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A resilient green meat supply chain network design; applying multi-objective robust optimization approach

Zeinab Sazvar[1], Sara Ebrahimkhani[2], Atie Izadi[3]

[1] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran; sazvar@ut.ac.ir

[2] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran; saraebrahimkhani@ut.ac.ir

[3] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran; atie.izadi@ut.ac.ir

ABSTRACT

In this paper, the resilience green meat supply chain network is investigated by proposing a multi-product, multi-period, multi-echelon and multi-objective mixed-integer linear programming formulation considering three conflicting objectives: minimizing total transportation and location costs, minimizing total CO_2 emissions released from transportation, and maximizing total capacity utilization. Disruption in each echelon of the green meat supply chain is considered. Also, transportation cost and demand parameters are sources of uncertainty, therefore, in order to cope with the uncertainties, robust optimization approach is applied. A solution approach based on the multi-choice goal programming (MCGP) approach considering utility function is utilized to solve the proposed model. As a result, the optimal product flow and number of each echelon will be determined. Finally, a set of numerical experiments and sensitivity analyses on uncertainty level and demand parameters to investigate the efficiency of the proposed model are conducted.

Keywords: Meat supply chain, Multi-objective programming, Mixed-integer linear programming, Ben-Tal robust optimization, Multi-choice goal programming

1. Introduction

With noticeable growth in population and simultaneous increase in incomes in developing countries, the food demand is rising rapidly. Food supply chain has a significant role in handling the food demand. Considering meat as the main meal, it is imperative to take the design of meat supply chain network seriously. Designing each echelon of food supply chain (FSC) requires large amounts of money. Thus, for the FSC to be efficient, cost reduction is of primary importance. Also, in recent years, environmental effects of products have received great attention from people. Therefore, initiatives to tackle environmental issues, particularly emission of greenhouse gases such as carbon dioxide (CO_2), which is released from transportation, need to be taken into special consideration. Moreover, one of the substantial factors to minimize the cost for logistics and facilities is optimization of capacity level. In order to satisfy the customer demand at the right time, a sufficient capacity level is a determining factor. Disruption in food supply chain networks (FSCN), particularly disruption in capacity level, is worth paying attention to, while designing the supply chain. Capacity disruptions lead to loss of inventory, unsatisfied demand, and consequently decrease in service level and sales. The main causes of capacity disruption are categorized into natural and man-made disasters (e.g., earthquakes, fire, flood, equipment damages, and labor strike).

In this paper, a multi-objective mixed-integer linear programming (MOMILP) model is proposed to design a green meat supply chain network. The goals of the proposed model are minimizing total cost and total CO_2 emissions of transportation, and maximizing total capacity utilization of facilities, considering the capacity disruptions. Also, the uncertainties in transportation cost and demand have been investigated.

The remainder of this paper is organized as follows. Section 2 presents the related literature of the research. Section 3 concerns with problem statement and assumptions. Section 4 describes the research problem and proposed MOMILP model. The uncertainty modeling is presented in section 5. The solution approach and the numerical analysis are illustrated in Section 6 and Section 7, respectively. Finally, Section 8 presents the conclusions and provides suggestions for future research.

2. Literature

In this section, the researches related to current study have been reviewed in order to find the research gap in this field.

Garcia-Flores et al. [2] investigated the northern Australia cattle industry and proposed a strategic optimization model to obtain the optimal location of cattle rest sites and optimal quantity in every echelon. Mohammed and Wang [5] formulated a multi-objective model for meat supply chain network design to minimize the total cost of transportation, number transportation vehicles, and delivery time of meat products. They obtained three Pareto solutions using the ε-constraint method, LP-metrics method, and the weighted Tchebycheff method. Mohammed et al. [4] developed a multi-objective model to optimize four conflicting objectives in meat supply chain. They used the modified weighted-sum and ε-constraint method to solve the suggested model. Rahimi et al. [10] introduced a new robust multi-objective multi-period model for supply chain planning under uncertain purchasing cost, selling price, and demand. They made a balance between the current and expected profit and employed LP-metrics method and solved the model as a single-objective mixed-integer programming model. Soysal et al. [12] provided a single-product multi-objective linear programming model for beef logistics network problem. The objectives were minimizing total CO2 emissions and total logistics cost. Mohebalizadeh and Hafezalkotob [6] developed a multi-objective mixed integer linear programming model for a sustainable supply chain network. They used fuzzy parametric programming (MFPP) and weighted metrics method to solve the developed model.

Chávez et al. [1] investigated perishable agricultural products transported from Mexico to the United States. They considered disruption in transportation and formulated a stochastic multi-objective minimum cost flow (SMMCF) model and proposed a simulation-based multi-objective optimization solution procedure. Pariazar and Sir [8] developed a multi-objective stochastic programming model to make a balance between costs and risk in the supply chain, considering disruption in production. A genetic algorithm-based search method was proposed to identify Pareto-optimal supply chain configurations. Shekarian et al. [11] examined multi-site, multi-product, multi-period, multi-objective, and multi-transportation channels under supply risk and demand risk. They studied the effects of flexibility and agility on reducing supply chain disruptions. The augmented ε-constraint method and the non-dominated sorting genetic algorithm are applied to solve multi-objective mixed integer programming model. Mohebalizadehgashti et al. [7] developed a multi-objective mixed-integer linear programming formulation for a green meat supply chain network in Southern Ontario, Canada, to minimize total cost and total CO2 emissions, and maximize total capacity utilization of facilities. The augmented ε-constraint method is employed to solve the proposed model. Also they considered uncertainty in demand and purchasing cost using decision trees technique.

The literature showed that in designing the meat supply chain networks, uncertainty and disruptions have been less addressed by researchers. This paper proposes resilience green meat supply chain network whose objectives are minimizing total transportation and fixed cost, minimizing total CO2 emissions released from transportation, and maximizing total capacity utilization with disruption in each echelon of the FSC. In order to cope with the uncertainties, the robust optimization approach is applied. Finally, the MOMILP model is solved using goal programming method. The main contribution of this research is incorporating concept of resiliency in the green meat supply chain network design problem under uncertainty.

3. Problem Definition

In this paper, a system consisting of farms, abattoirs, retailers, and customers with different kinds of product is investigated. Figure 1 shows the above four-echelon supply chain network. Farms supply various types of animals for abattoirs. In abattoirs, a type of meat plant in which livestock is slaughtered, meat is processed and then transported to retailers. Finally, retailers are in charge of selling meat to customers. The proposed model assists abattoirs in choosing farms and retailers to work with. Furthermore, it determines the product flow transported between each echelon and the location of each abattoir. The assumptions of the model are as follows: Maximum capacity of farms, abattoirs, and retailers are deterministic. The transportation cost and customer demand are uncertain parameters. Inventory of product in abattoirs and retailers, and shortage are not allowed. Other parameters, including the purchasing price of animals, fixed cost of working with a farm, opening an abattoir, and selling meat via a retailer, are known in advance. The transportation distance and cost from each layer to another is known. For the CO_2 emission due to the transportation, a factor is used. Also, for disruption in capacity level of farms, abattoirs, and retailers, other factors are applied.

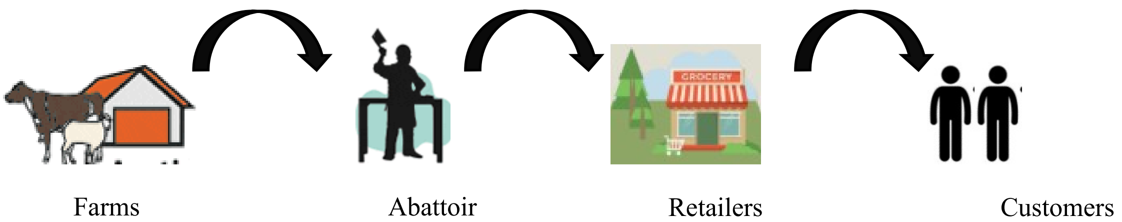

Figure 1. A four-echelon meat supply chain network

4. Model formulation

The notations of the proposed model are defined in the following:

Sets:

F: set of potential farm locations *(1 … f … F)*
A: set of potential abattoir locations *(1 … a … A)*
R: set of potential retailer locations *(1 … r … R)*
C: set of customers *(1 … c … C)*
J: set of products *j* including livestock and meat *(1 … j … J)*
T: set of time periods *(1 … t … T)*

Parameters:

p_{fjt}: purchasing cost per ton of livestock *j* from farm *f* in period *t*
n_f: fixed-cost of working with farm *f*
b_a: fixed-cost for opening abattoir *a*
e_r: fixed-cost for selling products via retailer *r*
de_{fa}: transportation distance (mile) from farm *f* to abattoir *a*
ge_{ar}: transportation distance (mile) from abattoir *a* to retailer *r*
he_{rc}: transportation distance (mile) from retailer *r* to customer *c*
kc_{fajt}: unit transportation cost per mile for livestock *j* from farm *f* to abattoir *a* in period *t*
lc_{arjt}: unit transportation cost per mile for processed meat *j* from abattoir *a* to retailer *r* in period *t*
mc_{rcjt}: unit transportation cost per mile for meat *j* from retailer *r* to customer *c* in period *t*
d_{cjt}: demand (ton) of customer *c* for meat *j* in period *t*
x_{fj}: maximum supply capacity (ton) of farm *f* for livestock *j*

o_{aj}: maximum supply capacity (ton) of abattoir *a* for processed meat *j*
u_{rj}: maximum supply capacity (ton) of retailer *r* for meat *j*
α: CO2 emission factor per ton and per mile
w_j: weight (ton) of product *j* including livestock and meat
β_f: capacity disruption factor in farm *f*
β_a: capacity disruption factor in abattoir *a*
β_r: capacity disruption factor in retailer *r*

Decision Variables:

QU_{fajt}: quantity of livestock *j* (ton) transported from farm *f* to abattoir *a* in period *t*
QN_{arjt}: quantity of processed meat *j* (ton) transported from abattoir *a* to retailer *r* in period *t*
QA_{rcjt}: quantity of meat *j* (ton) transported from retailer *r* to customer *c* in period *t*
Z_f: binary variable, equals to 1 if farm *f* is selected, 0 otherwise
I_a: binary variable, equals to 1 if abattoir *a* is open, 0 otherwise
Y_r: binary variable, equals to 1 if retailer *r* is selected, 0 otherwise

Mathematical Modeling:

According to above definitions, the research problem can be formulated as follows:

$$MinZ1=\sum_f\sum_a\sum_j\sum_t(p_{fjt}+kc_{fajt}*de_{fa})*QU_{fajt}+\sum_a\sum_r\sum_j\sum_t lc_{arjt}*ge_{ar}*QN_{arjt}+\sum_r\sum_c\sum_j\sum_t mc_{rcjt}*he_{rc}*QA_{rcjt}+\sum_f n_f*Z_f+\sum_a b_a*I_a+\sum_r e_r*Y_r \quad (1)$$

$$MinZ2=\alpha(\sum_f\sum_a\sum_j\sum_t w_j*de_{fa}*QU_{fajt}+\sum_a\sum_r\sum_j\sum_t w_j*ge_{ar}*QN_{arjt}+\sum_r\sum_c\sum_j\sum_t w_j*he_{rc}*QA_{rcjt} \quad (2)$$

$$MaxZ3=\sum_f\sum_a\sum_j\sum_t QU_{fajt}/x_{fj}+\sum_a\sum_r\sum_j\sum_t QN_{arjt}/o_{aj}+\sum_r\sum_c\sum_j\sum_t QA_{rcjt}/u_{rj} \quad (3)$$

S.t:

$$\sum_a\sum_j QU_{fajt}\le Z_f.\sum_j\beta_f*x_{fj} \qquad \forall f,t \quad (4)$$

$$\sum_r\sum_j QN_{arjt}\le I_a.\sum_j\beta_a*o_{aj} \qquad \forall a,t \quad (5)$$

$$\sum_c\sum_j QA_{rcjt}\le Y_r.\sum_j\beta_r*u_{rj} \qquad \forall r,t \quad (6)$$

$$\sum_f QU_{fajt}\ge\sum_r QN_{arjt} \qquad \forall a,j,t \quad (7)$$

$$\sum_a QN_{arjt}\ge\sum_c QA_{rcjt} \qquad \forall r,j,t \quad (8)$$

$$\sum_r QA_{rcjt}=d_{cjt} \qquad \forall c,j,t \quad (9)$$

$$Z_f,I_a,Y_r\in\{0,1\} \qquad \forall f,a,r \quad (10)$$

$$QU_{fajt},QN_{arjt},QA_{rcjt}\ge 0 \qquad \forall f,a,r,c,j,t \quad (11)$$

The Equation (1) represents the first objective function, which is minimizing total transportation cost and fixed costs. The purchasing and transportation cost of animals that are transported from farms to abattoirs are the first part of the function. The second and third terms denote the transportation cost of transferring meat from abattoirs to retailers and from retailers to customers, respectively, and they are followed by the fixed costs related to farms, abattoirs, and retailers. Equation (2) minimizes the emission of CO2, while equation (3) maximizes capacity utilization of facilities. Constraints (4), (5), and (6) restrict the capacity of farms, abattoirs, and retailers, respectively, considering capacity disruption. Constraints (7) and (8) ensure that the amount of meat sent to and by each abattoir and retailer, respectively, in each time period and for each product, are equal. Constraint (9) requires that the entire demand of every customer is satisfied. Constraints (10) and (11) indicate binary decision variables and non-negative decision variable.

5. Uncertainty Modeling

Due to changes in the business environment, uncertainty exists in nature of supply chain network design problem. In this study some parameters like demand of customers and transportation costs considered as an uncertain parameter. Hence, the Ben-Tal robust optimization approach is applied to deal with the uncertainties, interested readers can see Pishvaee et al. [9]. The robust counterpart of the proposed model can be formulated as follows:

$$Min Z1 \tag{12}$$

S.t:

$$\sum_f\sum_a\sum_j\sum_t(p_{fjt} * QU_{fajt} + \overline{kc}_{fajt} * de_{fa} * QU_{fajt} + \eta^{kc}_{fajt}) + \sum_a\sum_r\sum_j\sum_t(\overline{lc}_{arjt} * ge_{ar} * QN_{arjt} + \eta^{lc}_{arjt}) + \sum_r\sum_c\sum_j\sum_t(\overline{mc}_{rcjt} * he_{rc} * QA_{rcjt} + \eta^{mc}_{rcjt}) + \sum_f n_f * Z_f + \sum_a b_a * I_a + \sum_r e_r * Y_r \le Z1 \tag{13}$$

$$\rho_{kc} * G^{kc}_{fajt} * QU_{fajt} \le \eta^{kc}_{fajt} \tag{14}$$

$$\rho_{kc} * G^{kc}_{fajt} * QU_{fajt} \ge -\eta^{kc}_{fajt} \tag{15}$$

$$\rho_{lc} * G^{lc}_{arjt} * QN_{arjt} \le \eta^{lc}_{arjt} \tag{16}$$

$$\rho_{lc} * G^{lc}_{arjt} * QN_{arjt} \ge -\eta^{lc}_{arjt} \tag{17}$$

$$\rho_{mc} * G^{mc}_{rcjt} * QA_{rcjt} \le \eta^{mc}_{rcjt} \tag{18}$$

$$\rho_{mc} * G^{mc}_{rcjt} * QA_{rcjt} \ge -\eta^{mc}_{rcjt} \tag{19}$$

$$\sum_r QA_{rcjt} \ge d_{cjt} - \rho_d * G^d_{cjt} \tag{20}$$

$$\sum_r QA_{rcjt} \le d_{cjt} + \rho_d * G^d_{cjt} \tag{21}$$

$$\eta \ge 0 \tag{22}$$

Equations (2)-(8), (10), (11)

Where G_{fajt}^{kc}, G_{arjt}^{lc}, and G_{rcjt}^{mc} represent "uncertainty scale" in transportation cost of product *j* in period *t* between farm *f*, abattoir *a*, retailer *r*, and customer *c*. The parameters ρ_{kc}, ρ_{lc}, and ρ_{mc} are "uncertainty levels" in transportation cost between farm *f*, abattoir *a*, retailer *r,* and customer *c*. Also, G_{cjt}^{d} is "uncertainty scale" in customer demand for product *j* in period *t*.

6. Solution Approach

In this paper, the multi-choice goal programming (MCGP) approach considering utility function is employed to solve the multi-objective problem. Interested readers can consult Jadidi et al. [3] for more information. The notations and the model are presented as follows:

k: Index for objectives

X_i: Number of units ordered to supplier *i*

$f_k(X)$: Objective *k*

y_k: Kth aspiration level

$f_{k,min}$: Minimum of y_k

$f_{k,max}$: Maximum of y_k

w_k^d: Relative importance connecting (d_k^-, d_k^+)

d_k^-: Negative goal deviation

d_k^+: Positive goal deviation

δ_k^-: Normalized deviation of y_k from $f_{k,min}$

w_k^δ: Weight associated with δ_k^-

λ_k: Utility value

$$Min \sum_{K=1}^{3}[w_k^d(d_k^- + d_k^+) + w_k^\delta \delta_k^-] \tag{23}$$

S.t:

$$\lambda_k \le \frac{f_{k,\max} - y_k}{f_{k,\max} - f_{k,\min}} \tag{24}$$

$$f_k(X) + d_k^- - d_k^+ = y_k \tag{25}$$

$$\lambda_k + \delta_k^- = 1 \tag{26}$$

$$f_{k,\min} \le y_k \le f_{k,\max} \quad (27)$$

$$d_k^- d_k^+ = 0 \quad (28)$$

$$d_k^-, d_k^+, \delta_k^-, \lambda_k \ge 0 \quad (29)$$

7. Computational Experiments

In this part, the performance of the proposed mathematical model is investigated by numerical experiments. The parameters for numerical examples are given in Table 1.

Table 1- Value of parameters

Parameter	*Random distribution*	*Parameter*	*Random distribution*
p_{fjt}:	Uniformint (3000,7000)	u_{rj}	Uniformint (1500,2000)
n_f	Uniformint (10000,20000)	w_j	Uniform (0.5,0.7)
b_a	uniformint (1000000,2000000)	β_f	Uniform (0.1,0.9)
e_r	Uniformint (20000,30000)	β_a	Uniform (0.1,0.7)
de_{fa}	Uniformint (30,50)	β_r	Uniform (0.1,0.6)
ge_{ar}	Uniformint (10,40)	A	222 g per ton-mile
he_{rc}	Uniformint (20,30)	[illegible] = ρ_{lc} = ρ_{mc}	0.1
kc_{fajt}	Uniformint (30,50)	G^{kc}_{fajt}	2.12
lc_{arjt}	Uniformint (15,30)	G^{lc}_{arjt}	2.3
mc_{rcjt}	Uniformint (10,25)	G^{mc}_{rcjt}	3.87
d_{cjt}	Uniformint (10,30)	$w^d_1 = w^\delta_1$	0.33
x_{fj}	Uniformint (1500,2000)	$w^d_2 = w^\delta_2$	0.33
o_{aj}	Uniformint (1500,2000)	$w^d_3 = w^\delta_3$	0.33

A set of sensitivity analyses on the two parameters ρ and d are conducted. Figure 2 shows the changes of the uncertainty level, ρ, on Z_1, Z_2, and Z_3. As shown in Figure 2, by increasing ρ, total cost faces a non-linear increase, CO_2 emissions grow higher and capacity utilization decreases. Nevertheless, the increase in total cost is faster than the growth in CO_2 emissions. Therefore, one suggested scheme to cope with the uncertainty level, the parameters need to be estimated more accurately. In addition, Figure 3 describes the changes of customer demand, d, on Z_1, Z_2, and Z_3. As customer demand increases, the total cost, CO_2 emissions, and capacity utilization increase.

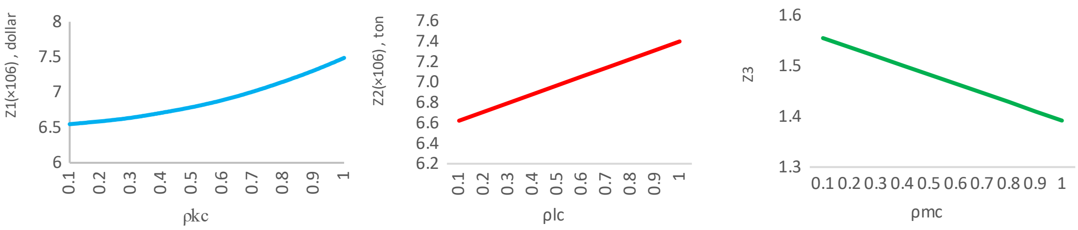

Figure 2. Changing on Z1, Z2, and Z3 by increasing ρ

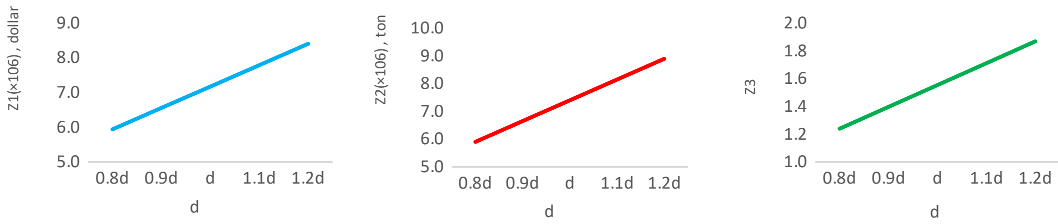

Figure 3. Changing on Z_1, Z_2, and Z_3 by increasing d

8. Conclusion

The supply chain network problem considered in this study is a multi-product, multi-period, and multi-objective green meat supply chain network including four echelons: farms, abattoirs, retailers, and customers. First, a multi-objective mixed-integer linear programming (MOMILP) model is developed. Then, the Ben-Tal robust optimization approach is employed to handle uncertainty. Finally, the model is solved by the multi-choice goal programming (MCGP) approach considering utility function. One of the main contributions of this paper is to consider disruptions in green meat supply chain network design problem. The other contribution is its consideration of uncertainties in both transportation cost and customer demand. The proposed model determines the optimal unit of products ordered by each echelon, the optimal number of farms, abattoirs, and retailers and how they are connected to each other.

Some possible future research directions can be defined as follows: (1) considering the meat as a perishable product while designing its supply chain network; (2) investigating the impact of uncertainty in lead time of meat product.

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