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Prediction of uncertain parameters of fresh product in two stage fuzzy multi objective supply chain

Weili Cheng[1], Dongyin Xu[1,*], Junyan Chen[1]

Abstract. Research is made with respect to multi-facility location of dual supply chain of fresh agricultural products. In this thesis, a design method considering satisfaction and tracing costs is presented for two stage fuzzy multi-objective (TSEMO) supply chain of indefinite parameters of fresh agricultural products so as to effectively solve multi-facility location during distribution of fresh agricultural products (FAP). Such model gives full consideration to conventional transportation cost and fixed facility location cost, as well as waste handling cost and tracing cost, builds satisfaction attenuation function to express member's satisfaction in supply chain, and seeks a solution in combination with two stage probability linear programming. The result of experiment verifies effectiveness of algorithm.

Key words. Satisfaction, Tracing costs, Fresh agricultural products, Supply chain, Fuzzy multi-objective.

1. Introduction

Fresh agricultural products mainly include vegetable, fruit, meat, aquatic product and other livestock, which are slightly handled by agricultural department or not handled, and unable to be stored for a long time at normal temperature [1, 2]. Along with increased urban population and improved living standards, there is an increasingly growing demand for fresh agricultural products in quantity and quality. However, present research is limited to some extent with respect to fresh agricultural products supply chain.

Scholars mostly focuses on 2 key factors concerning supply chain network design: facility location and product distribution [3]. For instance, in literature [4], dynamic

[1]Department of Agricultural IOT, Jiangsu Agri-animal Husbandry Vocational College, Taizhou Jiangsu, 225300, China

*. Corresponding author

facility location of variable parameter is presented during consideration. In literature [5], multi-level optimization method is used to seek a solution for supply chain network design. In literature [6], fixed parameter multi-level supply chain model is presented for facility location and distribution route optimization in a single cycle. In literature [7], linear model considering inventory and specific production & logistic costs is presented. In literature [8], evolutionary algorithm is applied to research for multi-objective supply chain location in a single cycle. Besides, many scholars carry out supply chain network design from a perspective of integration. In literature [9], urban logistics network with minimal target cost is developed on the basis of logistic time demand model. In literature [10], four-level dairy products supply network design is studied and dynamic multi-stage single-objective model established. Many researches, such as literature [11], are focused on multi-objective optimization of supply chain. However, fresh agricultural products supply chain is seldom studied in literature. In literature [12], uncertain and fuzziness of supply chain design is studied. In literature [13], fuzzy multi-objective programming for fuzzy parameters is applied to design for edible vegetable oil supply chain network.

In literatures above, most models are studied at fixed parameters. In fact, due to change of economic environment, supply chain model parameters are also in a state of time varying. If fixed parameters model is still considered, deviation will occur. Multi-facility location is studied here for dual supply chain of fresh agricultural products. The goal is to minimize overall costs and enhance customer's satisfaction, and consider, on the basis of characteristics of fresh agricultural products, not only conventional transportation cost and fixed facility location cost, but also waste handling cost, as well as tracing cost. Additionally, satisfaction attenuation function is built to express member's satisfaction in supply chain. And fuzzy multi-objective two-phase method is applied to model solving.

2. Two stage fuzzy linear programming

Fresh agricultural products supply network is designed by means of fuzzy set theory and two stage multi-objective linear programming, in 2 stages [13]:

2.1. Stage 1: Maximal and minimal operators method

Inaccurate fuzzy coefficients for multi-objective fuzzy linear programming are described as follows:

$$\begin{aligned} &\max z = [\tilde{c}_l x, \cdots, \tilde{c}_n x]^{\mathrm{T}} = [Z_1(x), \cdots, Z_n(x)]^{\mathrm{T}} \\ &s.t.\ x \in X,\ X = \left\{ x \in R^n : Ax \le \tilde{b}, x \ge 0 \right\} . \end{aligned} \tag{1}$$

In this formula, $A = (a_{ij})_{m\times n}$, $\tilde{c}_i \in R^{r+l}(i = 1, \cdots n)$, $\tilde{b} \in R^m$, $\tilde{c}_i = [c_i^p, c_i^m, c_i^o]$ is fuzzy triangular coefficient, c_i^p is the most pessimistic value, c_i^m is the most possible value, c_i^o is the most positive value. Triangular probability is distributed as shown in Fig.1.

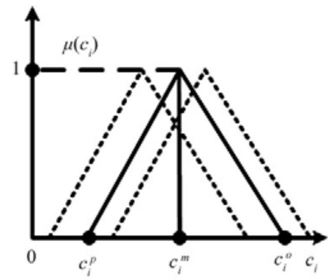

Fig. 1. Triangular probability distribution

Membership function is calculated as shown in formula (2)

$$\mu c_i(x) = \begin{cases} \dfrac{x - c_i^P}{c_i^m - c_i^P}, \ c_i^p < x < c_i^m \\ 0, \ x \le c_i^p || x \ge c_i^o \\ \dfrac{c_i^o - x}{c_i^o - c_i^m}, \ c_i^m < x < c_i^o \end{cases} \tag{2}$$

In this formula, when $c_i^p = c_i^m = c_i^0$, $\tilde{c}_i$ is 1 fragility. After triangular probability distribution parameters are given, fuzzy objective function (1) can be rewritten as

$$\max((z^p)^{\mathrm{T}}, (z^m)^{\mathrm{T}}, (z^0)^{\mathrm{T}}) . \tag{3}$$

Auxiliary multi-objective linear programming shown in the formula (3) can be rewritten as

$$\begin{cases} \min z_1 = (z^m - z^p)^{\mathrm{T}} x \\ \max z_2 = (z^m)^{\mathrm{T}} x \\ \max z_3 = (z^o - z^m)^{\mathrm{T}} x \\ s.t. \ x \in X \end{cases} \tag{4}$$

In the formula (4), multi-objective programming can be solved by means of maximal and minimal operators method of fuzzy set theory. Under problem (1)'s constraint, vector formed by maximal value of each objective function can be described as follows:

$$Z^* = [Z_1^*, \cdots Z_N^*] = [\max z_1(x), \cdots, \max z_n(x)] . \tag{5}$$

Formula (5) is an ideal solution vector of formula (1); under problem (1)'s constraint, vector formed by minimal value of each objective function can be described as follows:

$$Z^- = \left[Z_1^-, \cdots Z_N^*\right] = [\min z_1(x), \cdots, \min z_n(x)] . \tag{6}$$

Formula (6) is a negative ideal solution vector of formula (1); membership function of objective is defined as follow:

$$\mu(Z_k) = \frac{Z_k(x) - Z_k^-}{Z_k^* - Z_k^-}(k = 1, \cdots, N)\,. \tag{7}$$

As for multi-objective programming based on the maximal and minimal operators method, problem (1) can be converted to single-objective problem:

$$\max\ \lambda^o,\ s.t.\ \lambda^o \leq \frac{Z_k(x) - Z_k^-}{Z_k^* - Z_k^-}\ k = 1, \cdots, N\,. \tag{8}$$

In the formula, $\lambda^o \in [0, 1]$, $x \in X$. Despite many advantages, solution sought by means of the maximal and minimal operators method is still unable to ensure its calculation efficiency and obtain the optimal solution of problem (1). With this regard, two-stage method is presented.

2.2. Stage 2: Fuzzy compromise method

The first stage of two-stage method adopts the said he maximal and minimal operators method. At the second stage, single-objective problem (8) can be rewritten as:

$$\max \lambda = \sum_{k=l}^{N} w_k \lambda_k,\ s.t.\ \lambda_k^l \leq \lambda_k \leq \mu_k(x)\,. \tag{9}$$

Constraint is

$$\sum_{k=l}^{N} w_k = 1,\ w_k > 0,\ \lambda_k^l, \lambda_k \in [0, 1]\,. \tag{10}$$

In the formula, λ_k^l is the minimal satisfaction of kth objective function given by decision maker. Minimal satisfaction of deep optimization objective function makes λ_k^l closer to the optimal value. Besides, λ_k^l can make other individuals close to their optimal value. Thus, if decision maker sets the minimal satisfaction too high, there may be no solution for problems (9∼10) as a result. λ_k^l is required to be adjusted appropriately in order to obtain feasible solution.

3. Fresh agricultural products supply description

From a perspective of theory, fresh agricultural products supply chain network is a large and complicated system and decision maker needs to consider different constraints and conflicts among plantation, wholesaler and final user, as well as different location and function of factory equipment.

In this research, supply chain network is defined as $G = (A, E)$, where dual channel and 4 stages are included: production base, logistics center, distribution center and client. A stands for network node, E for network connection edge, real line for conventional channel supply process and dotted line for e-business channel supply process, as shown in Fig.2.

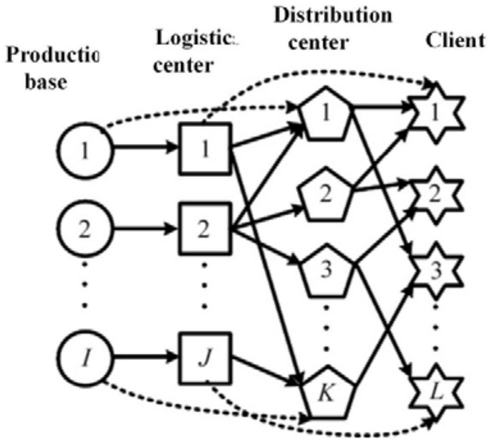

Fig. 2. Supply chain network of fresh agricultural products

In order to optimize supply chain, the first purchase is supply of network design and the problem of site selection for equipment. The involved basis hypothesis is:

①To consider network planning for supply of single agricultural products within the period.

②To set identical labor handling costs of fresh agricultural products on all floors.

③ Satisfy demands of all fresh agricultural products at all notes of the supply chain.

Multi-objective linear programming model of probability for fresh agricultural products is as follows:

Target 1 (total cost minimization) transportation cost in the supply chain is related to constraint of position and capacity of multi-objective facilities, which to a large degree can reduce transportation cost through fixed plant facilities. However, there are many product losses in the supply process of fresh agricultural products, thus it is necessary to handle labor cost of rubbish. It is hypothesized that total output of fresh agricultural products should be used to subtract loss for meeting demands of customers. Then, loss settlement costs for fresh agricultural products in the whole supply process is

$$\begin{aligned} W_d =\tilde{w}_d(&\sum_{(i,j)\in E} \alpha_{ij}x_{ij} + \sum_{(j,k)\in E} \alpha_{jk}y_{jk} + \sum_{(k,l)\in E} \alpha_{kl}z_{kl} + \\ &\sum_{(i,k)\in E} \alpha_{ik}x_{ik} + \sum_{(j,l)\in E} \alpha_{jl}z_{jl} \, . \end{aligned} \tag{11}$$

Where α_{ij} indicates loss rate from production base i to logistics center j; α_{jk} indicates loss rate from logistics center j to distribution center k; α_{kl} indicates loss rate from distribution center k to client l; α_{ik} indicates loss rate from production base i to distribution center k; α_{jl} indicates loss rate from logistics center j to client l.

In addition, food safety problem is the main problem concerned by the public.

Information attributes of food cover planting location, producer, seed gene, standing production book, date, and time. In terms of client and relevant organizations, information of modern food supply chain should be fully provided. Tracing costs of fresh agricultural products can be summarized as follows:

$$W_t = \tilde{w}_d \left(\sum_{(i,j)\in E} (1-\alpha_{ij})\, x_{ij} + \sum_{(j,k)\in E} (1-\alpha_{jk})\, x_{jk} \right). \tag{12}$$

Where the first item is tracing cost of logistics center and the second item is tracing cost of distribution center.

Based on above-mentioned analysis, overall operation costs of supply chain for fresh agricultural products include transportation cost between nodes, fixed cost of equipment location, assembly and disassembly cost, tracing cost of system. Due to rapid change of economic environment, relevant designed parameters of supply chain for fresh agricultural products are not accurate. Designed objective function of supply chain under inaccurate environment is:

$$\begin{aligned} \min Z_1 =&(\sum_{(i,j)\in E} \tilde{s}_{ij}x_{ij} + \sum_{(j,k)\in E} \tilde{e}_{jk}y_{jk} + \sum_{(k,l)\in E} \tilde{u}_{kl}z_{kl} + \\ & \sum_{(i,k)\in E} \tilde{s}_{ik}x_{ik} + \sum_{(j,l)\in E} \tilde{u}_{jl}z_{jl}) + \sum_{t} \tilde{f}_i v_i + \\ & \sum_{j} \tilde{g}_j r_j + \sum_{k} \tilde{h}_k r_k + W_d + W_t \,. \end{aligned} \tag{13}$$

Where $\tilde{s}_{ij}$, $\tilde{e}_{jk}$, $\tilde{u}_{kl}$, $\tilde{s}_{ik}$, $\tilde{u}_{jl}$, $\tilde{f}$, $\tilde{g}_j$, and $\tilde{h}_k$ indicate inaccurate parameters of triangular distribution.

Item 1∼5 in equation (13) indicate transportation cost on all floors. Item 6∼8 indicate fixed costs of alternative production base, logistics center, and distribution center. Item 9∼10 indicate traceable cost and waste treatment cost.

Objective 2 (enterprise satisfaction at logistics demand node) the typical problem of facility location can be described as follows:

All equipment nodes have certain covering radius, thus if all demand points are in the covering radius, clients in the system will be completely covered. Scholars establish a attenuation function model covered by facility service based on upper and lower limit scope of facility service provided by the largest covering problem. Aiming at response time of logistics demands for supply chain node, client satisfaction function based on service time is introduced.

$$g_j(t_{ij}) = \begin{cases} x_{ij},\ if\ t_{ij} \le t_j \text{ and } x_{ij} > 0 \\ \dfrac{x_{ij}(T_j - t_{ij})}{T_j - t_j},\ \text{if } t_j < t_{ij} \le T_j \text{ and } x_{ij} > 0 \\ 0,\ if\ t_{ij} > T_j \text{ or } x_{ij} = 0 \end{cases} \tag{14}$$

Where t_j indicates the minimum response time required by demand node j; T_j

indicates the maximum response time of demand node j; t_{ij} indicates the shortest logistics time from production equipment i to distribution demand node j; x_{ij} indicates logistics demand volume of demand point j. If logistics distribution can be finished ($x_{ij} > 0$) within the shortest required time, customer satisfaction will be set as x_{ij}. If the distribution time can not be finished within the longest required time or if $x_{ij} = 0$, customer satisfaction will be set as 0. If the distribution time is between the longest required time and the shortest required time, satisfaction will be declined with increase of distribution time, which is shown as Fig. 3.

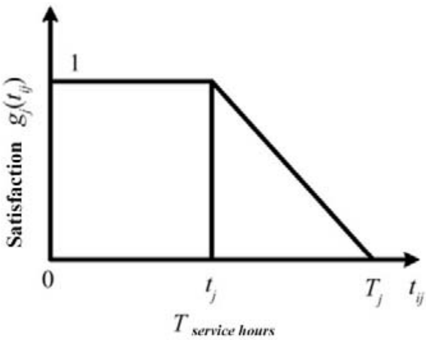

Fig. 3. User satisfaction function

Above-mentioned method can be applied to satisfaction function quantitative logistics demand points k and l. Therefore, in terms of all logistics demand points, objective function of the maximum satisfaction for fresh agricultural products can be defined as

$$\max Z_4 = [\sum_{(i,j)\in E} g_j(t_{ij}) + \sum_{(j,k)\in E} g_k(t_{jk}) + \sum_{(i,k)\in E} g_k(t_{ik}) + \sum_{(k,l)\in E} g_l(t_{kl}) + \sum_{(j,l)\in E} g_l(t_{jl})] \,. \tag{15}$$

Model constraints are

$$\sum_{(i,j)\in E} x_{ij} + \sum_{(j,k)\in E} x_{jk} \le \sum_i \tilde{a}_i v_i \,. \tag{16}$$

$$\sum_{(i,j)\in E} (1-\alpha_{ij})\, x_{ij} = \sum_{(j,k)\in E} y_{jk} + \sum_{(j,l)\in E} z_{jl} \le \sum_j \tilde{b}_j r_j \,. \tag{17}$$

$$\sum_{(j,k)\in E} y_{jk}(1-\alpha_{jk}) + \sum_{(i,k)\in E} x_{ik}(1-\alpha_{ik}) = \sum_{(k,l)\in E} z_{kl} \,. \tag{18}$$

$$\sum_{(k,l)\in E} z_{kl} \le \sum_k \tilde{c}_k q_k \,. \tag{19}$$

$$\sum_{(k,l)\in E} z_{kl}\left(1-\alpha_{kl}\right)+\sum_{(j,l)\in E} z_{jl}\left(1-\alpha_{jl}\right)\geq \sum_{l} \tilde{d}_l\,. \tag{20}$$

$$\sum_{i} v_i \leq V, \sum_{j} r_j \leq R, \sum_{k} q_k \leq P\,. \tag{21}$$

Where $v_i, r_j, q_k \in \{0,1\}$, then $x_{ij}, x_{ik}, y_{jk}, z_{jl}, z_{kl} \geq 0$.

Capacity constraints of production base, logistics center, and distribution center for dual-channel supply chain are shown in above-mentioned constraints (16-20). The largest quantity constraint of equipment location is shown in constraint (21).

4. Analysis and conversion of model

4.1. Handling of inaccurate parameter

Certain variable and parameter can be used in network model design of traditional supply chain. However, most systems are uncertain in reality. Therefore, triangle fuzzy value can be used to describe supply chain management of inaccurate coefficient. At the time of using triangle fuzzy value, inaccurate description of objective function and constraint condition for Stage 1 is as follows:

$$\begin{cases} \tilde{a}_i=[a_i^p, a_i^m, a_i^o];\ \tilde{b}_j=[b_j^p, b_j^m, b_j^o];\ \tilde{c}_k=[c_k^p, c_k^m, c_k^o] \\ \tilde{d}_l=[d_l^p, d_l^m, d_l^o];\ \tilde{s}_{ij}=[s_{ij}^p, s_{ij}^m, s_{ij}^o];\ \tilde{s}_{ik}=[s_{ik}^p, s_{ik}^m, s_{ik}^o] \end{cases} \tag{22}$$

In terms of above-mentioned equation, item distribution in the bracket indicates the most optimistic value, the most probable value, the most pessimistic value, and triangular distribution, which is shown in Fig. 1.

4.2. Fragility conversion of constraint and objective

(1) Conversion of objective function coefficient

Both multi-objective linear programming model and model constraints of probability for fresh agricultural products have uncertain parameter. In terms of fuzzy multi-objective linear programming problem, the minimization problem is $\min((z^p)^{\mathrm{T}}, (z^m)^{\mathrm{T}}, (z^o)^{\mathrm{T}})$, which can be transformed into the maximization problem solving according to method of Stage 1 Section 2.1. Triangle fuzzy value indicates objective function Z_1, which can be transformed into multi-objective problem with fragility parameter:

$$\left(\max\left(z^m-z^p\right)^{\mathrm{T}}, \min\left(z^m\right)^{\mathrm{T}}, \min\left(z^o-z^m\right)^{\mathrm{T}}\right)\,.$$

According to equation (4), inaccurate total cost of objective function for supply chain in Stage 1 can be transformed into fragility objective, which is as follows:

$$\begin{aligned}\mathrm{minz}_1 = & \mathrm{z}_1^{\mathrm{m}} = (\sum_{(i,j)\in E} s_{ij}^m x_{ij} + \sum_{(j,k)\in E} e_{jk}^m y_{jk} + \sum_{(k,l)\in E} u_{kl}^m z_{kl} + \\ & \sum_{(i,k)\in E} s_{ik}^m x_{ik} + \sum_{(j,l)\in E} u_{jl}^m z_{jl}) + \sum_i f_i^m v_i + \\ & \sum_j g_j^m r_j + \sum_k h_k^m q_k + \hat{W}_d + \hat{W}_t \,.\end{aligned} \tag{23}$$

Where,

$$\begin{aligned}\hat{W}_d = & w_d^m (\sum_{(i,j)\in E} \alpha_{ij} x_{ij} + \sum_{(j,k)\in E} \alpha_{jk} y_{jk} + \sum_{(k,l)\in E} \alpha_{kl} z_{kl} + \\ & \sum_{(i,k)\in E} \alpha_{ik} x_{ik} + \sum_{(j,l)\in E} \alpha_{jl} x_{jl}) \,.\end{aligned} \tag{24}$$

$$\hat{W}_t = w_t^m \left(\sum_{(i,j)\in E} (1-\alpha_{ij})\, x_{ij} + \sum_{(i,k)\in E} (1-\alpha_{ik})\, x_{ik} \right) . \tag{25}$$

$$\begin{aligned}& \max z_2 = z_1^o - z_1^m = \\ & \sum_{(i,j)\in E} \left(s_{ij}^o - s_{ij}^m\right) x_{ij} + \sum_{(j,k)\in E} \left(e_{jk}^o - e_{jk}^m\right) y_{jk} + \\ & \sum_{(k,l)\in E} \left(u_{kl}^o - u_{kl}^m\right) z_{kl} + \sum_{(i,k)\in E} \left(s_{ik}^o - s_{ik}^m\right) x_{ik} + \\ & \sum_{(k,l)\in E} \left(u_{jl}^o - u_{jl}^m\right) z_{jl} + \sum_i \left(f_i^o - f_i^m\right) v_i + \\ & \sum_j \left(g_j^o - g_j^m\right) r_j + \sum_k \left(h_k^o - h_k^m\right) q_k + \bar{W}_d + \bar{W}_t \,.\end{aligned} \tag{26}$$

Where,

$$\begin{aligned}\bar{W}_d = & \left(w_d^o - w_d^m\right) (\sum_{(i,j)\in E} \alpha_{ij} x_{ij} + \sum_{(j,k)\in E} \alpha_{jk} y_{jk} + \\ & \sum_{(k,l)\in E} \alpha_{kl} z_{kl} + \sum_{(i,k)\in E} \alpha_{ik} x_{ik} + \sum_{(j,l)\in E} \alpha_{jl} x_{jl}) \,.\end{aligned} \tag{27}$$

$$\bar{W}_t = \left(w_t^o - w_t^m\right) \left(\sum_{(i,j)\in E} (1-\alpha_{ij})\, x_{ij} + \sum_{(i,k)\in E} (1-\alpha_{ik})\, x_{ik} \right) . \tag{28}$$

$$\begin{aligned}\max z_3 = z_1^m - z_1^p = \\ &(\sum_{(i,j)\in E}\left(s_{ij}^m - s_{ij}^p\right)x_{ij} + \sum_{(j,k)\in E}\left(e_{jk}^m - e_{jk}^p\right)y_{jk} + \\ &\sum_{(k,l)\in E}\left(u_{kl}^m - u_{kl}^p\right)z_{kl} + \sum_{(i,k)\in E}\left(s_{ik}^m - s_{ik}^q\right)x_{ik} + \\ &\sum_{(k,l)\in E}\left(u_{jl}^m - u_{jl}^p\right)z_{jl}) + \sum_i\left(f_i^m - f_i^p\right)v_i + \\ &\sum_j\left(g_j^m - g_j^p\right)r_j + \sum_k\left(h_k^m - h_k^p\right)q_k + \bar{\bar{W}}_d + \bar{\bar{W}}_t\,.\end{aligned} \tag{29}$$

$$\begin{aligned}\bar{\bar{W}}_d = \left(w_d^m - w_d^p\right)(\sum_{(i,j)\in E}\alpha_{ij}x_{ij} + \sum_{(j,k)\in E}\alpha_{jk}y_{jk} + \\ \sum_{(k,l)\in E}\alpha_{kl}z_{kl} + \sum_{(i,k)\in E}\alpha_{ik}x_{ik} + \sum_{(j,l)\in E}\alpha_{jl}x_{jl})\,.\end{aligned} \tag{30}$$

$$\bar{\bar{W}}_t = \left(w_t^m - w_t^p\right)\left(\sum_{(i,j)\in E}\left(1-\alpha_{ij}\right)x_{ij} + \sum_{(i,k)\in E}\left(1-\alpha_{ik}\right)x_{ik}\right)\,. \tag{31}$$

$$\begin{aligned}\max z_4 = z_4^m = \max[\sum_{(i,j)\in E} g_j\left(t_{ij}\right) + \sum_{(j,k)\in E} g_k\left(t_{jk}\right) + \\ \sum_{(i,k)\in E} g_k\left(t_{ik}\right) + \sum_{(k,l)\in E} g_l\left(t_{kl}\right) + \sum_{(j,l)\in E} g_l\left(t_{jl}\right)]\,.\end{aligned} \tag{32}$$

(2) Conversion of inaccurate constraint coefficient system

Weight should be used according to Literature [14]; constraint (16) can be transformed into the following form:

$$\sum_i\left(w_1 a_{i,\beta}^p + w_2 a_{i,\beta}^m + w_3 a_{i,\beta}^o\right)v_i \geq \sum_{(i,j)\in E} x_{ij} + \sum_{(i,k)\in E} x_{ik}split \tag{33}$$

Where w_1 indicates conservative estimate weight; w_2 indicates weight of the most probable value; w_3 indicates the optimum estimate weight, which meets $w_1 + w_2 + w_3 = 1$. Weighted value can be obtained according to experience or experiment. β indicates the minimum probability of acceptance. According to experimental result, $w_1 = 1/6$, $w_2 = 4/6$, and $w_3 = 1/6$. Conversion equation of other constraints (17-20) is as follows:

$$\begin{aligned}&\sum_{j}\left(w_1 b^{p}_{j,\beta}+w_2 b^{m}_{j,\beta}+w_3 b^{o}_{j,\beta}\right) r_j \geq \\ &\sum_{(i,j)\in E}\left(1-\alpha_{ij}\right) x_{ij} = \sum_{(j,k)\in E} y_{jk} + \sum_{(j,l)\in E} z_{jl}\,.\end{aligned} \tag{34}$$

$$\begin{aligned}&\sum_{(j,k)\in E} y_{jk}\left(1-\alpha_{jk}\right)+\sum_{(i,k)\in E} x_{ik}\left(1-\alpha_{ik}\right)= \\ &\sum_{(k,l)\in E} z_{kl} \leq \sum_{k}\left(w_1 c^{p}_{k,\beta}+w_2 c^{m}_{k,\beta}+w_3 c^{o}_{k,\beta}\right) q_k\,.\end{aligned} \tag{35}$$

$$\begin{aligned}&\sum_{(k,l)\in E} z_{kl}\left(1-\alpha_{kl}\right)+\sum_{(j,l)\in E} z_{jl}\left(1-\alpha_{jl}\right) \geq \\ &\left(w_1 d^{p}_{l,\beta}+w_2 d^{m}_{l,\beta}+w_3 d^{o}_{l,\beta}\right)\,.\end{aligned} \tag{36}$$

4.3. Linear programming solving of two-stage probability

In order to solve multiple objective function of equation (23-32), utility theory, fuzzy programming, objective programming, and others can be used. For example, the minimum-the maximum method can be used to solve the problem of multi-objective programming though the solution may be not effective. Therefore, two-stage method is used so as to improve algorithm. After parameter conversion, ideal value Z_k^* and negative ideal value Z_k^- are required to be defined before conversion of single objective function. Relevant mixed integer linear programming (MILP) model can be expressed as follows:

$$\begin{cases} z_1^* = \min z_1^m,\ z_1^- = \max z_1^m \\ z_2^* = \max(z_1^m - z_1^o),\ z_2^- = \min(z_1^m - z_1^o) \\ z_3^* = \min(z_1^p - z_1^m),\ z_3^- = \max(z_1^p - z_1^m) \\ z_4^* = \max z_4^m,\ z_4^- = \min z_4^m\,. \end{cases} \tag{37}$$

Membership function of all objectives is described as follows:

$$\mu\left(z_1\right)=\begin{cases} 1,\ z_1 < z_1^* \\ \dfrac{z_1^- - z_1}{z_1^- - z_1^*},\ z_1^* \leq z_1 \leq z_1^- \\ 0,\ z_1 > z_1^- \end{cases} \tag{38}$$

$$\mu\left(z_2\right)=\begin{cases}1,\ z_2<z_2^* \\ \dfrac{z_2^- - z_2}{z_2^- - z_2^*},\ z_2^*\le z_2\le z_2^- \\ 0,\ z_2>z_2^-\end{cases} \tag{39}$$

Computational process of membership function $\mu\left(z_3\right)$ is similar to $\mu\left(z_1\right)$, while computational process of membership function $\mu\left(z_4\right)$ is similar to $\mu\left(z_2\right)$.

Solving in Stage 1: based on multi-objective linear programming of the minimum-the maximum method, multi-objective problem can be converted to single objective as follows:

$$\max\lambda^o,\ s.t.\ \lambda^o\le\mu z_k(k=1,2,3,4)\,. \tag{40}$$

$$\sum_i(w_l a_{i,\beta}^p+w_2 a_{i,\beta}^m+w_3 a_{i,\beta}^o)v_i\ge\sum_{(i,j)\in E}x_{ij}+\sum_{(i,k)\in E}x_{ik}\,. \tag{41}$$

$$\begin{aligned}&\sum_j(w_1 b_{j,\beta}^p+w_2 b_{j,\beta}^m+w_3 b_{j,\beta}^o)r_j\ge\\&\sum_{(i,j)\in E}\left(1-a_{ij}\right)x_{ij}=\sum_{(j,k)\in E}y_{jk}+\sum_{(j,l)\in E}z_{jl}\,.\end{aligned} \tag{42}$$

$$\begin{aligned}&\sum_{(j,k)\in E}y_{jk}\left(1-\alpha_{jk}\right)+\sum_{(i,k)\in E}x_{ik}\left(1-\alpha_{ik}\right)=\\&\sum_{(k,l)\in E}z_{kl}\le\sum_k\left(w_1 c_{k,\beta}^p+w_2 c_{k,\beta}^m+w_3 c_{k,\beta}^o\right)q_k\,.\end{aligned} \tag{43}$$

$$\begin{aligned}&\sum_{(k,l)\in E}z_{kl}\left(1-\alpha_{kl}\right)+\sum_{(j,l)\in E}z_{jl}\left(1-\alpha_{jl}\right)\ge\\&\left(w_1 d_{l,\beta}^p+w_2 d_{l,\beta}^m+w_3 d_{l,\beta}^o\right).\end{aligned} \tag{44}$$

$$\sum_i v_i\le V,\ \sum_j r_j\le R,\ \sum_k q_k\le P\,. \tag{45}$$

$$\begin{cases}v_i,r_j,q_k\in\{0,1\}\,,\ \forall i,\forall j,\forall k\\ x_{ij},x_{ik},y_{jk},z_{jl},z_{kl}\ge 0,\ \forall i,\forall j,\forall k,\forall l\\ \lambda^0\in[0,1]\end{cases} \tag{46}$$

Solving in Stage 2: satisfaction of all objective functions can be separately described in the stage. After obtaining the optimal solution for equation (30∼36), in combination of constraint condition, the following equation can be obtained:

$$\max \lambda = \frac{1}{N} \sum_{k=l}^{N} \lambda_k \ (k = 1, 2, 3, 4), \ s.t. \lambda^o \leq \lambda_k \leq \mu_k(x)\,. \tag{47}$$

$$\sum_i (w_1 a^p_{i,\beta} + w_2 a^m_{i,\beta} + w_3 a^o_{i,\beta}) v_i \geq \sum_{(i,j)\in E} x_{ij} + \sum_{(i,k)\in E} x_{jk}\,. \tag{48}$$

$$\begin{gathered} \sum_j (w_l b^p_{j,\beta} + W_2 b^m_{j,\beta} + W_3 b^o_{j,\beta}) r_j \geq \\ \sum_{(i,j)\in E} (1 - \alpha_{ij})\, x_{ij} = \sum_{(j,k)\in E} y_{jk} + \sum_{(j,l)\in E} z_{jl}\,. \end{gathered} \tag{49}$$

$$\begin{gathered} \sum_{(j,k)\in E} y_{jk}\,(1 - \alpha_{jk}) + \sum_{(i,k)\in E} x_{ik}\,(1 - \alpha_{ik}) = \\ \sum_{(k,l)\in E} z_{kl} \leq \sum_k (w_l c^p_{k,\beta} + w_2 c^m_{k,\beta} + w_3 c^o_{k,\beta}) q_k\,. \end{gathered} \tag{50}$$

$$\begin{gathered} \sum_{(k,l)\in E} z_{kl}\,(1 - \alpha_{kl}) + \sum_{(j,l)\in E} x_{ijl}\,(1 - \alpha_{jl}) \geq \\ (w_l d^p_{l,\beta} + w_2 d^m_{l,\beta} + w_3 d^o_{l,\beta})\,. \end{gathered} \tag{51}$$

$$\begin{cases} \sum_i v_i \leq V, \sum_j r_j \leq R, \sum_k q_k \leq P \\ v_i, r_j, q_k \in \{0, 1\}\,, \ \forall i, \forall j, \forall k \\ x_{ij}, x_{ik}, y_{jk}, z_{jl}, z_{kl} \geq 0, \ \forall i, \forall j, \forall k, \forall l \\ \lambda^o, \lambda_k \in [0, 1] \end{cases} \tag{52}$$

5. Experimental analysis

5.1. Experimental setting

In order to verify effectiveness of the method, practical model shall be used to verify. Assuming that for supply chain of dual-channel fresh agricultural products, potential production base is $i = 4$, quantity for logistics center is $j = 4$, quantity for distribution center is $k = 4$, quantity for clients is $l = 6$, and transportation mode is container truck.

Imprecise capacity and fixed cost setting: capacities $\tilde{a}_i$ for production bases are respectively $(800, 950, 105)$, $(780, 800, 910)$, $(470, 590,\ 680)$ and $(630, 700, 800)$, and fixed costs are $(1\ 850, 2\ 000,\ 2\ 150)$, $(1\ 600, 1\ 750, 1\ 950)$, $(1\ 150, 1\ 300, 1\ 450)$ and $(1\ 390, 1\ 500, 1\ 710)$. Capacities for logistics centers $\tilde{b}_j$ are respectively $(350, 400, 450)$ $2\ 150)$, $(420, 550, 625)$, $(450, 490, 570)$ and $(430, 500, 630)$. Fixed costs are $(1\ 700, 1\ 800, 1\ 900)$, $(1\ 950, 2\ 200, 2\ 350)$, $(1\ 950, 2\ 050,\ 2200)$ and $(1\ 900,\ 2\ 100, 2\ 300)$. Capacities for distribution centers $\tilde{c}_k$ are respectively $(550, 600,\ 700)$, $(430, 500, 620)$, $(300, 350, 430)$, $(380, 420,\ 490)$ and $(360, 400, 450)$, and fixed costs are $(2\ 200, 2\ 350,\ 2\ 450)$, $(1\ 900, 2\ 100, 2\ 300)$, $(1\ 750, 1\ 850,\ 1\ 950)$, $(1\ 800, 1\ 900, 2\ 050)$ and $(1\ \ 700, 1\ \ 800, 1\ 900)$. For Imprecise transportation cost and transportation time parameters, settings for $\tilde{s}_{ij}$, t_{ij}, $\tilde{e}_{jk}$, t_{jk}, $\tilde{u}_{kl}$, t_{kl}, $\tilde{s}_{ik}$, t_{ik}, $\tilde{u}_{jl}$ and t_{jl} are omitted.

Related parameter setting for Objective 1: in order to simplify probability calculation for waste loss during the supply chain process, supposing $\alpha_{ij} = \alpha_{jk} = \alpha_{kl} = \alpha_{ik} = \alpha_{jk} = 0.1$, treatment for per unit waste cost is $\tilde{W}_d = (8, 10, 11)$, and traceable cost for per unit is $\tilde{w}_t = (5, 6, 7)$. Demand volume for client/market is $\tilde{d}_l = (325, 380, 425, 140, 128, 600)$.

Table 1. The upper and lower boundary for transmission time of dual-channel nodes

Node demand	Logistics center	Distribution center		Customer	
		Traditional channel	E-commerce channel	Traditional channel	E-commerce channel
The upper boundary	0.5	0.6	0.8	0.8	0.9
The lower boundary	0.2	0.3	0.4	0.5	0.5

Related parameter setting of Objective 2: in supply chain, logistics node demand includes logistics center j, distribution center k and client l. Apart from demand volume, the upper and lower limits for demands and time of all demand points shall be considered. The specific condition is shown in Table 1.

5.2. Procedure for supply chain of fresh agricultural products with dual channels

Supply chain for fresh agricultural products with dual-channels can be described as follows:

Step1 Utilize Equation (13) and (15) to formulate FAP multi-objective supply chain network model with dual channels.

Step2 Imprecise data model of triangular fuzzy number Utilize 5.1 Section to set parameter and triangular fuzzy number for imprecise coefficient of Objective Function 1, and set boundary constraint and fragility coefficient of Objective Function 2.

Step3 Utilize Equation (23-32) to converse imprecise objective function to new fragility objective function.

Step4 Utilize Equation (33-36) to converse imprecise constraint to new fragility constraint, and make $\beta = 0.5$, $w_1 = w_3 = 1/6$ and $w_2 = 4/6$.

Step5 Utilize Equation (14) to calculate transportation satisfactions in all stages, and insert results into Equation (32).

Step6 Utilize Equation (37) to calculate ideal solution and negative ideal solution of auxiliary objective function, and result is shown in Table.2.

Table 2. Ideal solution and negative ideal solution of auxiliary objective function

Objective function	Ideal solution	Negative ideal solution
z1	$\min z_1 = 50\ 534$	$\max z_1 = 107\ 861$
z2	$\min\left(z_1^m - z_1^o\right) = 6\ 675$	$\max\left(z_1^p - z_1^m\right) = 18\ 123.4$
z3	$\max\left(z_1^p - z_1^m\right) = 16\ 059.3$	$\min\left(z_1^p - z_1^m\right) = 6\ 539$
z4	$\max z_4 = 7\ 159.5$	$\min z_4 = 251.12$

Step 7 Utilize membership function to construct single objective function (Equation (38-39)), and utilize Equation (40) to calculate the optimal satisfaction degree λ^0 in Stage 1.

Step8 Utilize the optimal satisfaction result obtained in Step 7 to obtain satisfaction degree result λ^0 for per objective function to take it as constraint of Stage 2 (Equation (47). Then calculate the optimal satisfaction degree λ in Stage 1, and optimize the optimal satisfaction of all objective functions. $(\lambda_1, \lambda_2\lambda_3, \lambda_4)$ can be got.

Step9 Combine result $(\lambda_1, \lambda_2\lambda_3, \lambda_4)$ and Equation (38-39) obtained in Step8, and get the optimal scheme (z_1, z_2z_3, z_4).

Step10 For variation scope $z_1\,(z_1 - z_3, z_1, z_1 + z_2)$, transportation rule between optimal facility site-selection and nodes can be got.

5.3. Analysis for parameter sensitivity in Stage 2

Variation relation between parameters: λ_1, λ, λ_2, λ_3 and λ_4. Variation $\lambda_1 \in (0,1)$ for solution satisfaction λ_1 and variation process for 4 parameters of λ, λ_2, λ_3 and λ_4 shall be analyzed, and they are shown in Fig.4.

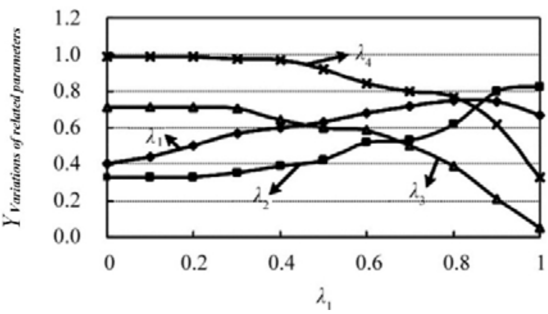

Fig. 4. Parameter variation process

Transportation (distribution) satisfaction and operation cost between nodes of supply chain are contradictory: with the increasing of satisfaction λ_1 for operation cost function z_1 of chain supply, satisfaction λ_4 for operation cost function z_4 of supply chain declines from 1 to 0.3. In addition, satisfaction λ_2 for Objective Function z_2 increases, but satisfaction λ_3 for Objective Function z_3 declines. The maximum of overall satisfaction λ is between 0.7-0.8. When $\lambda_1 = 0.9$, λ starts to decline after reaching the maximum.

For influence of parameter λ_1 on Objective Function $z_1 - z_4$, supposing variation scope for satisfaction λ_1 is $\lambda_1 \in (0, 1)$, experimental result is shown in Fig.5.

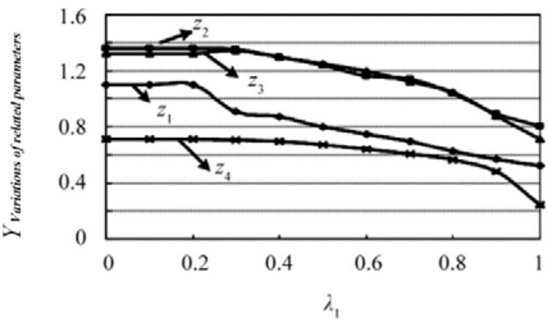

Fig. 5. Influence of parameter λ_1 on objective function $Z_1 \sim Z_4$

Curve for influence of parameter λ_1 on Objective Function $Z_1{-}Z_4$ is shown in Fig.5. It can be seen from Fig.5 that objective function value has not changed much when λ_1 varies from 0 to 0.25. When λ_1 is more than 0.25, Objective Function $Z_1{-}Z_4$ both decline with the increasing of parameter λ_1.

5.4. Comparison for objective optimization effect

Through calculation and analysis, satisfaction in Stage I is $\lambda^0 = 0.607$, and objective function vector is $z^0 = [74\,101, 10\,532, 12\,168, 4\,346]$. Site-selection scheme for supply chain and production distribution plan between nodes are shown in Fig.6.

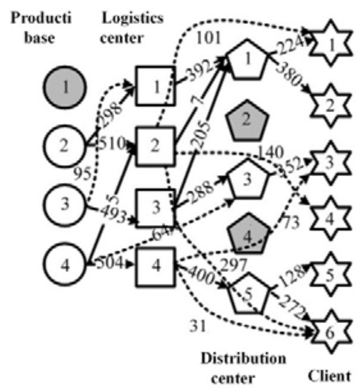

Fig. 6. The optimal solution of stage 1

According to parameter sensitivity analysis for Stage II in Fig.4, it can be known that solution for Stage I at this time is not the optimal.

At the time of conducting supply chain of garlic, confirmed weight for objective $z_1$is $\omega_1 = 0.5$, and corresponding weights for z_2, z_3 and z_4 are respectively $\omega_2 = \omega_3 = 0.1$ and $\omega_4 = 0.3$according to experts' experience. According to the aforementioned sensitivity analysis, it can be known that the optimal objective occurs in $\lambda_1 = 0.9$, and satisfaction comlocation vector for per objective function is $[0.887, 0.749, 0.835, 0.779]$. Vector for objective function is $Z = [57\ 963, 13\ 165, 13\ 762, 5\ 967]$. location and production distribution scheme between nodes of supply chain are shown in Fig.7.

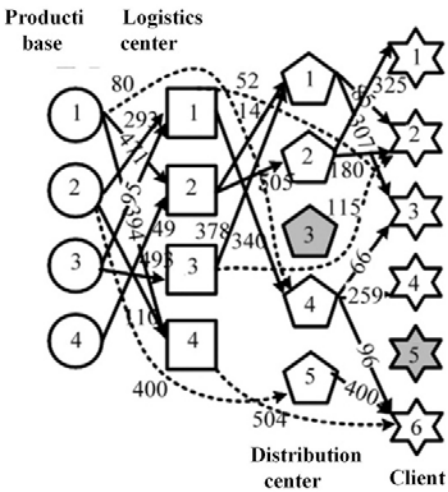

Fig. 7. The optimal solution of stage 2

Contrast algorithm is subject to Literature [12-13] algorithm, and contrast index is still subject to satisfaction for per objective function and vector for objective function value. Solution comparison and experimental result for Stage 1 and Stage 2 are shown in Table 3.

Table 3. Comparison of experimental data

Objective function	Algorithm in the Thesis	Literature [12]	Literature [13]
z_1	57 963	6 587	6 943
z_2	13 165	11 753	10 846
z_3	13 762	12 916	13 028
z_4	5 967	4 682	4 958
Computing time	6.3 s	9.4 s	11.6 s

It can be known from data and related definitions of Objective (23-32) in Table 3 that proposed algorithm is superior than Literature [12-13] for contrast algorithm in convergence value of all objective functions. On computing time index, optimization time used in proposed algorithm is also superior than contrast algorithm, which represents effective of proposed algorithm.

6. Conclusion

Design method for supply chain of two stage fuzzy multi-objective (Two stage fuzzy multi-objective, TSFMO) for indefinite parameter of fresh agricultural products considering satisfaction and tracing cost was proposed in the Thesis. Firstly, based on characteristics of fresh agricultural products, traditional transportation cost and location cost for fixed facility were considered, and treatment and tracing cost for waste were also considered at the same time. Satisfaction attenuation function was established to express satisfaction in members of supply chain to improve model's applicability; secondly, aimed at economical environment variation, FAP supply chain model for fuzzy parameter was set. In order to obtain the optimal solution, probabilistic linear programming in two stages was utilized to solve to improve optimization result; finally, through experimental display, proposed algorithm just needed 6.3 s to complete optimization process under the condition of having the optimal optimization objective value, which represented higher computing accuracy and efficiency of algorithm.

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