at time t	τ_{ij}	Score of supplier j for product i in social criteria achieved through fuzzy Inference system approach
D_{ik}	Demand of product i at time k, $k \in T$	ω_{ij}	Score of supplier j for product i in economic qualitative criteria achieved through fuzzy Inference system
H_{it}	Holding cost of product iat time t	x_{ijt}	Quantity of product i purchased from supplier j at time t
r	Inflation rate	Y_{jt}	Binary variable: 1, if an order allocated to supplier j at time t, otherwise, 0
C_{ij}	Available capacity of supplier j for product i	z	Discount rate
R	Effective inflation rate (r-z)	Q	Quantity

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1. INTRODUCTION

During the past decades, supplier selection has grown in importance as a strategic issue in the area of supply chain management [1-3]. The supplier selection process was traditionally affected by different intangible and tangible criteria such as technical capability, service level, price, and quality [4, 5]. The emergence of sustainability over the past few decades has witnessed increasing interest from practitioners and academia in the field of sustainable supplier selection [6, 7]. Hence, many organizations have begun to emphasize on considering environmental, social, and economic dimensions of sustainability in their supplier selection processes by adapting sustainable supply chain creativities [8, 9]. According to the studies in the literature, the perception is that there are three important decisions related to supplier selection. These three decisions are concerned with the kind of products to be ordered, the quantities required, and when they are required [10, 11]. These three decisions make order lot-sizing and supplier selection closely related. Lot-sizing problems contain the objective of determining the period in which an order should take place and the quantities to be ordered to satisfy demand while minimizing costs [11]. One of the critical factors that can affect a buyer’s decisions and the lot-size of each product is the inflation rate. The effect of inflation has become a constant characteristic and a very important issue in several developing economies, especially in the third world countries [12]. Considering the effect of inflation on lot-sizing can reduce the total cost of purchasing over the planning horizon. Since the inflation rate leads to an increase in products prices, it can harm companies that do not consider this issue in their purchasing and inventory control functions. There are few studies in the existing literature that have considered the effect of the inflation rate on inventory control [13, 14]. However, there are very limited studies that considered the effect of the inflation rate on inventory lot-sizing integrated with sustainable supplier selection, even though it should be considered when addressing purchasing and logistic issues. Hence, this study is conducted to address the aforementioned gap. In this study, a multi-objective mathematical model is proposed for the integrated problem of sustainable supplier selection and multi-period multi-product lot-sizing under inflationary conditions. The rest of the paper is organized as follows: Section 2 examines the literature on the subject. Section 3 belongs to research methodology. In Section 4, results and discussions are provided. Finally, conclusions are presented in Section 5.

2. LITERATURE REVIEW

Over the past decades, there has been an increasing interest among scholars and practitioners in integrated problem of supplier selection and multi-period lot-sizing [2, 10, 15-17]. Basnet and Leung [15] developed an uncapacitated multi-period, multi-product lot-sizing problem that incorporated supplier selection. In this model, orders were allocated to one or more suppliers in each defined period. Ordering costs were considered each time an order was placed. Their work has become one of the most significant for vendor selection [10]. Their proposed LP model attempted to minimize the total costs associated with purchasing including purchasing, ordering, and holding costs. A study that built on previous studies conducted by Basnet and Leung [15] was performed by Woarawichai et al. [11]. They added storage space and budget constraints to the original model proposed by Basnet and Leung [15] using LINGO software. Hammami et al. [18] proposed a capacitated single objective mathematical model in order to integrate supplier selection with multi-period multi-product lot-sizing in order to minimize the aggregate costs of purchasing. In their proposed model, uncertainties in delivery lead times and different types of transportation were taken into account. Two multi-objective MINLP models were developed by Rezaei and Davoodi [19] for multi-period multi-product lot sizing with supplier selection and solved the models using GA. Although several studies have been accomplished in the field of supplier selection and multi-period lot-sizing, there is still no comprehensive model or framework for supplier selection and order allocation that simultaneously considers all three aspects of sustainability while the effect of inflation is taken into account.

3. RESEARCH METHODOLOGY

In order to cope with the integrated problem of sustainable supplier selection and multi-period multi-product lot-sizing, a comprehensive framework is proposed. The proposed approach of this paper includes four steps as presented below:

3. 1. Selecting Products and Their Corresponding Suppliers In this step, products that should be purchased based on the production plan of a company are selected. Afterward, qualified suppliers to provide the selected products are identified.

3. 2. Selecting Appropriate Criteria to Evaluate Suppliers This step is concerned with selecting all criteria in order to evaluate suppliers for the product. The criteria are selected based on the results of previous studies found in the literature. These criteria must be validated by expert opinions and then the criteria relevant to the company are extracted.

3. 3. Suppliers' Assessment This component of the research framework evaluates the suppliers. In this step, a fuzzy inference system (FIS) is used. In order to assess the suppliers all of the data regarding the selected sub criteria and their influencing factors (IFs) are collected. After collecting all of the data, these data are transferred into grades of membership as a fuzzy set of inputs. Subsequently, the target ranges of the input variables are defined. To conduct the output membership function, the target range is set between zero and one to represent the worst and the best values for each criterion, respectively. Then, fuzzy rules are constructed. The fuzzy "if–then" rules are constructed by the company's experts. To implement the fuzzy evaluation, MATLAB fuzzy logic toolbox is utilized.

3. 4. Model Formulation In this step, a multi-objective mathematical model for multi-period multi-product lot-sizing under inflationary condition and supplier selection is proposed.

3. 4. 1. Objective Functions

3. 4. 1. 1. Total Cost Based on this objective function, total inventory costs over the time horizon should be minimized. The total inventory cost (TIC) is sum of purchasing, ordering, holding, and transportation costs. As the effect of inflation rate is considered in this study, therefore, these costs will be increased/decreased over the time horizon. According to Buzacott [20], the following formula can be used in order to consider the effect of the effective inflation rate on each parameter:

$$b(t) = b_0 * e^{rt} \tag{1}$$

where b denotes a hypothetical parameter b_0, is the value of b at time zero, t indicates the period of time, and e is for exponential function.

Purchasing cost (PC): The total purchasing cost in this research can be stated as [2]:

$$PC = \sum_i \sum_j \sum_t P_{ijt} . x_{ijt} \tag{2}$$

In the presence of inflation rate, and according to Equation (2), the price of product i purchased form supplier j, at period t ,p_{ijt} ,can be formulated as:

$$P_{ijt} = P_{ij} . e^{Rt} \tag{3}$$

Therefore, the total purchasing cost can be stated by:

$$PC = \sum_i \sum_j \sum_t P_{ij} e^{Rt} . x_{ijt} \tag{4}$$

Ordering cost (OC): the ordering cost includes costs of processing orders and inspection and return of poor quality products. According to Basnet and Leung [15], the total ordering cost (OC) is formulated as:

$$\text{OC} = \sum_j \sum_t O_j Y_{jt} \tag{5}$$

However, in the presence of inflation rate, ordering cost of supplier j at time t, $O_{jt} = O_j . e^{Rt}$, the total cost of placing orders from different suppliers, OC, can be formulated as:

$$\text{OC} = \sum_j \sum_t O_j \, e^{Rt} \, Y_{jt} \tag{6}$$

Holding cost (HC) [15]:

$$\sum_j \sum_{k=1}^{t} x_{ijk} - \sum_{k=1}^{t} D_{ik} \tag{7}$$

Usually, holding cost of product *i* is shown by H_i. However, as the effect of inflation rate over the planning horizon is considered in this research, the holding cos of product *i* must be calculated in period *t* and can be shown by H_{it}. Therefore, the total holding cost can be stated as:

$$\sum_i \sum_t H_{it} \left(\sum_j \sum_{k=1}^{t} x_{ijk} - \sum_{k=1}^{t} D_{ik} \right) \tag{8}$$

in which, H_{it} can be formulated as $H_i . e^{Rt}$ which shows the holding cost of product *i* at the beginning of the period *t* under the condition with the inflation rate of *R*. However, as the inventory is kept in the warehouse between two periods (for example between period 1 and period 2) and consequently the holding cost is increased in this time interval according to the presence of inflation rate, this formula is not able to calculate the correct value of holding cost during period *t*. Therefore, it is needed to calculate the average value of holding cost during period *t* and Period *t+1*. Therefore, mean value theorem is applied in order to find the average

value of holding cost between two periods. The mean value theorem for integral can be shown as follows:
If function f is continuous on $[a,b]$, there exists a number c in $[a,b]$ that [21]:

$$f(c)=\frac{1}{b-a}\int_a^b f(x)dx \tag{9}$$

Therefore, based on Equation (9), the correct value of the holding cost of product i at period t can be calculated by:

$$H_{it}=H_i.(\frac{1}{\beta}\int_t^{t+\beta}e^{Rt}dt) \tag{10}$$

where, β demonstrates the time interval between two periods. And:

$$\int_t^{t+\beta}e^{Rt}dt=\frac{1}{R}(e^{R(t+\beta)}-e^{Rt}) \tag{11}$$

Therefore, holding cost of product i at period t can be shown as:

$$H_{it}=\frac{H_i}{\beta R}(e^{R(t+\beta)}-e^{Rt}) \tag{12}$$

Then, the total holding cost can be expressed as:

$$\text{HC}=\sum_i\sum_t\frac{H_i}{\beta R}(e^{R(t+\beta)}-e^{Rt})(\sum_j\sum_{k=1}^{t}x_{ijk}-\sum_{k=1}^{t}D_{ik}) \tag{13}$$

Transportation cost (TPC): TPC can be formulated as follows:

$$\text{TPC}=\sum_i\sum_j\sum_t x_{ijt}.\varphi_{jt} \tag{14}$$

Therefore,

$$\text{TPC}=\sum_i\sum_j\sum_t x_{ijt}.\varphi_j.e^{Rt} \tag{15}$$

Therefore, the cost objective function (Z_1) is presented as follows:

$$Min\ Z_1=\sum_i\sum_j\sum_t x_{ijt}.p_{ij}.e^{rt}+\sum_j\sum_t O_j.e^{rt}Y_{jt}+\sum_i\sum_t\frac{H_i}{\beta r}(e^{r(t+\beta)}-e^{rt})(\sum_j\sum_{k=1}^{t}x_{ijk}-\sum_{k=1}^{t}D_{ik})+\sum_i\sum_j\sum_t x_{ijt}.\varphi_{jt} \tag{16}$$

3. 4. 1. 2. Total Economical Qualitative Score The following objective function (Z_2) is designed to maximize the total economical qualitative score:

$$Max\ Z_2=\sum_i\sum_j\sum_t x_{ijt}.\omega_{ij} \tag{17}$$

3. 4. 1. 4. Total Environmental Score This objective function is aimed at maximizing the total environmental score of suppliers. Z_3 can be shown by:

$$Max\ Z_2=\sum_i\sum_j\sum_t x_{ijt}.E_{ij} \tag{18}$$

3. 4. 1. 4. Total Social Score This objective function is designed to maximize the total social score of suppliers.

$$Max\ Z_4=\sum_i\sum_j\sum_t x_{ijt}.\tau_{ij} \tag{19}$$

3. 4. 2. Constraints The constraints of the proposed mathematical model are given as follows:

3. 4. 2. 1. Demand Constraint The demand constraint shows that demands of different products must be filled in each period. Hence:

$$\sum_j\sum_{k=1}^{t}x_{ijk}-\sum_{k=1}^{t}D_{ik}\geq 0,\ \forall i\in I \tag{20}$$

3. 4. 2. 2. Capacity Constraint The capacity constraint assures that the supplier can't supply the products more than their capacity [11, 15]:

$$x_{ijt}\leq C_{ij},\ \forall i\in I,\ \forall j\in J,\ \forall t\in T \tag{21}$$

3. 4. 2. 3. Charging Ordering Cost Constraint This constraint elucidates that an order cannot take place without a transaction cost. This can be shown by [15]:

$$(\sum_{k=t}^{T}D_{ik}).Y_{jt}-x_{ijt}\geq 0,\ \ \forall i\in I,\ \forall j\in J,\ \forall t\in T \tag{22}$$

3. 4. 2. 4. Storage Capacity Constraint This constraint says that there is limited capacity for buyers in each period. The storage constraint is given by [11]:

$$\sum_i V_i.(\sum_j\sum_{k=1}^{t}x_{ijk}-\sum_{k=1}^{t}D_{ik})\leq S \tag{23}$$

where $\sum_j\sum_{k=1}^{t}x_{ijk}$ is the total amount of product i purchased until a specific period, k. It shows that the inventory level in each period must not be greater than the capacity of the warehouse.

3. 4. 2. 5. End of Horizon Inventory Level Constraint Based on the model assumptions, at the end of the planning horizon, there shouldn't be any products in the warehouse [11].

$$(\sum_j\sum_{t=1}^{T}x_{ijt}-\sum_{t=1}^{T}D_{it})=0,\ \text{for all } i \tag{24}$$

3. 4. 2. 6. Binary Constraints These constraints show that the quantity of purchasing for each product in each period from each supplier cannot be less than zero [15].

$$x_{ijt} \geq 0, \quad Y_{jt} = 0,1 \tag{25}$$

The final multi- objective model seems as follows:

$$\begin{aligned} Min\ z_1 = &\sum_i \sum_j \sum_t x_{ijt} . p_{ij} . e^{rt} + \\ &\sum_j \sum_t O_j . e^{rt} . Y_{jt} + \sum_i \sum_t \frac{H_i}{nr} (e^{r(t+n)} - e^{rt}) (\sum_j \sum_{k=1}^{t} x_{ijk} - \sum_{k=1}^{t} D_{ik}) \\ &+ \sum_i \sum_j \sum_t x_{ijt} . \varphi_j \end{aligned} \tag{26}$$

$$Max\ \ z_2 = \sum_i \sum_j \sum_t x_{ijt} . \omega_{ij} \tag{27}$$

$$Max\ \ z_3 = \sum_i \sum_j \sum_t x_{ijt} . E_{ij} \tag{28}$$

$$Max\ \ z_4 = \sum_i \sum_j \sum_t x_{ijt} . \tau_{ij} \tag{29}$$

Subject to

$$\sum_j \sum_{k=1}^{t} x_{ijk} - \sum_{k=1}^{t} D_{ik} \geq 0, \ \forall i \in I \tag{30}$$

$$\sum_i \sum_j x_{ijt} . q_{ij} \geq Q \quad , for\ all\ \ t \tag{31}$$

$$\sum_i \sum_j x_{ijt} . l_{ij} \leq L \quad , for\ all \tag{32}$$

$$x_{ijt} \leq C_{ij} , \ \forall i \in I , \ \forall j \in J , \ \forall t \in T \tag{33}$$

$$(\sum_{k=t}^{T} D_{ik}) Y_{jt} - x_{ijt} \geq 0, \ \forall i \in I , \ \forall j \in J , \ \forall t \in T \tag{34}$$

$$\sum_i V_i . (\sum_j \sum_{k=1}^{t} x_{ijk} - \sum_{k=1}^{t} D_{ik}) \leq S \tag{35}$$

$$(\sum_j \sum_{t=1}^{T} x_{ijt} - \sum_{t=1}^{T} D_{it}) = 0, \ \text{all } i \tag{36}$$

$$x_{ijt} \geq 0 \quad , Y_{jt} = 0,1 \tag{37}$$

4. CASE STUDY

In order to show the applicability of the proposed method, a leading Iranian food company was used as a real world case study in this study. This company purchased large volumes of these packaging films from suppliers. The three kinds of packaging film were 420, 422, and 432. The required demand for the product *i* in period *t* is tabulated in Table 1.

4. 1. Criteria Definition and Selection For sustainable supplier evaluation, relevant criteria and sub criteria were extracted from previous studies. In order to validate the criteria to be used for evaluation purposes, the company's experts were asked to select the relevant criteria for their company. The selected criteria are shown in Table 2.

4. 2. Data Collection In this section, the data regarding the selected criteria were gathered using a comprehensive 6 month data gathering. The collected data is shown in Tables 3 and 4.

TABLE 1. Demands

Period / Product	1	2	3	4	5	6
Film 322	15000	15000	15000	16500	16500	16500
Film 420	20000	20000	20000	22000	22000	22000
Film 422	20000	20000	20000	22000	22000	22000

TABLE 2. Selected environmental and social criteria

Criteria	Sub criteria	Influencing factor
Economic (ECO)	Cost	Purchasing cost Holding cost Ordering cost Transportation cost
	Economic Qualitative (EQ)	Quality (Q) Technology (T) Delivery (DE) Loyalty (L)
Environmental (EN)	Environmental Management System(EMS)	Environmental Management Certificates (EMC) Management's commitment to the environment and Support (MEC)
	Pollution (PO)	Pollution Control Capability (PC) Product Waste (PW)
	Green Competencies (GC)	Energy Consumption Control (EC) Recycling Capabilities (RC)
Social (SO)	Worker Safety and Labor Health (WS)	Occupational Health and Safety Management System (OHSMS) Personnel Engagement in Health and Safety Committee (PEHS) Health and Safety Incident (HSI)
	Training Education and Community Development (TE)	Employee Training (Managers) (ETM) Employee Training (Personnel) (ETP) Supporting Educational Institutions (SEI) Grant and Donation (GD)
	Contractual Stakeholder (CS)	Information Disclosure (ID) Stakeholder Engagement (SE)

For the criteria that are dimensionless, the ranges for evaluation are defined between one and three, while for the others, the units are defined in the Table 4.

4. 3. Calculating Suppliers Scores in Sustainability Criteria FIS was utilized for sustainable supplier evaluation process.

TABLE 3. Supplier/Product data

	Product	Supplier			
		S1	S 2	S3	S4
Pij(IRR)	Film 1	81000	80000	82000	79000
	Film 2	78000	77000	79000	77000
	Film 3	78000	77000	79000	77000
Oj(IRR)		5000000	5000000	5000000	5000000
φ_j(IRR/ kg)		172.2	486.6	126	30
Cij (kg/t)	Film 1	20000	15000	25000	12000
	Film 2	25000	15000	25000	15000
	Film 3	25000	15000	25000	15000

TABLE 4. Suppliers Data

IFs	Unit	Supplier			
		S1	S 2	S3	S4
OHSMS	Dimensionless	3	2	3	2
PEHS	Percent	0.23	0.1	0.125	0.12
HSI	Percent/year	0.04	0.06	0.05	0.07
ATM	Hours/year	63	35	68	21
ATP	Hours/year	35	18	41	15
SEI	Number/year	8	6	12	4
GD	Percent/year	2	1	1.5	1
ID	Dimensionless	3	2	3	3
SE	Dimensionless	3	2	3	2
EMC	Dimensionless	3	2	3	2
MEC	Dimensionless	3	2	3	2
PW	Percent/year	0.03	0.07	0.04	0.08
PC	Dimensionless	3	2	3	1
EC	Dimensionless	3	2	3	2
RC	Dimensionless	3	2	2	2
QU	Dimensionless	3	2	2	2
TC	Dimensionless	3	2	3	1
DE	Dimensionless	3	3	2	2
LO	Dimensionless	3	2	2	2

MATLAB fuzzy toolbox was used to perform the evaluation process. The results are shown in Table 4.

4. 4. Order Allocation In this step, the optimum order allocation to suppliers is calculated. In order to deal with this problem, the proposed model was used. As the weights of the objective functions were important for calculating the final results, fuzzy analytic hierarchy process (FAHP) was used to determine the weights. Owing to limited space, only the final results are shown in Table 5. Readers can refer to Chang [22] for a detailed explanation of FAHP steps.

According to Zimmerman [23] a fuzzy multi-objective model can be formulated as follows:

Find a vector $x^T = [x_1, x_2 ..., x_n]$ to satisfy

$$\tilde{Z}_k = \sum_{j=1}^{n} c_{jk} x_j \lesssim Z_k^0 \qquad k = 1, 2, ..., p \tag{38}$$

$$\tilde{Z}_l = \sum_{j=1}^{n} c_{jl} x_j \gtrsim Z_l^0 \qquad l = p+1, p+2, ..., q \tag{39}$$

Subject to

$$g_s(x) = \sum_{i=1}^{n} a_{sj} x_j \le b_s, \qquad s = 1, ..., m \tag{40}$$

$$x_j \ge 0, \quad j = 1, 2, ..., n \tag{41}$$

where c_{jk}, c_{jl}, a_{sj}, and b_s are crisp values. The fuzzy environment is denoted by "□". The symbol "≤~" denotes the fuzzified format of "≤" and is linguistically interpreted as "basically less than or equal to". Likewise, symbol "≥~" means "essentially greater than or equal to". Z_l^0 and Z_k^0 are expressed as the goal that the DM intends to achieve. Objective functions Z_i with i= 1,...,q were expressed by fuzzy sets with linearly increasing membership functions from 0 to 1. In this approach, every objective function is separated into its maximum and minimum scores.

TABLE 5. Weights of objective functions

Objective function	Weight
Z_1=Cost	W_1=0.277836
Z_2= Economic qualitative	W_2=0.2182940
Z_3=Environment	W_3=0.337386
Z_4=Social	W_4=0.166484

μ_{zk} and μ_{zl} denote the linear membership function for minimization and maximization goals which are presented by:

$$\mu_{zl}(x)=\begin{cases}1 & \text{for } Z_l \ge Z_l^+ \\ f_{\mu zl}=(Z_l(x)-Z_l^-)/(Z_l^+-Z_l^-) & \text{for } Z_l^- \le Z_l(x) \le Z_l^+ \\ 0 & \text{for } Z_l \le Z_l^-\end{cases} \quad (42)$$

$$\mu_{zk}(x)=\begin{cases}1 & \text{for } Z_k \le Z_k^- \\ f_{\mu z_k}=(Z_k^+-Z_k(x))/(Z_k^+-Z_k^-) & \text{for } Z_k^- \le Z_k(x) \le Z_k^+ \\ 0 & \text{for } Z_k \ge Z_k^+\end{cases} \quad (43)$$

where, Z_k^- and Z_l^+ are the best solution of the model which are obtained through solving each objective function separately. Moreover, Z_k^+ and Z_l^- are the worst value of each objective function. Considering the weight of each objective function, Lin [24] proposed a weighted max–min model for multi-objective fuzzy programming.

$$\text{Max } \lambda \quad (44)$$

Subject to:

$$W_i\lambda \le f_{\mu z_i}, \quad i=1,...,q \quad (45)$$

$$g_r(x) \le b_r \quad (46)$$

$$\lambda \in [0,1] \quad (47)$$

$$\sum_{j=1}^{q} W_i = 1,\ W_i \ge 0 \quad (48)$$

$$x_i \ge 0,\ i=1,...,n \quad (49)$$

The weight of each objective function is determined based on the experts' opinions inside the company using FAHP approach. This model is equivalent to solving the multi-objective model with new membership functions as follows:

$$\mu_{zk}(x)=\begin{cases}1 & \text{for } Z_k \le Z_k^- \\ f_{\mu z_k}/w_j=((Z_k^+-Z_k(x))/(Z_k^+-Z_k^-))/w_j & \text{for } Z_k^- \le Z_k(x) \le Z_k^+ \\ 0 & \text{for } Z_k \ge Z_k^+\end{cases} \quad (50)$$

$$(k=1,2,...,p) \quad (55)$$

$$\mu_{zl}(x)=\begin{cases}1 & \text{for } Z_l \ge Z_l^+ \\ f_{\mu zl}/w_j=((Z_l(x)-Z_l^-)/(Z_l^+-Z_l^-))/w_j & \text{for } Z_l^- \le Z_l(x) \le Z_l^+ \\ 0 & \text{for } Z_l \le Z_l^-\end{cases} \quad (51)$$

$$(l=p+1,p+2,...,q)$$

The results are shown in Table 6.

The final results of optimization using this method are shown in Tables 7 and 8. Table 7 shows the amount of each product allocated to suppliers in each period. Table 8 presents the value of the objective functions and λ achieved through the optimization process.

4. 5. Managerial Implications and discussions

To show the importance of inflation in the proposed model, it was run without considering inflation and the results were compared with that when the model was run with inflationary conditions. The results are shown in Figures 1 and 2. As shown in Figure 1, when the model was solved without the effect of inflation, the orders were wholly allocated to S1. However, under inflationary conditions, orders were shared between S1 and S3 because the model attempted to allocate the orders in the early periods to S1 until the entire product available from S1 had been purchased.

TABLE 6. Ideal positive and negative solutions

	Z_k^+	Z_k^-	Z_l^+	Z_l^-
Z1	3042554E+10	2975294E+10	-	-
Z2	-	-	114530.4	75632.27
Z3	-	-	309222.1	177996.9
Z4	-	-	254149.1	169024.6

TABLE 7. Order allocation

x_{ijt}	Q	x_{ijt}	Q	x_{ijt}	Q
x_{113}	12500	x_{211}	25000	x_{221}	15000
x_{121}	15000	x_{212}	25000	x_{246}	15000
x_{122}	15000	x_{213}	25000	x_{311}	25000
x_{131}	15000	x_{226}	7000	x_{312}	25000
x_{133}	25000	x_{232}	8000	x_{313}	25000
x_{141}	12000	x_{233}	6000	x_{321}	15000
x_{326}	7000	x_{332}	8000	x_{335}	6000
x_{346}	15000				

TABLE 8. The objective functions values based on weighted max-min approach

Objective functions				
Cost	Economic qualitative	Environment	Social	λ
0.3017179E+11	94839.91	250652.6	216931.8	1

The remaining 64500 kg of the product was allocated to S3. The orders were allocated to these two suppliers due to their high scores in various areas of sustainability. Figure 2 shows the behavior of the proposed model in terms of total volume of purchasing in each period with and without considering the effect of inflation rate. It shows that in the absence of inflation rate, when the model tried to make a balance between the costs (ordering, holding, and transporting costs) to minimize the total cost of purchasing, the best solution was achieved when the order quantities in each period were equal to the demand of each product in each period. Figure 3 shows the total order quantities of all products to be allocated to each supplier using the single objective cost-based model and the multi-objective model.

As shown in Figure 3, the single-objective model, which minimized the total purchasing cost, the orders were allocated to S4, S 2, and S1 in quantities of 168000 kg, 112000 kg, and 66500 kg, respectively. The majority of the orders were allocated to S4, which provided the products at lower prices.

However, when the multi-objective model was used, most of the orders were shared between S1 and S3 because of their high performances in other criteria.

It is worth mentioning that based on the results of single-objective and multi-objective models, the company's experts mentioned that the proposed multi-objective model has led to a better results for them.

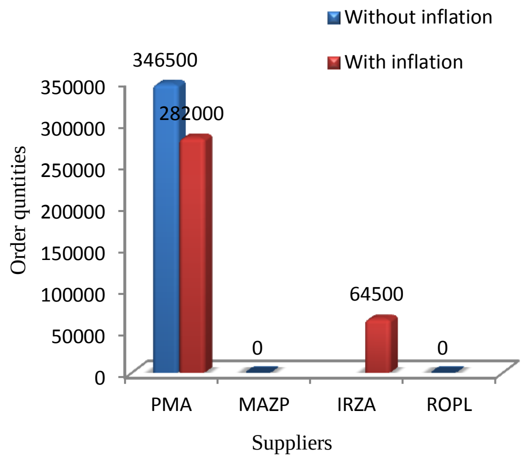

Figure 1. Order allocations to supplier with and without considering inflation

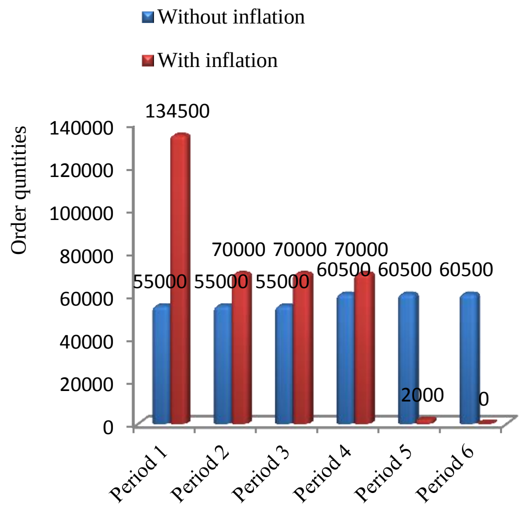

Figure 2. Volume of purchases for each period with and without considering inflation

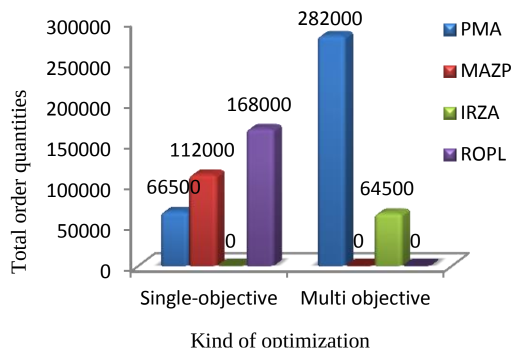

Figure 3. Order using single-objective and multi-objective models

5. CONCLUSIONS

The supplier selection decision has become more important for the companies that are looking for pure sustainable business practices along their upstream supply chain activities. Although several projects in the field of sustainable supplier selection have been carried out to select the best suppliers without order allocation, little attention has been devoted to incorporating sustainability issues for allocating the orders to suppliers considering lot-sizing problem. Moreover, very limited studies are available which incorporate the effect of inflation into the integrated problem of supplier selection and multi-period lot-sizing. Therefore, this research focused on developing a comprehensive multi-objective mathematical model for the integrated problem of sustainable supplier selection integrated with multi-period multi-product lot-sizing under inflationary conditions. The results show that the proposed approach could help managers to have better procurement plan in a sustainable supply chain while inflation rate is taken into account. For the future works, researchers could study on sustainable third-party logistics provider selection and order allocation. Moreover, future research can focus on the problem of sustainable supplier selection and order allocation in a closed loop supply chain. Furthermore, another future research may propose Pareto-efficient approaches for solving the multi-objective model.

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A Multi-objective Mathematical Model for Sustainable Supplier Selection and Order Lot-sizing under Inflation

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چکیده

محققان و متخصصان در سال‌های اخیر علاقه روز افزونی به حوزه انتخاب تامین کنندگان پایدار و تعیین اندازه انباشته سفارش داشته‌اند. اگرچه تحقیقات متعددی اخیرا در این زمینه انجام شده است، لیکن توجه کمی به فرموله کردن یک مدل چند هدفه برای مسئله یکپارچه تعیین اندازه انباشته چند دوره‌ای - چند محصولی و انتخاب تامین کنندگان پایدار تحت شرایط تورمی شده است. در این تحقیق، یک مدل ریاضی برای تعین اندازه انباشته چند دوره–چند محصولی تحت شرایط تورمی و انتخاب تامین کننده پایدار توسعه داده شده است. مدل پیشنهادی شامل چهار تابع هدف کمینه سازی هزینه، بیشینه سازی امتیازات اجتماعی، زیست محیطی و اقتصادی می‌باشد. در مدل پیشنهادی تلاش شده است تا به طور همزمان توازن بین هزینه‌های مختلف تحت شرایط تورمی برقرار شود تا تابع هدف هزینه و دیگر توابع هدف بهینه گردد. کاربردی بودن مدل پیشنهادی به وسیله یک مثال در دنیای واقعی نشان داده می‌شود. نتایج نشان داد که مدل پیشنهادی می-تواند یک برنامه خرید کارا برای کمپانی مورد مطالعه با در نظر گرفتن تاثیر نرخ تورم بررسی باشد و نگرانی مجموعه در زمینه مسایل پایداری را کاهش دهد.

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