Model study on stochastic flow logistics network considering neighbourhood information of nodes

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Abstract

The significance and stochasticity of node have an effect on logistics network activity. This paper describes the importance of node by integrating the node neighbourhood information, which relates to the neighbourhood arc energy consumption and node degree which shows the node connectivity in logistics network, and during which this paper introduces the parameter α to represent the preference degree of energy consumption. This paper develops a multi-objective model seeking to energy consumption minimization and reliability maximization in the light of node stochasticity and the influence of node importance. The MPs (Minimal Path Set) is employed during the process of modelling. Genetic algorithm is applied to solve this model and a numerical experiment is presented to demonstrate the effect of significance and stochasticity of node to logistics path choice and flow assignment.

Keywords: stochastic flow network, neighbourhood information, energy consumption constraint, multi-objective model, logistics network

1 Introduction

Logistics network, as the supporter for logistics activity, not only ensures the implement of logistics activity but also affects the reality of logistics activity due to its structure specification and elements parameters. In general, the logistics network G is regarded as a network which composes of node/vertex set V and arc set A. And the network is noted $G=(V,A)$. V and A signify the supporter of logistics activity, and the network configure of $G=(V,A)$ has an important influence on logistics activity arrangement. The nodes undertake these activities such as loading and unloading, packaging, distribution processing and so on, and these nodes connect different edge/arc to fulfil the logistics activity. These properties of nodes, the difference on connectivity and stochasticity, affect the entire logistics network activity, on account of the presentation of node connectivity is significance of node, therefore this paper will do some research about impact analysis of the significance and stochasticity of logistics network to logistics activity.

The area of the node significance has been considered by many researchers who mainly focused on the measurement approach [1-10]. [1] proposed the node degree to appraise the importance of node. [3] presented betweenness centrality to evaluate the node importance. [2, 4] provided with the method of node deletion aiming at communications network system, and [4] described the significance of node adopting node contraction, and [6] improved the node contraction in weighted complex network. [5] improved the efficiency and validity of evaluating node importance based on node closeness and node key degree. [7] integrated the node degree, node betweenness and high peak hour traffic flow based on fuzzy clustering method to assess the node importance in traffic complex network. [9] presented the evaluation method of node importance base on load flow considering the contribution of the nodes for the whole network. [8] introduced the evaluation of edge importance considering the influence over node importance from the characteristics of node connection, and established the evaluation method of node importance based on agglomeration. [10] determined the node importance by devising the matrix of transfer efficiency and that of the operation influence coefficient, which considered the neighbourhood information of node for logistics network. [10] indicated that node importance may be different on account of information influence coming from node neighbourhood edge/arc and others nodes, although these nodes have the same node degree of node betweenness. All methods abovementioned give good results relating to some research area, however, it is not sufficient to logistics network, especially for new issue in logistics network area.

Logistics network, one form of stochastic flow network, has the properties of uncertainty and stochasticity deriving from node and/or arc service capability, and these properties influence entire logistics network activity arrangement. [11, 12] fully deals with the stochastic flow network, and indicated that each node and/or arc has a designated capacity. Nodes/arcs have different lower levels due to various partial and complete failures; therefore the system capacity is not fixed. To the question of stochastic-flow network, a majority of researchers concentrated on system reliability, especially the algorithm design of solving system reliability based on MPs [13-22] and MCs [11, 12, 23-27] in light of specific questions. In

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addition a small number of researchers focused on the optimization of stochastic-flow network. [28] built a multi-objective model to minimize cost and maximize network reliability depending on the concept of MPs, and designed genetic algorithm to solve problem. [29] optimized the flow assignment of stochastic-flow logistics network considering the weight variety to attain these objectives of minimum cost, maximum network reliability, minimum maximal delivery time of single path. Similarity the MPs is introduced during the progress of modelling. The studies talked above displayed better results for reliability appraisal and solution, but only pay attention to reliability. Though certain researchers gave an emphasis on optimization problem of stochastic-flow network, they cannot give much attention to logistics network, in particular cannot integrate the stochasticity with node importance with regard to stringent pressure of energy-extensive consumption logistics network is facing.

With respect to energy saving and consumption reducing, it becomes a big question due to energy shortage and environmental pressure. Logistics is relatively energy-intensity and is rapidly expanding mainly as a result of trade increment. While energy consumption is related to the property of logistics network and parameters setting, this paper will demonstrate this aspect. So far a lot of researchers discussed energy consumption involved in logistics relevant activity. [30] built a framework with seven key parameters relating to the freight-intensity of economy, the division of freight traffic between modes, the utilization of vehicle capacity. The energy efficiency of logistics operations and the ratio of emissions to energy use, and then et author indicated that by altering these parameters companies and governments should be able to decouple the growth in demand for logistics from the associated energy requirements. [31] pointed out that the design of systems and processes in intra-logistics is an essential part of factory planning, and suggested that energy efficiency-oriented planning of logistics systems should be considered. [31] and [30] analysed the energy consumption in view of system perspective. [32] discussed the port logistics network activity and indicated that the energy consumption could be decreased by coordinating vessel berthing resource allocation and speed of ship. Undoubtedly the energy consumption have been crucial practical problems and attracted attention, however, the related work is shortage relatively. There is no research that discussed the influence of the properties of logistics network to logistics network energy consumption, thereby this paper will introduce the energy consumption factor into the appraisal system of node significance by virtue of node neighbourhood information and establish the relation between node significance and energy consumption.

According to the above analysis, this paper will analyse the influence of node importance considering energy factor and node stochasticity to logistics network activity, during which the paper redefine the node importance of stochastic logistics network considering neighbourhood information of node. And then a stochastic flow logistics network shall be presented under energy consumption preference degree, during which the MPs is taken. Genetic algorithm is utilized to solve this problem and the numerical experiment demonstrated an effect of significance and stochasticity of node to logistics path choice and flow assignment as well as energy consumption.

2 Analysis of stochastic-flow logistics network (SFLN)

Logistics network, one form of stochastic-flow network, has common characters with the others stochastic-flow network such as power net and communication network. The common character is the capacity stochasticity of the network components (nodes and/or arcs) which followed some probability distribution coming from statistical information or empirical analysis. The uncertainty will act on the stochastic-flow network activities. Besides that, logistics network is a kind of complex network. Node significance is key issue in the area of complex network, therefore this paper shall give more attention to node significance of logistics network, which differentiate from general complex network. This section mainly refers to two sides: node stochasticity and node significance. Concerning node stochasticity, we deemed that capacity of node is a random variable, which follow certain probability distribution and impact the path choice and flow assignment for logistics activity. In respect to node significance, we proposed evaluation system of node significance which integrated into the energy consumption and indicated that the result of node significance have an effect on the logistics activities.

2.1 NODE STOCHASTICITY

Node stochasticity means that the capacity of node is not fixed but has different value at a certain probability, and the stochasticity leads to the uncertainty of logistics network activities. Assuming that the capacity of some node is an integer random variable, its distribution law is as follow:

$$\begin{array}{c|ccccc} X & x_1 & x_2 & \cdots & x_k & \cdots \\ \hline p_k & p_1 & p_2 & \cdots & p_k & \cdots \end{array}, \; p_k \geq 0, \; k = 1, 2, ...$$

and $\sum_{k=1}^{\infty} p_k = 1$, x_k is an integer.

We can see that distribution law of node capacity contains two sides context:

1) all possible value x_k,

2) p_k, probability corresponding to possible value. x_k and p_k jointly determine the capacity of node, and in further affect the path choice, flow assignment and logistics network transfer reliability.

All possible value of node capacity is defined as width domain, namely the interval length $[Min, Max]$; probability corresponding to possible value is defined as depth domain, namely the value of p_k. In practice the width domain and depth domain of node capacity may change when alter logistics network structure, in other words the stochasticity of node capacity possesses changeability, and the changeable node capacity impact logistics network activities again.

We supposed that distribution law of node capacity is as follows in specific logistics network structure:

X	0	10	30	50	100
p_k	0.03	0.07	0.08	0.12	0.70

Once adjusting logistics network structure, the distribution law of node capacity may vary as follows:

X	0	20	50	80	120
p_k	0.02	0.08	0.15	0.20	0.55

In this paper we will not allow for the alteration of logistics network structure, so we only discuss the stochasticity of node capacity under given network structure without considering the alteration on distribution law. That means the logistics network structure is constant but not flexible.

2.2 NODE SIGNIFICANCE

Generally, the significance of node is closely related to the amount of neighbourhood arc, the more neighbourhood arc, the more flow bearing on node, and the class of node dominate the flowing of the entire logistics network activities; on contrary, the less neighbourhood arc, the less flow bearing, and this class of node effect small and lower importance. This method of appraisal to node significance is called node degree. In logistics network, the node significance has relation to the business relationship degree of neighbourhood connected node as well as node degree. And the relationship degree of neighbourhood connected node is interpreted as function difference of arc [10]. This paper will reconstruct the appraisal system of node significance based on flow bearing ability of node itself and business relationship degree of neighbourhood connected node we could also call neighbourhood information of node. The significance of node is composed of node degree which represents the connectivity of node and the weight of neighbourhood arc which is represented by energy coefficient reciprocal. Here the term "energy coefficient" is referred to energy consumption per unit flow when transporting from one node to another by some arc. Assumed that the energy coefficient matrix of the entire network is $E=\left[e_{i,j}\right]_{n\times n}$, $e_{i,j}$ represents the energy coefficient connecting node v_i and v_j, N represents the number of node. Then the weight of arc is showed:

$$w_{ij}=\begin{cases}1/e_{ij} & i\neq j, v_j\in\Gamma_i \\ 0 & else\end{cases}, \tag{1}$$

where Γ_i represents the neighbourhood connected node set of v_i and $\Gamma=(\Gamma_1,\Gamma_2,...\Gamma_n)$. Taking into consideration the inverse multi-arc between two connection nodes, such as a_{35},a_{53} between nodes v_3,v_5, thereby Equation (1) is divided in:

$$\vec{w}_{ij}=\begin{cases}1/\vec{e}_{ij} & i\neq j, v_j\in\Gamma_i \\ 0 & else\end{cases}, \tag{2}$$

$$\overleftarrow{w}_{ij}=\begin{cases}1/\overleftarrow{e}_{ij} & i\neq j, v_j\in\Gamma_i \\ 0 & else\end{cases}, \tag{3}$$

where $\vec{e}_{ij}$ represents the energy coefficient of neighbourhood arc outflow of v_i, $\overleftarrow{e}_{ij}$ represents the energy coefficient of neighbourhood arc inflow of v_i. We define the restraint degree of node (RDN) deriving from neighbourhood arc energy coefficient is I_i, and I_i is expressed as follows:

$$I_i=\frac{1}{n_i}\sum_{j=1}^{n_i}(\vec{w}_{ij}+\overleftarrow{w}_{ij})\ \ v_j\in\Gamma_i. \tag{4}$$

The number of node v_i all neighbourhood arc is n_i. Normalization of I_i is expressed:

$$I_i^u=I_i/\sum_{i=1}^{n}I_i, \tag{5}$$

where n is the number of all nodes. Supposed that the node degree of v_i is d_i and the average degree of network is $\bar{\kappa}$. The node significance of v_i is indicated as following equation:

$$h_i=\alpha I_i^u+(1-\alpha)\frac{1}{n}\frac{d_i}{\bar{\kappa}}, \tag{6}$$

where I_i accounts for the restraint degree of node v_i flow from energy coefficient of node neighbourhood arc. If every arc which is connected with node v_i has high energy coefficient, the flow through (inflow and outflow) may be relatively low by way of v_i because of the energy consumption limitations for entire logistics network. The connection capability of v_i, that is d_i, reflect the absolute bearing capacity of node v_i in the whole logistics network. α is the weight. By adjusting the parameter of α, which expressed the emphasis for energy, we can fulfil the flow assignment based on the consideration of node connection capacity and logistics network energy consumption requirement. When the value of α is zero, it implies that the d_i of node degree totally dominated the bearing capacity of node v_i without considering the energy factor. When the value of α is one, it indicates that the I_i of restraint degree of node v_i considering energy coefficient restriction of node neighbourhood arc dominated the bearing capacity of node v_i, and it means placing ultimate emphasis on energy for node flow through. By integrating I_i and d_i, we get the node importance of v_i, and then assign the node flow of v_i in according with its node importance considering the demand requirements.

Equation (6) shows that energy consumption is closely related to node importance. There are two sides, one side is the I_i of node restraint degree basically coming from $e_{i,j}$, energy coefficient of neighbourhood arc; the other side is the value of α, which indicates the preference strength for energy consumption. I_i, d_i, α all of them determined node importance. As a given logistics network, we assume I_i and d_i could be get immediately, and the value of α may vary depending on different preference strength in this paper.

3 Stochastic-Flow logistics network model

In this paper, we discuss flow assignment on arc and node for SFLN considering the node neighbourhood information which includes node significance and stochasticity. As far as node significance, we considered the influence of the energy consumption of node neighbourhood arc to node bearing capacity and further affect flow assignment; as far as stochasticity, we discuss capacity limitation and variation of node followed some probability distribution which causes the uncertainty for flow assignment of SFLN. We propose a multi-objective model for SFLN, and introduce *MPs* [14] (minimal path sets) to model. The objective of this model is energy minimization and reliability maximization. We represent SFLN as G in following discussion.

3.1 ASSUMPTIONS

- To develop a mathematical model, we first present the assumptions and notations respectively. The main assumptions considered in this problem formulation for the SFLN, are as follows.
- The capacity of each node is an integer-valued random variable which takes values according to a given distribution.
- The capacities of different nodes are statistically independent.
- Each arc is perfectly reliable without capacity limitation.
- Each node has only the ability of transhipment without considering energy consumption.
- There is no multi-arc with same direction between nodes; if there is a pair of arcs with inverse direction between two nodes, visiting the same node is not allowed in one path.
- Flow in SFLN must satisfy the so-called flow-conservation.

3.2 PARAMETERS AND DECISION VARIABLES

The following notations are used in the model formulation.

Index sets:

$V=(v_i \mid 1\le i\le n)$: set of nodes in G, n represents the number of transfer nodes.

$A=(a_{ij} \mid i=1,...,n,\ j=1,...,n, v_i, v_j \in V, i\ne j)$: set of arcs in G.

$S=(v_1,v_2,...,v_\sigma)\subset V$: set of source nodes, σ is the number of source nodes.

$T=(v_{n-\theta+1},v_{n-\theta+2},...,v_n)\subset V$: set of terminal nodes, θ is the number of terminal nodes.

$N=V-\{S,T\}$: set of transfer nodes $v_m(m=\sigma+1,...,n-\theta)$.

$\Gamma_m \subset V$: set of neighbourhood connected nodes to transfer node $v_m \in N$.

$M=(M_m \mid m=\sigma+1,...,n-\theta, v_i\in N)$: set of capacity to transfer node, M_m is the maximum capacity to node $v_m\in N$ and the value of M_m is integer on an interval $[0,M_m]$ with some probability.

$U=(u_1,u_2,...,u_\sigma)$: set of quantity supplied to source nodes.

$D=(d_{n-\theta+1},d_{n-\theta+2},...,d_n)$: set of quantity demanded to terminal nodes.

Ω_f: set of feasible solution.

Parameters of the model:

$x_m\in M_m(m=\sigma+1,...n-\theta)$: capacity of node $v_i\in N$ under certain condition.

$x_{fm}(m=\sigma+1,...n-\theta)$: flow by the way of transfer node $v_m\in N$ and x_{fm} should less than or equal to $x_m\in M_m$.

$X_f=(x_{f\sigma+1},x_{f\sigma+2},...x_{fn-\theta})$: flow assignment for all transfer nodes under Ω_f.

f_{ij}: flow of arc a_{ij}, f_{ij} has not capacity limitation.

e_{ij}: energy consumption coefficient of a_{ij}.

$g(f_{ij})$: a concave function related to the flow of arc a_{ij} considering energy consumption.

$u_p(p=1,...,\sigma)$: maximum supply to source node $v_p\in S$.

$d_q(q=n-\theta+1,...,n)$: demand of terminal node $v_q\in T$.

h_m: node significance of node $v_m\in N$, which influences the flow assignment of nodes.

$R(f)$: reliability of G satisfying Ω_f.

$E(f)$: total energy consumption of G on the condition of Ω_f.

$MPs_{p,q,k}$: the *k-th* path of *MPs* from source node v_p to terminal node v_q.

$k_{p,q}$: the number of MPs from source node v_p to terminal node v_q.

C_m represents the condition of $(x_{fm} \le x_m)$.

$P(C_m)$ is the probability for the event satisfying $(x_{fm} \le x_m)$.

Decision variables:

$f_{p,q,k}$ – flow assignment for some path from source node v_p to terminal node v_q. $f_{p,q,k}$ is not negative number and is integer. And $f = (f_{1,n-\theta+1,1}, \cdots f_{p,q,k}, \dots, f_{\sigma,n,k_{\sigma,n}})$ is flow assignment for possible paths from source nodes to terminal nodes.

In addition:

- Minimal path means a path which consists of a series of successive nodes and arcs from a certain source node to a certain terminal node. All possible minimal paths constitute MPs.
- $MPs = \{MPs_{p,q,k} \mid p = 1,\dots,\sigma, q = n-\theta+1,\dots,n, k = 1,\dots,k_{p,q}\}$ represent the set of all possible minimal paths.

The flow of transfer node $v_m \in N$ can be received using the following equation:

$$x_{mi} = \sum_{p=1}^{\sigma} \sum_{q=n-\theta+1}^{n} \sum_{k=1}^{k_{p,q}} \{ f_{p,q,k} \mid v_m \in MPs_{p,q,k}, m = \sigma+1,..,n-\theta \}, \quad (7)$$

As the significance of transfer node $v_m \in N$ has an effect to the flow bearing of transfer node $v_m \in N$, so we assumed that the flow bearing of each transfer node is in proportion to the value of its significance, and it can be expressed as below:

$$\frac{x_{fm} = \sum_{p=1}^{\sigma} \sum_{q=n-\theta+1}^{n} \sum_{k=1}^{k_{p,q}} \{ f_{p,q,k} \mid v_m \in MPs_{p,q,k} \}}{\sum_{m=\sigma+1}^{n-\theta} x_{fm}} = h_m . \quad (8)$$

We could get f_{ij} of arc a_{ij} according to MPs that passed through arc a_{ij}. The formula is shown as the following:

$$f_{ij} = \sum_{p=1}^{\sigma} \sum_{q=n-\theta+1}^{n} \sum_{k=1}^{k_{p,q}} \{ f_{p,q,k} \mid a_{ij} \in MPs_{p,q,k} \} . \quad (9)$$

3.3 MODEL

The reliability of entire SFLN depends on the condition $(x_{fm} \le x_m)$ of every transfer node, because the capacity of transfer node is stochastic random variable and the capacity of every arc is not limited. In addition, we assumed theses capacities of different nodes are statistically independent, thereby we can show the reliability of SFLN as follows:

$$R(f) = \Pr\{C_{\sigma+1} \cap C_{\sigma+2} \cap \dots \cap C_{n-\theta}\} = \prod_{m=\sigma+1}^{n-\theta} P(C_m) . \quad (10)$$

In respect to energy consumption, it contains energy consumption of every arc without node energy consumption according to assumption. The entire energy consumption is formulated as below:

$$E(f) = \sum_{i=1}^{n} \sum_{j=1, j\ne i}^{n} e_{ij} g(f_{ij}) \quad (a_{ij} \in Mps_{p,q,k}) . \quad (11)$$

According to above analysis, we give the model. The objective function is expressed as following:

$$Max R(f) \;\; Min E(f) \quad \forall f \in \Omega_f . \quad (12)$$

Subject to:

$$\sum_{p=1}^{\sigma} \sum_{k=1}^{k_{p,q}} f_{p,q,k} = d_q, \quad q = n-\theta+1,\dots,n \quad , \quad (13)$$

$$\sum_{q=n-\theta+1}^{n} \sum_{k=1}^{k_{p,q}} f_{p,q,k} \le u_p, \qquad p = 1,\dots,\sigma \quad , \quad (14)$$

$$\sum_{p=1}^{\sigma} \sum_{q=n-\theta+1}^{n} \sum_{k=1}^{k_{p,q}} \{ f_{p,q,k} \mid v_m \in MPs_{p,q,k}, v_m \in N \} \le M_m, \quad m = \sigma+1,\dots,n-\theta, \quad (15)$$

$$f_{p,q,k} \ge 0, \; f_{p,q,k} \text{ is integer} . \quad (16)$$

In the proposed model of SFLN, the Equation (12) seeks to minimize the energy consumption and maximize the reliability in SFLN.

(*i*) the energy consumption associated with energy consumption coefficient of arc e_{ij} and the flow of arc f_{ij}.

(*ii*) the function $g(f_{ij})$ effect the total energy consumption of each arc considering the scale of flow.

(*iii*) the reliability associated with the reliability of every transfer node $P(C_m)$. Equation (13) ensures the demands of terminal nodes are met. Equation (14) guarantees the shipping quantity for every source node does not exceed its supply. Equation (15) bounds that flow of every transfer node less than the capacity limitation of every transfer node. Equation (8) enforces that the assigned flow bearing of every transfer node should be in apportion to its significance. Equation (16) enforces non-negativity and integer for the flow assignment of minimal path.

4 Numerical experiment

For a given SFLN, we need get the value of significance for every transfer node when given parameter α according to Equation (6) prior to model solution. In regard to others numerical value, such as node degree and $E = \left[e_{i,j} \right]_{n \times n}$, we could compute depending on definition and given data. Once getting the value of significance, we can deal with the model.

The integer coded genetic algorithm will be adopted to solve the model in light of complexity. Supposed that the flow assignment $f_{p,q,k}$ of each minimal path is one chromosome and all minimal path set constitute a gene.

Penalty function is applied to deal with constraint and fitness function is determined by the ratio of reliability to energy consumption.

4.1 EXPERIMENT OF SFLN

To illustrate the applicability of the proposed model, a numerical experiment is conducted in this section for SFLN. The SFLN is given as following Figure 1, and the matrix of energy consumption coefficient for every arc is given in Figure 2.

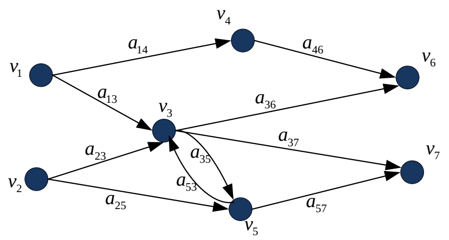

FIGURE 1 Stochastic-Flow Logistics Network

$$E=\begin{bmatrix}0&0&8&2&0&0&0\\0&0&8&0&4&0&0\\0&0&0&0&4&8&4\\0&0&0&2&0&0&0\\0&0&6&0&0&0&3\\0&0&0&0&0&0&0\\0&0&0&0&0&0&0\end{bmatrix}_{7\times 7}$$

FIGURE 2 Matrix of Energy Consumption Coefficient

This experiment considers different value of parameter α to given SFLN, and we obtain the significance of transfer node and determine the principle of flow in accordance with significance of transfer node as follows (Table 1).

TABLE 1 Significance of transfer nodes on different preference and proportion of flow bearing

Significance of h$_m$ parameter α	v$_3$	v$_4$	v$_5$	Proportion of w bearing v$_3$:v$_4$:v$_5$
α =0.00	0.50	0.16*	0.33	3:1:2
α =0.35	0.44	0.22	0.33	4:2:3
α =0.65	0.40	0.27	0.33	6:4:5
α =1.00	0.34	0.33	0.34	1:1:1

Remarks:*The figures are rounded.

By search method, we get the nine minimal paths in Figure 1.

$MPs_{1,6,1}=\{v_1,a_{14},v_4,a_{46},v_6\}; MPs_{1,6,2}=\{v_1,a_{13},v_3,a_{36},v_6\};$
$MPs_{2,6,1}=\{v_2,a_{23},v_3,a_{36},v_6\}; MPs_{2,6,2}=\{v_2,a_{25},v_5,a_{53},v_3,a_{36},v_6\};$
$MPs_{1,7,1}=\{v_1,a_{13},v_3,a_{37},v_7\}; MPs_{1,7,2}=\{v_1,a_{13},v_3,a_{35},v_5,a_{57},v_7\};$
$MPs_{2,7,1}=\{v_2,a_{23},v_3,a_{37},v_7\}; MPs_{2,7,2}=\{v_2,a_{23},v_3,a_{35},v_5,a_{57},v_7\};$
$MPs_{2,7,3}=\{v_2,a_{25},v_5,a_{57},v_7\}.$

The minimal path via transfer node is listed in Table 2.

TABLE 2 Minimal paths via transfer node

Minimal path, Transfer node v_m	$MPs_{p,q,k_{p,q}}$
v_3	$MPs_{1,6,2}, MPs_{2,6,1}, MPs_{2,6,2}, MPs_{1,7,1}, MPs_{1,7,2}, MPs_{2,7,1}, MPs_{2,7,2}$
v_4	$MPs_{1,6,1}$
v_5	$MPs_{2,6,2}, MPs_{1,7,2}; MPs_{2,7,2}, MPs_{2,7,3}$

Setting value: $U=(9,9), D=(6,6)$, $g(f_{ij})=\sqrt{f_{ij}}$, and we get the distribution law of capacity for transfer node as following Table 3.

TABLE 3 Distribution law of transfer node

Node	Capacity	Probability
v_3	0	0.000
	1	0.002
	2	0.003
	3	0.004
	4	0.006
	5	0.085
	6	0.125
	7	0.175
	8	0.200
	9	0.400
v_4	0	0.002
	1	0.003
	2	0.005
	3	0.010
	4	0.100
	5	0.145
	6	0.735
	7	0.000
	8	0.000
	9	0.000
v_5	0	0.001
	1	0.005
	2	0.009
	3	0.035
	4	0.075
	5	0.100
	6	0.785
	7	0.000
	8	0.000
	9	0.000

The population size is 200, and initialize. We get optimization flow assignment of all *MPs* after 300 iterations for parameter $\alpha=1.00$. Part of the feasible values of objective function and corresponding code are given during iteration corresponding to Table 4. And the flow of each arc is get via Equation (9) corresponding to Table 5.

TABLE 4 Part of feasible values of objective function and corresponding code

$R(f)$	$E(f)$	$f_{1,6,1}$	$f_{1,6,2}$	$f_{2,6,1}$	$f_{2,6,2}$	$f_{1,7,1}$	$f_{1,7,2}$	$f_{2,7,1}$	$f_{2,7,2}$	$f_{2,7,3}$
7.67118*E*-01*	6.981360*E*+01	5	0	0	1	1	1	1	1	2
7.67118*E*-01	6.423753*E*+01	5	1	0	0	1	2	0	1	2
7.67118*E*-01	6.540765*E*+01	5	0	1	0	1	2	0	1	2
7.67118*E*-01	6.696739*E*+01	5	0	0	1	0	1	2	1	1
7.67118*E*-01	6.904259*E*+01	5	0	0	1	1	2	1	0	2
7.67118*E*-01	6.540765*E*+01	5	1	0	0	0	2	1	1	2
7.67118*E*-01	6.540765*E*+01	5	0	1	0	0	2	1	1	2

*Remarks: when $\alpha = 1.00$, the flow bearing of each transfer node is equal 1:1:1, that means each transfer node has the same flow bearing, thereby according to the Equation (10),we get the same value of reliability for different flow assignment. It is a special case.

TABLE 5 Flow of arc of feasible value corresponding to Table 4

f_{13}	f_{46}	f_{13}	f_{23}	f_{36}	f_{37}	f_{35}	f_{53}	f_{25}	f_{57}
5	5	2	2	1	2	2	1	3	4
5	5	4	1	1	1	3	0	2	5
5	5	3	2	1	1	3	0	2	5
5	5	1	3	1	2	2	1	2	3
5	5	3	1	1	2	2	1	3	4
5	5	3	2	1	1	3	0	2	5
5	5	2	3	1	1	3	0	25	5

Similarly, we get the optimal value for different parameter α.

TABLE 6 Optimal value to different preference

α	$M_{PS} = (f_{p,q,k})$	$f_{i,j}$	$R(f)$	$E(f)$
α = 0.00	(3,0,1,2,1,2,1,2,0)	(3,3,3,4,3,2,4,2,2,4)	8.444400*E*+01	3.110860*E*-01
α = 0.35	(4,0,0,2,1,2,1,2,0)	(4,4,3,3,2,2,4,2,2,4)	8.082551*E*+01	4.615800*E*-01
α = 0.65	(4,1,0,1,1,1,1,1,2)	(4,4,3,2,2,2,2,1,3,4)	7.472573*E*+01	7.805700*E*-01
α = 1.00	(5,1,0,0,1,2,0,1,2)	(5,5,4,1,1,1,3,0,2,5)	6.423753*E*+01	3.671180*E*-01

4.2 RESULT ANALYSIS

According to the result of Table 6, we draw the graph of Figure 3.

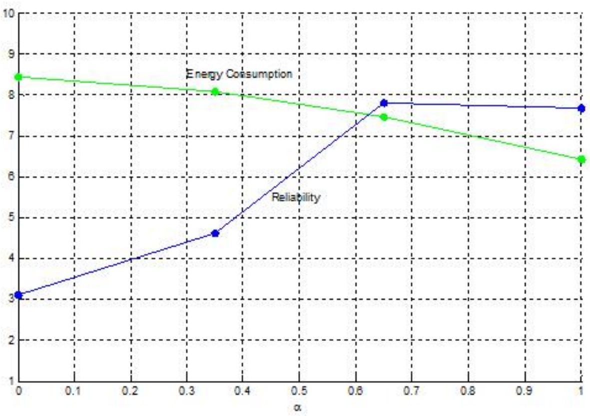

FIGURE 3 Comparison of optimal value for different preference

The horizontal axis represents parameter α of energy consumption preference; in vertical axis the green broken line represents energy consumption and the blue broken line is reliability. We can see that the value of energy consumption drops gradually along with the increase of parameter α, which can be explained that total energy consumption of SFLN may drop when given more emphasis to energy and then the emphasis finally effect the flow assignment by way of transfer node significance. Based on the experimental results, we do not find causal relation between parameter α and system reliability, and we think that it may be the result of stochasticity for transfer node. It should be studied in further. It is worth mentioning, because the significance of transfer node is introduce to influence flow assignment, the system reliability of SFLN must decrease compared with the same SFLN without restriction from significance of transfer node.

5 Conclusions

This paper has studied the SFLN considering neighbourhood information of transfer node. In light of energy consumption pressure to logistics activity, this paper proposed the restraint degree of node coming from neighbourhood arc energy coefficient and combined the node degree to represent the significance of node. The parameter α, which indicates the preference degree to energy is introduced to integrated RDN and node degree. For stochasticity of node, a bi-objective model has been developed and the significance of node embed in model had influence to flow assignment for model. The numerical experiments have shown that the energy consumption will drop along with the strength of preference to energy consumption. But the reliability of SFLN and parameter has no dependency according to present study.

Although this paper proposed the RDN and redefined the significance of node, and analysed the influence of α (actually via significance of node) to energy consumption, we had not balanced the preference of energy and reliability, namely we had not attain the associativity between α and reliability. In addition, we discussed stochasticity of node in the given SFLN; however, the variation of distribution law to node has not been involved. And further steps for research will be extension of the SFLN.

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