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RESEARCH NOTE

A New Combination of Robust-possibilistic Mathematical Programming for Resilient Supply Chain Network under Disruptions and Uncertainty: A Real Supply Chain

A. Hamidieh, A. Arshadi khamseh*, B. Naderi

Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran

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A B S T R A C T

Nowadays, the design of a strategic supply chain network under disruption is one of the most important priorities of the governments. One of the strategic purposes of managers is to supply the sustainable agricultural products and food in stable conditions which require the production of soil nutrients. In this regard, some disruptions such as sanctions and natural disasters have a destructive effect on the supply of raw materials and the uncertainty of input parameters plays an undesirable impact on the decision-making levels including strategic, tactical, and operational levels. The present study introduced a new model of resilient supply chain network which was compatible with the realities of the structure of the supply chain for fertilizer in Iran. Notably, the effectiveness of the designed system was promoted by the dominant strategies of reliability. Further, a new robust possibilistic approach was proposed which guaranteed the optimality and feasibility robustness through the efficient solution to deal with the parametric uncertainty. Finally, the results showed that the proposed new robust possibilistic combination promoted the optimality robustness and its effectiveness using an optimal average cost and minimum standard deviation.

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1. INTRODUCTION

In recent years, increasing the agricultural production to meet the increasing food demand in Iran has been regarded as one of the most critical priorities of the agriculture. In this regard, it is essential to pay more attention to soil fertility and the increased use of basic resources and production factors such as soil, water, and the like. In addition, one of the strategic purposes of the agriculture is to use the nutrients like fertilizers to increase soil yield per unit area. Phosphate fertilizers such as triple super phosphate play an essential role in the economic production of the product.

Triple super phosphate fertilizer is obtained from the reaction of phosphoric acid and phosphate rock, which is produced as granular and non-granular products. In fact, this fertilizer is mainly made from phosphate rock used to produce phosphoric acid [1]. The low grade of many rock phosphate mines and their resource limitation in Iran has recently increased the import of active phosphate soil in the country. Therefore, it is necessary to design a supply chain network which can store the required soil phosphate for the production of fertilizer in the strategic stores to produce suitable fertilizers for the provinces in different crop periods.

Unstable business conditions and natural and human disturbance were highly considered due to the strategic importance of the supply chain. Obviously, the cases mentioned above have created a high degree of uncertainty in the network which prevents optimized network performance [2]. This uncertainty in network design was intensified by the long-term decision-making [3]. Therefore, the main challenge for the industry owners is to provide a solution which can cope with the uncertainties of the business environment and has the least possible fluctuation of performance [4]. In this study, a high degree of uncertainty took place in the parameters of production costs, transportation, market demand, capacity utilization, and so on, due to

*Corresponding Author Email: alireza.arshadikhamseh@gmail.com (A. Arshadi khamseh)

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agricultural policy changes assigned by the government and farmers. To cope with this increasing uncertainty, a robust supply chain network was developed which offered an effective function on how to deal with the indeterminate parameters [5].

In this regard, many researchers have considered the robust optimization approach. Snyder and Daskin [6] applied the scenario-based random planning to increase the reliability of the supply chain network. Pan and Nagi [7] developed a robust scenario-based random model to deal with demand uncertainty in a supply chain network. Pishvaee et al. [8] developed a robust planning approach within the possibilistic planning framework and provided a new robust possibilistic approach. Hatefi and Jolai [9] provided a robust programming model for the closed loop supply chain network which was designed to deal with the internal and external risks of the network. Zhang and Zhang [10] presented a possibilistic programming model and defined the limited value of absolute deviation in the model and guaranteed the feasibility robustness. Hamidieh et al. [11] developed a robust possibilistic programming model which optimized the closed loop supply chain network with a response strategy and controlled the intensity of the flow of components and products in direct and reverse directions. Farrokh et al. [12] presented a robust possibilistic programming model which considered absolute possibilistic deviation in the objective function and considered the flexibility factor in the model. Fazli and Hamidieh [13] developed the multi-level possibilistic supply chain network model to deal with uncertainty and disruptions. The other major challenge for supply chain network design is its associated disruptions and risks. The risk sources of the disruption include operational risk, natural disasters, and terrorist incidents and political events [14]. Hence, the primary factor in supply chain network design is the identification of the disruptive behavior including facility characteristics such as location, size, sales, etc., the nature of the rules governing the facilities and the socio-geographic characteristics of the host community in the supply chain network [15, 16]. Therefore, analyzing the above characteristics in supply chain network design seems necessary. Thus, supply chain resilience design is an effective approach which has been developed to cope with supply chain risk sources [17]. Supply chain resilience, identification of potential sources of risk and implementation of the appropriate strategy through a coordinated approach among network facilities are implemented to reduce network vulnerability [18]. The resilience aims to restore the supply chain after a disruption in the least amount of time and with the lowest cost. In this regard, some effective strategies were defined for each upper and lower level and internal operation of the supply chain, and they were used based on the type, structure, and function of the network [19]. Some strategies like sourcing and visibility were applied in the upper levels of the supply chain like surplus and multi-level capacities, strategic inventory and strategic surplus capacity at the level of internal operations and flexible and demand-driven management in the lower level of supply chain strategies [20]. In this regard, Klibi and Martel [21] developed the location-transportation models based on multiple sourcing strategies and routing by focusing on increasing resilience in the upstream and operational levels of the supply chain. Sawik [22] introduced the resilient supply chain by combining the resilience strategies of the emergency inventory of raw materials and multiple sourcing. Hasani and Khosrojerdi [23] focused on the six main resilience strategies, including dispersion of facilities, semi-finished products manufacturing, multiple sourcing, surplus inventory, the strength of the facilities and bill of the original and alternative materials (BOM) in the design of the global supply chain network. Some features of the present study and the specific economic and political situation in Iran have created some challenges for uncertainty and disruption simultaneously. Thus, a robust possibilistic approach based on fuzzy programming was used to deal with the uncertainty, and four effective strategies were utilized to increase the resilience of a supply chain network in supply chain network design. The following four strategies could improve the reliability of different supply chain levels (above, internal and lower operation) and apply resilience to the entire system as follows:

(a) Predicting multi-level capacity for active network facilities

(b) Determining strategic inventory for network distribution facilities

(c) Creating a transportation mode in transportation network facilities

(d) Controlling the intensity of input facilities disruption and production centers

Regarding the issues above, the differences between the present study and other studies are as follows:

Integrating the distribution system and raw material control (phosphate rock) from domestic mining and import.

Controlling and classifying the quality of aggregate phosphate rock in the warehouses to organize and sending them to the appropriate production center.

Increasing the need for provinces for TSP fertilizers and ensuring demand coverage in different crop periods.

Providing the demand of the regions in different crop periods based on the limitations of the Iran transportation system.

Creating strategic inventory at two levels of raw material distribution and final product.

Designing a new supply chain network for fertilizer with high reliability and resilience approach in the country.

Implementing robust-possibilistic approach to deal with parametric uncertainty.

2. PROBLEM DEFINITION AND MODEL FORMULATION

The present study is based on the actual production of triple super phosphate fertilizer (TSP) in the chemical industry of Iran. TSP fertilizer is made from the chemical reaction of phosphate rock and phosphoric acid. This fertilizer is produced in a variety of granular and powdered products. The primary source of TSP fertilizer is phosphate rock, which is supplied by import and mining. The amount of phosphoric acid in the fertilizer obtained from the phosphate rock is different. As illustrated in Figure 1, phosphate rock is brought to the central warehouse of the province through two routes of imports and mines which has provided the required strategic inventory for the warehouse and the fertilizer production centers. After the production process, the TSP fertilizer is sent to the distribution centers in the province, and the strategic inventory supplies the distribution and demand markets. Finally, a part of the fertilizer is sent to the demand market and another part to export points.

Following nomenclatures should be rendered to formulate the model.

Indices:

u	index of supplier consortiums
w	index of the central warehouse of chemical material
m	index of province's rock-phosphate mines
g	index of province's demand (store and farm)
f	index of chemical fertilizer factories
l	index of transportation mode
k	index of countries demand points
v	index of provincial distribution centers
t	index of periods
r	index of degree of quality
a	index of the capacity level of the central warehouse of chemical material
b	index of the capacity level of provincial distribution centers
c	index of the capacity level of chemical fertilizer factories
p	index of product (group of triple super-phosphate fertilizers)

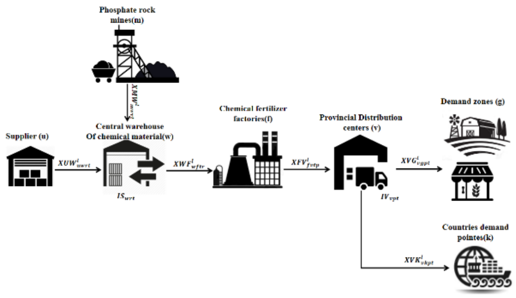

Figure 1. Supply chain network structure

Parameters:

FW_{wa}	Fixed cost of locating and opening the central warehouse of chemical material *w* with capacity level *a*
FV_{vb}	Fixed cost of locating and opening the provincial distribution centers *v* with capacity level *b*
FF_{fc}	Fixed cost of locating and opening the chemical fertilizer factory *f* with capacity level *c*
CU_u	Controlling and purchasing costs of rock-phosphate from supplier consortium *u*
CIM_m	Discovering and commissioning/purchasing costs of province's rock-phosphate mines *m*
CM_{mr}	Extraction cost of province's rock-phosphate mines *m* with quality degree *r*
CW_{wr}	Operating and holding cost of central warehouse of chemical material *w* with quality degree *r*
CF_{fp}	Production cost of product *p* at the chemical fertilizer factory *f*
CV_{vp}	Operating and holding cost of product *p* at the provincial distribution center *v*
$CAPU_u$	Maximum capacity of supplier consortium *u*
$CAPW_{wa}$	Maximum capacity of central warehouse of chemical material *w* with capacity level *a*
$CAPF_{fc}$	Maximum capacity of chemical fertilizer factory *f* with capacity level *c*
$CAPV_{vb}$	Maximum capacity of provincial distribution center *v* with capacity level *b*
TUW^l_{uw}	Transportation cost of rock-phosphate from supplier consortium *u* to central warehouse of chemical material *w* on transportation mode *l*
TMW^l_{mw}	Transportation cost of rock-phosphate from province's mines *m* to central warehouse of chemical material *w* on transportation mode *l*
TWF^l_{wf}	Transportation cost of rock-phosphate from central warehouse of chemical material *w* to chemical fertilizer factories *f* on transportation mode *l*
TFV^l_{fv}	Transportation cost of product from chemical fertilizer factory *f* to provincial distribution center *v* on transportation mode *l*
TVG^l_{vg}	Transportation cost of product from provincial distribution center *v* to province's demand (store and farm) *g* on transportation mode *l*
TVK^l_{vk}	Transportation cost of product from provincial distribution center *v* countries demand point *k* on transportation mode *l*
SIW	Strategic inventory level of central warehouse of chemical material *w*
SIV	Strategic inventory level of provincial distribution center *v*
ϕ_r	Percentage of the phosphoric acid in phosphate rock with quality degree *r*
PR_{ur}	Price of purchased rock-phosphate from supplier consortium *u* with quality degree *r*
PK_{pk}	Price of shipped product (group of triple super-phosphate fertilizers) *p* to countries demand point *k*

ΓH_p	Maximum phosphoric acid used to produce fertilizer (triple super-phosphate family) *p*
ΓL_p	Minimum phosphoric acid used to produce fertilizer (triple super-phosphate family) *p*
ב	Production rate of triple super-phosphate fertilizer family due to chemical reaction of phosphoric acid and rock-phosphate
DW_{wt}	Percentage of disrupted capacity of central warehouse *w* on period *t*
DF_{ft}	Percentage of disrupted capacity of fertilizer factory *f* on period *t*
DV_{vt}	Percentage of disrupted capacity of provincial distribution center *v* on period *t*
PW_w	Parameter of disruption occurrence at the central warehouse *w* with Bernoulli distribution and parameter ℓ_w
PF_f	Parameter of disruption occurrence at the fertilizer factory *f* with Bernoulli distribution and parameter λ_f
PV_v	Parameter of disruption occurrence at the provincial distribution central *v* with Bernoulli distribution and parameter ∂_v
DEG_{gpt}	Demand for product *p* at the customer zone *g* on period *t*
DEK_{kpt}	Demand for product *p* at country demand point *k* on period *t*

Decision variables:

XUW^l_{uwrt}	Quantity of shipped rock-phosphate with quality degree *r* from supplier *u* to central warehouse of chemical material *w* at the transportation mode *l* on period *t*
XMW^l_{mwrt}	Quantity of extracted rock-phosphate with quality degree *r* from phosphate rock mine of province *m* to central warehouse of chemical material *w* at the transportation mode *l* on period *t*
XWF^l_{wftr}	Quantity of shipped rock-phosphate with quality degree *r* from central warehouse of chemical material *w* to fertilizer factory *f* at the transportation mode *l* on period *t*
XFV^l_{fvtp}	Quantity of shipped product *p* from chemical fertilizer factory *f* to provincial distribution centers *v* at the transportation mode *l* on period *t*
XVG^l_{vgpt}	Quantity of shipped product *p* from provincial distribution centers *v* to demand zone *g* at the transportation mode *l* on period *t*
XVK^l_{vkpt}	Quantity of shipped product *p* from provincial distribution centers *v* to countries demand point *k* at the transportation mode *l* on period *t*
XR_{fprt}	Quantity of crushed rock-phosphate with quality degree *r* to produce *p* at the chemical fertilizer factory *f* on period *t*
XP_{fpt}	Quantity of produced product *p* at the chemical fertilizer factory *f* on period *t*
IS_{wrt}	Quantity of rock-phosphate inventory with quality degree *r* at the central warehouse of chemical material *w* on period *t*
IV_{vpt}	Quantity of product inventory (triple super-phosphate family) *p* at the provincial distribution center *v* on period *t*
XU_{ut}	*1* If supplier *u* is selected based on quality and price control on period *t* and *0* otherwise
XW_{wa}	*1* If central warehouse of chemical material *w* with capacity level *a* is opened and *0* otherwise
XV_{vb}	*1* If provincial distribution centers *v* with capacity level *b* is opened and *0* otherwise
XF_{fc}	*1* If chemical fertilizer factory *f* with capacity level *c* is opened and *0* otherwise
XM_{mt}	*1* If mine *m* is opened for extraction on period *t* and *0* otherwise

Described supply chain network regarding problem definition and nomenclatures is formulated as follows:

$$\begin{aligned}Min\ Z_1 = &\sum_w \sum_a XW_{wa} FW_{wa} + \sum_v \sum_b XV_{vb} FV_{vb} + \sum_u XU_{u,t} CU_u + \sum_w \sum_r \sum_t CW_{wr} IS_{wrt} \\ &+ \sum_m \sum_t XM_{m,t} CIM_m + \sum_w \sum_a XF_{fc} FF_{fc} + \sum_v \sum_p \sum_t CV_{vp} IV_{vpt} + \\ &\sum_u \sum_w \sum_l \sum_r \sum_t TUW^l_{uw} XUW^l_{uwtr} + \sum_u \sum_w \sum_l \sum_r \sum_t PR_{ur} XUW^l_{uwtr} + \\ &\sum_m \sum_w \sum_l \sum_r \sum_t (CM_{mr} + TMW^l_{mw}) XMW^l_{mwrt} + \sum_w \sum_f \sum_l \sum_r \sum_t TWF^l_{wf} XWF^l_{wfrt} + \\ &\sum_f \sum_v \sum_l \sum_p \sum_t \left(CF_{fp} + TFV^l_{fv}\right) XFV^l_{fvpt} + \sum_v \sum_g \sum_l \sum_p \sum_t TVG^l_{vg} XVG^l_{vgtp} + \\ &\sum_v \sum_k \sum_l \sum_p \sum_t TVK^l_{vg} XVK^l_{vkpt} - \sum_v \sum_k \sum_l \sum_p \sum_t PK_{pk} XVK^l_{vkpt}\end{aligned} \quad (1)$$

$$\boldsymbol{s.t.}\ \sum_w \sum_l \sum_r XUW^l_{uwtr} \leq CAPU_{ut} XU_{ut} \quad \forall u, t \quad (2)$$

$$\sum_w \sum_l \sum_r XMW^l_{mwrt} \leq CAPM_{mt} XM_{mt} \quad \forall m, t \quad (3)$$

$$\sum_u \sum_l XUW^l_{uwrt} + \sum_m \sum_l XMW^l_{mwrt} + IS_{w,r,t-1} = \sum_f \sum_l XWF^l_{wfrt} + IS_{wrt} \quad \forall w, r, t \quad (4)$$

$$\sum_r IS_{wrt} \leq \sum_a XW_{wa} CAPW_{wa} (1 - PW_w DW_{wt}) \quad \forall\, w, t \quad (5)$$

$$\sum_l \sum_v \sum_p XFV^l_{fvpt} \leq \sum_c CAPF_{fc} XF_{fc}\left(1 - PF_f DF_{ft}\right) \quad \forall f, t \quad (6)$$

$$\sum_p \sum_t IV_{pvt} \leq \sum_b CAPV_{vb} XV_{vb} (1 - PV_v DV_{vt}) \quad \forall v, t \quad (7)$$

$$\sum_w \sum_l XWF^l_{wfrt} = \sum_p XR_{fprt} \quad \forall\, f, r, t \quad (8)$$

$$\sum_r \phi_r XR_{fprt} \leq \Gamma H_p \sum_r XR_{fprt} \quad \forall f, t, p \quad (9)$$

$$\sum_r \phi_r XR_{fprt} \geq \Gamma L_p \sum_r XR_{fprt} \quad \forall f, t, p \quad (10)$$

$$\text{ב} \sum_r XR_{fprt} = \sum_l \sum_v XFV^l_{fvpt} \quad \forall f, t, p \quad (11)$$

$$\sum_l \sum_f XFV^l_{fvpt} + IV_{p,v,t-1} = IV_{pvt} + \sum_l \sum_g XVG^l_{vgpt} + \sum_l \sum_k XVK^l_{vkpt} \quad \forall v, t, p \quad (12)$$

$$\sum_w \sum_r \sum_t IS_{wrt} \geq SIW \quad (13)$$

$$\sum_v \sum_p \sum_t IV_{vpt} \geq SIV \quad (14)$$

$$\sum_u \sum_w \sum_r \sum_t XUW_{uwrt}^l + \sum_m \sum_w \sum_r \sum_t XMW_{mwrt}^l + \sum_w \sum_f \sum_r \sum_t XWF_{wfrt}^l + \sum_f \sum_v \sum_p \sum_t XFV_{fvpt}^l + \sum_v \sum_g \sum_p \sum_t XVG_{vgpt}^l + \sum_v \sum_o \sum_p \sum_t XVK_{vkpt}^l \leq CAPL_l \quad \forall l \quad (15)$$

$$\sum_l \sum_v XVG_{vgpt}^l \geq DEG_{gpt} \quad \forall g,t,p \quad (16)$$

$$\sum_l \sum_v XVK_{vktp}^l \leq DEK_{kpt} \quad \forall k,t,p \quad (17)$$

$$\sum_a XW_{wa} \leq 1 \quad \forall\, w \quad (18)$$

$$\sum_b XV_{vb} \leq 1 \quad \forall\, v \quad (19)$$

$$\sum_c XF_{fc} \leq 1 \quad \forall\, f \quad (20)$$

$$\sum_t XM_{mt} \leq 1 \quad \forall\, m \quad (21)$$

$$\sum_t XU_{ut} \leq 1 \quad \forall\, u \quad (22)$$

$$XW_{wa}, XV_{vb}, XF_{fc}, XU_{u,t}, XM_{m,t} \in \{0,1\} \quad (23)$$

$$XUW_{uwrt}^l, XMW_{mwrt}^l, XWF_{wfrt}^l, XFV_{fvpt}^l, XVG_{vgpt}^l, XVK_{vkpt}^l, XR_{fprt}, IS_{wrt}, IV_{vpt} \geq 0 \quad (24)$$

In the above mathematical model, the Equation (1) minimizes the network costs including the positioning, exploration, and commissioning of mines, purchasing and evaluation of phosphate rock, production, distribution, and transportation of phosphate rock and fertilizer without the cost of export. Equations (2) and (3) ensure that the output of mines and suppliers should not exceed their capacity. Equation (4) balances the input, output, and inventory levels of the phosphate rock of the central warehouse of material. Equations (5), (6) and (7) balance the facility capacity with the output. In addition, it can guarantee that the flow is allocated only to the remaining capacity if the vulnerable facility breaks down due to disruption, which is done by Bernoulli distribution. Equation (8) explains the combined variable which produces different types of products in various degrees of quality. Equations (9) and (10) determine the maximum and minimum levels of phosphoric acid. Equation (11) explains some products based on the combined variable and the reaction rate of fertilizer. Equation (12) balances the value of the input, output, and strategic inventory of provincial distribution centers. Equations (13) and (14) indicate that the amount of phosphate rock / TSP fertilizer stored in each period should not be less than the designated strategic inventory. Based on Equation (15), the amount of domestic transport chain does not exceed the current transport capacity of the country. Equations (16) and (17) guaranteed to cover the domestic demand and exports. Based on Equations (18-22), one facility opens at each candidate location. Equations (23) and (24) also explain the variables of the mathematical model. According to the above mentioned, it was defined how to determine the level of capacity for strategic inventory centers and production centers, which is in line with strategy (a). The constraints (4) and (12-14) explain the strategy of the strategic inventory (b) and constraint (15) covered various transportation modes according to the trend governing the network and fitted to strategy (c). The strategy (d) was applied as network disruption modeling through the constraints (5-7).

3. EXTENDED ROBUST POSSIBILISTIC PROGRAMMING

There are various uncertainties in the decision making process in the industrial environment which are resulted from the inadequate knowledge and experience of decision makers. An effective possibilistic programming approach was proposed to deal with this type of uncertainty governing the decision-making and prompt responses to customer demand. This method is based on the expected value and expected interval of the fuzzy number. The present study used the developed possibilistic programming approach based on the Jiménez approach [24]. Thus, the decision maker can change the level of confidence interactively and observe its effect on total costs [25]. First, a supply chain network design (SCND) basic model is introduced.

$$Min\ Z = (\widetilde{Fc})y + (\widetilde{CC})x \quad (25)$$

$$s.t. \quad Ax \geq \widetilde{DE} \quad (26)$$

$$Hx \leq (\tilde{V})y \quad (27)$$

$$Ty \leq 1 \ and \ Bx = 0 \quad (28)$$

$$y \in \{0,1\}, \ x \geq 0 \quad (29)$$

Based on the above-mentioned model, Fc, CC, and DE represent the vector of parameters, A, B, T, and H indicate the technical coefficients of the model, Fc, CC, DE, and V are regarded as capacity, demand, transport cost, processing, etc. and the cost of creating the facility, and x, y are continuous and binary variables, respectively. In addition, Equations (26) and (27) are considered as the limitations of the problem. The equivalent possibilistic programming model (PSCND) of the above basic model is as follows:

$$\boldsymbol{Min\ Z} = \left(\frac{Fc_1+Fc_2+Fc_3}{3}\right)y + \left(\frac{CC_1+CC_2+CC_3}{3}\right)x \quad (29)$$

s.t.

$$Ax \geq \begin{bmatrix} \alpha\left(\frac{DE_3+DE_2}{2}\right) \\ +(1-\alpha)\left(\frac{DE_2+DE_1}{2}\right) \end{bmatrix} \quad (30)$$

$$Hx \leq \begin{bmatrix} \beta\left(\frac{CP_1+CP_2}{2}\right) \\ +(1-\beta)\left(\frac{CP_2+CP_3}{2}\right) \end{bmatrix} y \quad (31)$$

$$Bx = 0 \text{ and } Ty \leq 1 \quad (32)$$

$$y \in \{0,1\}, \quad x \geq 0 \quad (33)$$

In the PSCND model, α and β indicate the minimum level of satisfaction of non-deterministic parameters and decision makers can determine the uncertainty parameters of the confidence levels based on their risk-aversion policy ($i.e., 0.5 < \alpha, \beta \leq 1$).

In this approach, decision makers determine the confidence levels based on frequent experiments [26]. The primary challenges of this approach are as follows:

- There is no guarantee to determine the optimal levels of confidence for constraint of problems
- Increasing the number of constraints of the problems leads to an increase in the number of tests to determine the confidence levels of constraints.
- It can cause deviation from soft constraints and infeasible answers and high costs in the network.

This model is not sensitive to the deviations of the objective function from its expected value, which imposes a high risk on the decision maker. Therefore, a robust possibilistic supply chain network design (RPSCND) model is presented to determine the optimal confidence level of programming model [27]:

$$Min\ Z = \begin{bmatrix} \underbrace{\left(\frac{Fc_1+Fc_2+Fc_3}{3}\right)y + \left(\frac{CC_1+CC_2+CC_3}{3}\right)x}_{E[Z]} \end{bmatrix} +$$

$$\eta \begin{bmatrix} \underbrace{FC_3 . y + (CC_3). x}_{Z_{max}} - \\ [E[Z]] \end{bmatrix} + \psi \begin{bmatrix} DE_2 - \alpha\left(\frac{DE_3+DE_2}{2}\right) \\ -(1-\alpha)\left(\frac{DE_2+DE_1}{2}\right) \end{bmatrix} + \quad (34)$$

$$\vartheta \begin{bmatrix} \beta\left(\frac{CP_1+CP_2}{2}\right) \\ +(1-\beta)\left(\frac{CP_2+CP_3}{2}\right) - CP_1 \end{bmatrix} y$$

$$S.t. constraints\ (30-32)$$

$$y \in \{0,1\}, \ x \geq 0, 0.5 < \alpha, \beta \leq 1$$

Based on the model (34), the first term indicates the average objective function expected from the total cost. The second term explains the robust optimality which minimizes the difference between the maximum possible value of the objective function and its mean value with the degree of significance η. This term is defined as possibilistic variability. The reduction of variability which is accompanied by increasing the variability coefficient η increases the optimality robustness. The third and fourth terms also control the feasibility robustness. θ, ψ represent the penalties of each unit of possible violations regarding the constraints of the problem. This violation includes unsatisfied demands and a lack of capacity. In fact, the third and fourth terms of the objective function are modified by the optimal values of θ, ψ. As illustrated in Equation (31) and model (34), the CP technical coefficient matrix has a fuzzy uncertainty and converts the proposed RPSCND into a linear model. Therefore, if the new variable $\delta = \beta y$, the linear equivalent model is presented as follows:

$$Min\ Z = [E[Z]] + \eta[Z_{max} - E[Z]] +$$

$$\psi \begin{bmatrix} DE_2 - \alpha\left(\frac{DE_3+DE_2}{2}\right) \\ -(1-\alpha)\left(\frac{DE_2+DE_1}{2}\right) \end{bmatrix} +$$

$$\vartheta \begin{bmatrix} \delta\left(\frac{CP_1+CP_2}{2}\right) \\ +(y-\delta)\left(\frac{CP_2+CP_3}{2}\right) - CP_1 y \end{bmatrix}$$

$$Ax \geq \left[\alpha\left(\frac{DE_3+DE_2}{2}\right) + (1-\alpha)\left(\frac{DE_2+DE_1}{2}\right)\right] \quad (35)$$

$$Hx \leq \left[\delta\left(\frac{CP_1+CP_2}{2}\right) + (y-\delta)\left(\frac{CP_2+CP_3}{2}\right)\right]$$

$$\delta \leq My$$

$$\delta \leq \beta$$

$$\delta \leq M(y-1) + \beta$$

$$Bx = 0 \text{ and } Ty \leq 1$$

$$y \in \{0,1\}, \ x, \delta \geq 0$$

$$, 0.5 < \alpha, \beta \leq 1$$

In the above model, M is a very large number, and the constraints of the problem ensure that if the binary variable is zero, the new variable is zero, and if the binary variable is one, the new variable becomes δ.

This model ensures that the objective function is only sensitive to positive deviations (the deviation from the values of the objective function is greater than its mean value) without limiting the negative deviations since the realization of the total cost is less suitable than its average value for the decision makers.

4. IMPLEMENTATION AND EVALUATION

The information and structure of the model were completed based on the feasibility studies of fertilizer production and the experiences of the supply chain operational managers. Additionally, the possibilistic distribution of the problem parameters was determined based on the amounts of the fuzzy triangular numbers.

First, how the parameters influence on the solution should be taken into consideration. The most important parameters of the model are the phosphate rock purchase price and the TSP fertilizer sale price. The function of the model indicates that the phosphate rock price imposes the most financial burden on the supply chain network. As the purchase price of phosphate increases, the value of objective function increases up to

70%, which can directly influence the exports (Figure 2).

As shown in Figure 3, An increase in the level of the capacity of the central warehouse has the greatest effect on the objective function. Moreover, an increase in transportation capacity has the least effect on enhancing the objective function. In fact, an increase in the capacity of the central warehouse results in increasing the flow of materials in the network and accordingly increasing the impact on the value of the objective function.

In this case study, the final product of the fertilizer supply chain network appears in two granular and powder types. The production costs of the above products cover a part of the total costs. The total costs are increased by elevated production costs due to the chemical reaction of reactive phosphate rock and phosphoric acid as well. In comparison with production costs, the maintenance and storage costs in two strategic depots have less impact on the total costs. As shown in Figure 4, the doubling of maintenance costs in strategic depots increases the total network cost by 8.7%, but the doubling of production costs increases the value of the objective function by 24%. Therefore, increased maintenance costs have a slight effect on increasing the objective function. Hence, the strategy of strategic inventory increases the network efficiency and improves the network reliability.

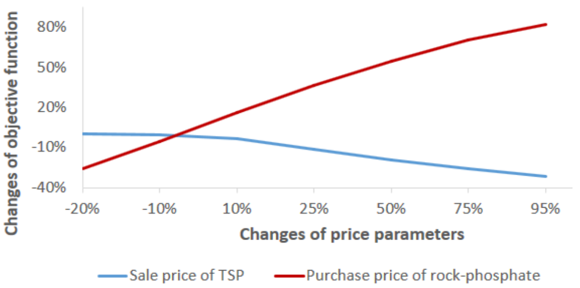

Figure 2. Changes of objective function against the price parameters

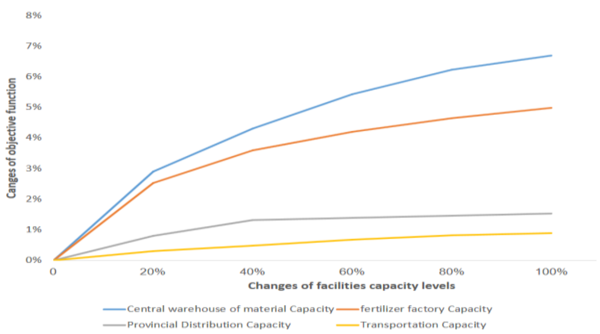

Figure 3. Changes of objective function against the price parameters

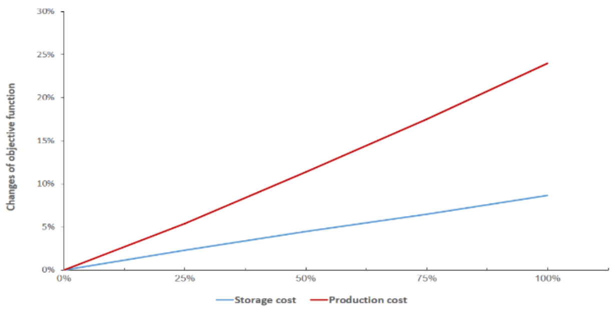

Figure 4. Changes of objective function based on the storage and production costs

Furthermore, a robust possibilistic approach was used to deal with Bernoulli parameters indicating a failure in disruption conditions to ensure that it is feasible per the worst value. In this section, the effectiveness of possibilistic and robust possibilistic programming models is evaluated. As confidence level increases, the possibilistic programming model will face risk aversion, which results in increasing the network costs, due to some sources like importing and extracting phosphate rock, the higher capacity of facilities and increasing the capacity of the transportation system to meet the needs of customers at higher confidence levels. Figures 2 and 3 illustrate the changes in the objective function under various confidence levels.

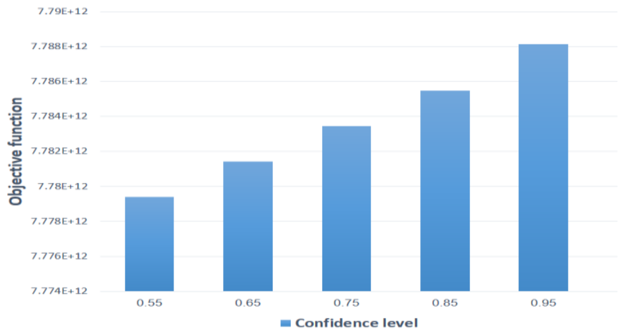

Figure 4. Changes of objective cost function based on confidence levels

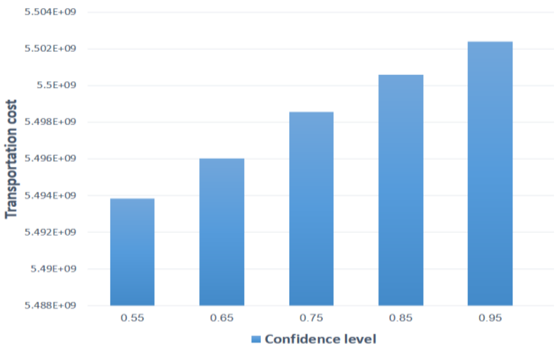

Figure 5. Changes in transportation costs based on confidenc levels

As displayed, an increase in the confidence level leads to an increase in the total cost and transport costs of the network.

Also, the proposed model is solved for optimality robustness and feasibility robustness coefficients. Figure 6 shows the results of computation of the average cost and the possibilistic variability of the objective function. As shown in Figure 6, by increasing the risk index in the objective function, the average cost increases, and in contrast, the rate of variability reduces. By optimizing the value of this indicator based on the choices of the decision makers, the optimality robustness is controlled.

The feasibility robustness of the model is explained in Figure 7.

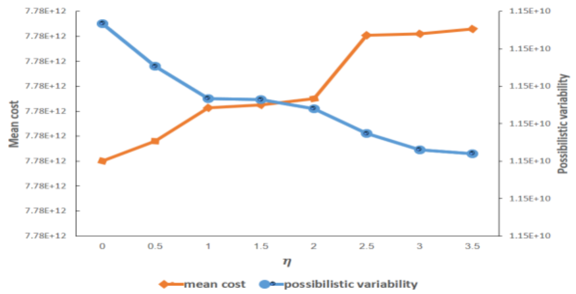

Figure 6. The mean possibilistic cost and possibilistic variation for different values of η

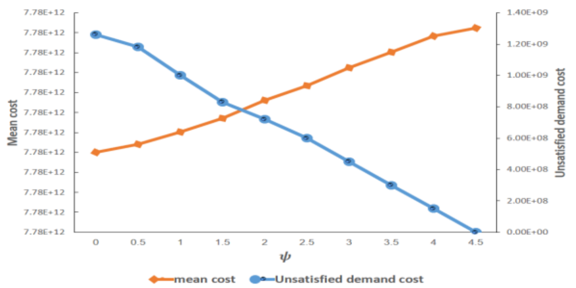

Figure 7. The not satisfied demand cost for different values of ψ

With increased ψ, the cost of demand non-satisfaction decreases, and eventually tends to zero. Also, the capacity constraint with the parameter θ reveals a function similar to the demand constraint. Finally, with increased ψ and θ values, the feasibility robustness of the model will increase.

The results of this model are compared with those of the possibilistic model to evaluate the optimality robustness of a robust-possibilistic model. It is worth noting that the possibilistic programming model cannot identify the least the satisfaction of confidence levels. The model is solved at three levels of confidence (0.6, 0.8 and 0.95). Further, the reduction of possibilistic variability can reduce the variability of the objective function. Therefore, a robust-possibilistic model is solved under two different values of η (0.8 and 2) during five tests to prove the issue mentioned above. The solutions resulting from solving the model are placed in the following mathematical combination under the nominal data, i.e., x^{nd}, y^{nd}. Also, $v^{Cap}\ and v^{DE}$ are decision variables, which determine the violations of chance constraints in the model. The results are given in Table 1.

$$\begin{aligned} & Min\ z = (Fc^{rs})y^{nd} + (Pc^{rs} + Tc^{rs})x^{nd} + \psi v^{DE} + \vartheta v^{Cap} \\ & s.t.\ \ Ax^{nd} + v^{DE} \geq DE^{rs} \\ & Bx^{nd} = 0 \\ & Hx^{nd} \leq (Cap^{rs})y^{nd} + v^{Cap} \\ & Tx^{nd} \leq 1 \\ & v^{DE}, v^{Cap} \geq 0 \end{aligned} \tag{55}$$

As shown in Table 1, the proposed robust-possibilistic programming with η =2 has a minimum standard deviation and an acceptable average. It should be noted that the feasibility robustness is not guaranteed by considering the mean of parameters of uncertainty in the objective function. The feasibility robustness is controlled based on the priorities of decision-makers if the proposed approach fails, on the other hand, industry decision makers insist that the average of the costs is minimized on a long-term horizon and the fuzzy cost variability is controlled to reduce short-term risks.

TABLE 1. Performance of PSCND and RPSCND models under realization

Realization	PSCND (Possibilistic prog.)			RPSCND(Robust-Possibilistic prog.)	
	0.6	0.8	0.95	0.8	2
1	7.78041E+12	7.78445E+12	7.78814E+12	7792738406548	**7786379734653**
2	7.78127E+12	7.78474E+12	7.78809E+12	7788654273512	**7787581624512**
3	7.78105E+12	7.78471E+12	7.78865E+12	7788331221350	**7785920486158**
4	7.78126E+12	7.78426E+12	7.78798E+12	7788093945931	**7787244215272**
5	7.78131E+12	7.78326E+12	7.78768E+12	7788031621844	**7786632733108**
Mean	7.78106E+12	7.78399E+12	7.78811E+12	7.78838E+12	**7.78675E+12**
Standard deviation	378005082	376394583	350473075	342327871	**336339506.8**

In the proposed robust-possibilistic model, a low medium cost and appropriate standard deviation are obtained. According to the above mentioned, two factors affect the robustness of the proposed solution. The first is the optimality robustness coefficient, which is also reflected in the results so that with its increase, the performance of the robust model improves and the other factor is the penalty for violating the constraints. In fact, the larger the fine, the provided solution is more robust.

5. CONCLUSION

The production of soil nutrients like fertilizers is regarded as one of the strategic objectives of the government and the vision document of any country to produce the sustainable agricultural products. In this strategic direction, some challenges such as sanctions, limited strategic inventories, the capacity of facilities and transport capacity of the country are created. In this regard, the unexpected disruption and the parametric uncertainty of the supply chain network are two main issues which have an unacceptable effect on the performance of this strategic supply chain. To deal with the above problems, resilient supply chain network was designed under minor and detailed disadvantages, which is consistent with the country's fertilizer supply structure. Moreover, powerful strategies were used to increase network reliability. Further, a new possibilistic programming model was suggested to cope with the uncertainty of the input parameters. Finally, the effectiveness and desirable results were obtained based on the comparison of the models and standard deviation values which indicated the high quality of the robust possibilistic optimality of the model.

In this regard, it is suggested that the proposed model should be investigated and analyzed in the supply chain design of the conversion-production industries such as cement and petrochemical industries. In addition, the problem should be solved by an innovative algorithm by using time reduction approach.

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A New Combination of Robust-possibilistic Mathematical Programming for Resilient Supply Chain Network Under Disruptions and Uncertainty: A Real Supply Chain

RESEARCH NOTE

A. Hamidieh, A. Arshadi khamseh, B. Naderi

Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran

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چکیده

امروزه طراحی شبکه زنجیره تامین راهبردی تحت وقوع اختلالات از الویت های مهم دولت ها است تامین محصولات کشاورزی و غذایی پایدار در شرایط با ثبات از اهداف استراتژیک مدیران محسوب می گردد که لازمه آن تولید مواد مغذی خاک است در این راستا، اختلالاتی چون شرایط تحریم و حوادث طبیعی بر روی تامین مواد خام تاثیری مخرب دارد همچنین عدم قطعیت پارامترهای ورودی بر سطوح تصمیم گیری(راهبردی،تاکتیکی و عملیاتی) اثری نامطلوب دارد. در پژوهش حاضر، مدل جدید شبکه زنجیره تامین تاب آور کود کشاورزی معرفی گردید که با واقعیت های ساختار تامین کود ایران منطبق بود همچنین با بکارگیری استراتژی های قدرتمند پایایی، اثربخشی سیستم طراحی شده ارتقا داده شد. علاوه بر این، به منظور مقابله با عدم قطعیت پارامتری، یک رویکرد جدید امکانی–استوار پیشنهاد گردید که با ارائه راه حل های کارا، استواری مدل و جواب را تضمین می نمود در نهایت نتایج تحقیق نشان می دهد ترکیب جدید امکانی–استوار پیشنهاد شده با متوسط هزینه مطلوب و حداقل انحراف استاندارد ، استواری مدل و اثربخشی آن را ارتقا داده است.

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