Uncertainty and Operations Research

Xiang Li
Xiaofeng Xu *Editors*

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Uncertainty and Operations Research

Decision analysis based on uncertain data is natural in many real-world applications, and sometimes such an analysis is inevitable. In the past years, researchers have proposed many efficient operations research models and methods, which have been widely applied to real-life problems, such as finance, management, manufacturing, supply chain, transportation, among others. This book series aims to provide a global forum for advancing the analysis, understanding, development, and practice of uncertainty theory and operations research for solving economic, engineering, management, and social problems.

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Contents

Research on Risk Assessment and Early Warning of Supply Chain Based on Extension in the Context for New Retailing

Shiming Liu, Huihong Chen and Ziyu Hu

Abstract Under the new retail background, enterprises pursue more rapid response and flexible supply chain, but also increase the vulnerability and risk of supply chain. Any link problems caused by the uncertainty of supply chain are very easy to cause supply collapse or operational obstacles. In order to reduce the influence of uncertainty and reduce the risk and loss caused by out of control, this paper, guided by the concept and thought of risk assessment, tries to introduce the extension assessment into the supply chain risk analysis in order to assess the supply chain risk through a quantitative analysis method and reduce the impact of uncertainty.

Keywords Extension · Risk assessment · Supply chain · Early-warning degree

1 Introduction

Under the new retail background, the retail chain, characterized by "small scale, good management, low cost, high gross profit, excellent service", is on the basis of deep ploughing entity, plus the power of e-commerce, and the new retailing of "Online + offline + logistics" combines the supply chain as the king, and integrates the advantages of strong resource ability. For the breakthroughs and new development hotspots and trends of many entity retailers, the competition pattern of new retailers has risen to competition among supply chains. People have made great efforts to make the supply chain more lean and lower cost, but at the same time, they have also increased the vulnerability and risk of the supply chain. Any problem in the supply chain may affect other links, affect the normal operation of the whole company, and even cause economic loss and social impact on the whole supply chain. In order to ensure the safety of supply chain and improve the ability of risk

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prevention and control, this paper applies the extension analysis method to supply chain, and provides a train of thought and Practice for the risk prevention and control of supply chain.

2 Theory, Practice and Feasibility Analysis

Extenics is initiated by Professor Cai Wen of Guangdong University of Technology. It uses a formal model to study the possibilities of developing things and the laws and methods of pioneering and innovation, and it is used to deal with the problems of contradictions. The parameter element model of the extension theory is a dynamic model, which is simpler than the neural network, and will not be affected by the limitation of the training set, which can affect the discriminant ability of the model, and can better fit the complex and dynamic change system of the risk early warning of the supply chain [1–4].

In extenics, matter-element, affair-element and relation-element are established as the basic logic cells of Extenics. These 3 basic logic cells can describe the property and method of the possessions in the great thousand world, also known as the basic element, which can be recorded as R = (matter element, event element, relation element) = (N, C, V), in which the matter element represents the properties and characteristics of the object, the element represents the interaction between objects and objects, and the relation element expresses the interaction and mutual relationship between the relations. Influence. In extenics, a problem solving model can be established in terms of matter element, matter element and relationship element according to a certain calculation method.

An object(N) may have multiple features, and the relationship of each feature has a corresponding value. At this point, the multidimensional matrix can be defined to represent the view formula (1):

$$\mathrm{R} = (N, C, V) = \begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \cdots & \cdots \\ & C_n & V_n \end{bmatrix} \tag{1}$$

In the formula:

N	The matter element;
C_1, C_2, …, Cn	The attribute name of the matter element;
V_i (i = 1, 2, …, n)	C_1,C_2, …, Cn Corresponding attribute values.

As the time t changes, the corresponding properties and corresponding values of matter-element will also change, so we can add t parameters to formula (1), as shown in formula 2.

$$R = (N(t), C(t), V(t)) = \begin{bmatrix} N(t) & C_1 & V_1(t) \\ & C_2 & V_2(t) \\ & \cdots & \cdots \\ & C_n & V_n(t) \end{bmatrix} \quad (2)$$

In the formula:

N(t) matter elements that vary with time;
C the attribute value of the measure;
V(t) he value corresponding to the attribute characteristics.

3 Classification of Risk Early-Warning Index System of Supply Chain

Supply chain risk comes from the uncertainty of supply chain; the existence and transmission of supply chain uncertainty affects the whole supply chain; the size of the risk depends essentially on the probability and severity of the occurrence of the uncertainty. According to the nature of supply chain, supply chain research generally considers that there are external risks and internal risks in supply chain. The external risk is uncontrollable, and no specific analysis is done for the time being. Based on the supply chain perspective and the key factor of risk early warning based on the perspective of the supply chain, this paper builds the risk early-warning index system based on Extenics in Supply Chain Based on the perspective of supply chain, which is based on the supply chain perspective, and see Table 1, which is based on the [5–8].

4 The Theoretical Foundation of Establishing the Risk Early Warning Model of Supply Chain

There are 28 early warning objects in supply chain risk warning, which can be expressed as formula (3):

$$\mathrm{R}_j = \left(N_j, C_j, V_{ji}\right) = \begin{bmatrix} N_j & C_1 & V_{j1} \\ & C_2 & V_{j2} \\ & \cdots & \cdots \\ & C_n & V_{jn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & <a_{j1}, b_{j1}> \\ & C_2 & <a_{j2}, b_{j2}> \\ & \cdots & \cdots \\ & C_n & <a_{jn}, b_{jn}> \end{bmatrix} \quad (3)$$

In the formula:

R_i(i = 1, 2, …, n) The overall situation of t supply chain risk input at a certain time;

Table 1 The safety pre-warning index based on extension theory

Risk indicators	Specific risk indicators	Risk indicators	Specific risk indicators
Demand risk	The accuracy rate of demand forecast C_1	Information risk	The degree of information sharing of node enterprises C_{15}
	Demand fluctuation amplitude C_2		Information sharing efficiency of node enterprises C_{16}
	Market demand strain capacity C_3		Supply chain complexity C_{17}
	New technology substitution effect degree C_4	Technical risk	Advanced technology C_{18}
Supply risk	Supplier production flexible C_5		Non imitability of technology C_{20}
	Supplier delivery rate C_6		New product launch cycle C_{21}
	Supplier inventory level C_7		Supply chain partners operating capability C_{21}
	Supplier qualification rate C_8	Operational risk	Supply chain enterprise cultural compatibility C_{22}
	Supplier innovation ability C_9		Supply chain enterprise goal concept compatibility C_{23}
Logistics risk	Impact degree of logistics cost C_{10}		Supply chain enterprise capacity complementarity C_{24}
	The perfection of logistics facilities C_{11}	Financial risk	Enterprise capital supply status C_{25}
	Logistics personnel reserve C_{12}		Financial system perfection C_{26}
	Logistics capability C_{13}		Financial plan rationality C_{27}
	Information degree of node enterprise C_{14}		Financing and the ability to resist risk C_{28}

N_j — the j supply chain risk grade divided;
C_i — the attributes corresponding to each N_i;
V_i — the attribute values corresponding to each N_i;
<aji, bji> — the numerical range of the attribute value, where a_{ji} indicates the lower limit and b_{ji} is the upper limit.

The generation of risk early-warning index system based on the research standards of supply chain risk department is based on extenics, taking the input data of risk early warning system as the main consideration parameter of risk early warning. According to 1.1 risk early warning index system and 1.2 risk warning threshold, the degree of early warning of supply chain risk early warning can be obtained. It is divided into five levels: safety V, no police IV, light police III, middle police II, heavy alarm I, see Table 2. The establishment of the risk early-warning index system of supply chain should be established as far as possible to realize the

Table 2 Safety pre-warning index valve values

Risk early-warning index	Demand risk C_1	Supply risk C_2	Logistics risk C_3	…	Financial risk C_{28}
Safety V	[0, 20]	[0.0, 0.5]	[0, 0.5]	…	[0, 10]
No warning IV	[20, 23]	[0.5, 0. 7]	[0.5, 2]	…	[10, 30]
Light warning III	[23, 30]	[0.7, 0.8]	[2, 30]	…	[30, 50]
Medium warning II	[30, 35]	[0.8, 0.9]	[30, 40]	…	[50, 70]
Serious warning I	[35, 60]	[0.9, 1]	[40, 80]	…	[70, 80]

quantification, rationalization and operationalization of early warning information, so that the early warning index system truly reflects the actual situation of the danger in the supply chain. The determination of the threshold value of each warning index mainly refers to the laws and standards of the supply chain, and determines the threshold of early warning indicators combined with the actual situation.

This table only gives some threshold values.

According to the demand for risk early warning, as shown in Eq. (4).

$$R_p = \left(N_p, C_j, V_{ip}\right) = \begin{bmatrix} N_p & C_1 & V_{1p} \\ & C_2 & V_{2p} \\ & \cdots & \cdots \\ & C_n & V_{np} \end{bmatrix} = \begin{bmatrix} N_p & C_1 & < a_{1p}, a_{1p} > \\ & C_2 & < a_{2p}, a_{2p} > \\ & \cdots & \cdots \\ & C_n & < a_{np}, a_{np} > \end{bmatrix} \tag{4}$$

In the formula:

R_p Construction of the node domain, R_p belongs to the value within the R_j range.

4.1 Construction of Risk Early Warning Correlation Function of Supply Chain

For each warning object, the definition formula (5) denotes I (I = 1, 2, …). 28) index and J (J = 1, 2,… (5)) the correlation degree of the security level, and the point of calculation for the early warning object ρ_i is evaluated by the value V_{ik} of the C_k which is not satisfied.

$$\mathrm{K}_i(V_i) = \begin{cases} \frac{\rho(V_i, V_{ij})}{\rho(V_i, V_{ip}) - \rho(V_i, V_{ij})}, & \rho(V_i, V_{ip}) \neq \rho(V_i, V_{ij}) \\ -\frac{\rho(V_i, V_{ij})}{|\rho(V_i, V_{ij})|}, & \rho(V_i, V_{ip}) = \rho(V_i, V_{ij}) \end{cases} \tag{5}$$

In the formula:

$K_i(V_i)$	the correlation between the i index and the j security level;
V_i	the current range;
$V_{ij} = <a_{ij}, b_{ij}>$	classical domain;
$V_{ip} = <a_{ip}, b_{ip}>$	domain;
$\|V_{ij}\|$	The range of the range of the range;
$\rho(V_i, V_{ij})$	The distance between point Vi and finite interval $V_{ij} = <a_{ij}, b_{ij}>$;
$\rho(V_i,V_{ip})$	The distance between point Vi and finite interval $V_{ip} = <a_{ij}, b_{ij}>$, The calculation formula is $\rho(x, <a, b>)=\|x - (a + b)/2\| - (a - b)/2$.

4.2 Construction of Risk Early-Warning Weight Coefficient of Supply Chain

Coefficient parameters for defining the early warning weight of the supply chain $\varphi_{\mathrm{ij}}(V_i, V_{ij})$ See formula (6), among i = 1, 2, …, 28; j = 1, 2, …, 5.

$$\varphi_{\mathrm{ij}}(V_i, V_{ij}) = \begin{cases} \frac{2(V_i + a_{ij})}{b_{ij} - a_{ij}}; & V \leq \frac{a_{ij} + b_{ij}}{2} \\ \frac{2(b_{ij} + V_i)}{b_{ij} - a_{ij}}; & V \geq \frac{a_{ij} + b_{ij}}{2} \end{cases} \tag{6}$$

In the formula:

$\varphi_{\mathrm{ij}}(V_i, V_{ij})$ The coefficient parameters of the early warning weight of the supply chain.

Generally speaking, $\sum_1^n \varphi_{ij} = 1$, there are several ways to choose the weight coefficient in extenics. When the risk early-warning of the supply chain is calculated in the larger category after the calculation, the possibility of conflict will increase, so the weight should also increase. The weight value can be defined by the definition formula (7); and the risk early warning of the supply chain in the evaluation process, if the index amount is calculated in a smaller category, will lead to the reduction of the possibility of the conflict, so the weight should also be reduced. We can define the formula (8) to take the weight value.

$$\varphi_{\mathrm{i}} = \begin{cases} j_{\max} \times \varphi(\mathrm{V_i}, V_{ij}), & \varphi_{ij\max}(\mathrm{V_i}, V_{ij}) \geq -\frac{1}{2} \\ \frac{1}{2} j_{\max}, & \varphi_{ij\max}(\mathrm{V_i}, V_{ij}) \leq -\frac{1}{2} \end{cases} \tag{7}$$

$$\varphi_{\mathrm{i}} = \begin{cases} (m - j_{\max} + 1) \times (1 + \varphi_{ij\max}(\mathrm{V_i}, V_{ij})), & \varphi_{ij\max}(\mathrm{V_i}, V_{ij}) \geq -\frac{1}{2} \\ \frac{1}{2}(m - j_{\max} + 1), & \varphi_{ij\max}(\mathrm{V_i}, V_{ij}) \leq -\frac{1}{2} \end{cases} \tag{8}$$

In the formula:

φ_{i} Weight value;

Finally, the weight coefficient of the corresponding index is calculated. See formula (9):

$$\omega_{\mathrm{i}} = \frac{\varphi_i}{\sum_1^n \varphi_i}. \tag{9}$$

4.3 Risk Early-Warning Grade Evaluation of Supply Chain

The function K (x) is set to represent the association property, and its numerical content is used to illustrate which security level of the early-warning object is consistent with the risk early warning of the supply chain, which is expressed in formula 10.

$$\mathrm{K}_j(R_0) = \sum\nolimits_1^n \omega_{\mathrm{i}}\mathrm{K}(V_i) \tag{10}$$

$$K_{j0}(R_0) = j \in \overset{\max}{\{1, 2, 3\ldots, m\}} K_j(R_0) \tag{11}$$

It shows that the early warning model will alert R$_0$ to its corresponding level $j_{0.}$

5 Application Calculation and Analysis

5.1 Supply Chain Early Warning Classic Domain Selection

According to the characteristics of early warning (3) and supply chain, different safety levels have different attribute contents and characteristic data ranges. We can design the classical field of supply chain risk by using formulas (12)–(16):

$$\mathrm{R}_1 = (I, C_1, V_{i1}) = \begin{bmatrix} N(I) & C_1 & V_1(1) \\ & C_2 & V_2(1) \\ & \ldots & \ldots \\ & C_n & V_n(1) \end{bmatrix} = \begin{bmatrix} C_1 & <35, 60> \\ C_2 & <0.9, 1> \\ \ldots & \ldots \\ C_n & <70, 80> \end{bmatrix} \tag{12}$$

$$\mathrm{R}_2 = (\mathrm{II}, C_2, V_{i2}) = \begin{bmatrix} N(\mathrm{II}) & C_1 & V_1(2) \\ & C_2 & V_2(2) \\ & \ldots & \ldots \\ & C_n & V_n(2) \end{bmatrix} = \begin{bmatrix} C_1 & <30, 35> \\ C_2 & <0.8, 0.9> \\ \ldots & \ldots \\ C_n & <50, 70> \end{bmatrix} \tag{13}$$

$$\mathrm{R}_3 = (\mathrm{III}, C_3, V_{i3}) = \begin{bmatrix} N(\mathrm{III}) & C_1 & V_1(3) \\ & C_2 & V_2(3) \\ & \ldots & \ldots \\ & C_n & V_n(3) \end{bmatrix} = \begin{bmatrix} C_1 & <23, 30> \\ C_2 & <0.7, 0.8> \\ \ldots & \ldots \\ C_n & <30, 50> \end{bmatrix} \quad (14)$$

$$\mathrm{R}_4 = (\mathrm{IV}, C_4, V_{i4}) = \begin{bmatrix} N(\mathrm{IV}) & C_1 & V_1(4) \\ & C_2 & V_2(4) \\ & \ldots & \ldots \\ & C_n & V_n(4) \end{bmatrix} = \begin{bmatrix} C_1 & <20, 23> \\ C_2 & <0.5, 0.7> \\ \ldots & \ldots \\ C_n & <10, 30> \end{bmatrix} \quad (15)$$

$$\mathrm{R}_5 = (\mathrm{V}, C_5, V_{i5}) = \begin{bmatrix} N(\mathrm{V}) & C_1 & V_1(5) \\ & C_2 & V_2(5) \\ & \ldots & \ldots \\ & C_n & V_n(5) \end{bmatrix} = \begin{bmatrix} C_1 & <0, 20> \\ C_2 & <0, 0.5> \\ \ldots & \ldots \\ C_n & <0, 10> \end{bmatrix} \quad (16)$$

5.2 Supply Chain Early Warning Area Selection

According to the characteristics of different security levels and supply chain early warning indicators, the selection of the supply chain risk early-warning area can be designed as follows: the threshold of early warning index of the security state of the supply chain risk early warning index system can be obtained by the formula of the supply chain risk warning area (17).

$$\begin{aligned} \mathrm{R}_p = \left(N_p, C_j, V_{ip}\right) &= \begin{bmatrix} N_p & C_1 & V_{1p} \\ & C_2 & V_{2p} \\ & \ldots & \ldots \\ & C_n & V_{np} \end{bmatrix} = \begin{bmatrix} P_i & C_1 & <a_{1p}, b_{1p}> \\ & C_2 & <a_{2p}, b_{2p}> \\ & \ldots & \ldots \\ & C_n & <a_{np}, b_{np}> \end{bmatrix}_p \\ &= \begin{bmatrix} I:V & \mathrm{C}_1 & <0, 60> \\ & \mathrm{C}_2 & <0, 1> \\ & \ldots & \ldots \\ & \mathrm{C}_{28} & <0, 80> \end{bmatrix} \end{aligned} \quad (17)$$

5.3 Selection of Early-Warning Index Value of Supply Chain

The value of each early warning index in Table 1 is shown as shown in Table 3, in which PI (pre-warning index) refers to early warning indicators; $\mathrm{P_{IV}}$ (pre-warning index value) refers to early warning value, $\mathrm{V_i}$ is the value of the early warning index corresponding to the attribute characteristic $\mathrm{C_i}$, $\mathrm{V_1}$, $\mathrm{V_2}$, … $\mathrm{V_{28}}$'s early warning indicators are 24, 0.6, …, 90.

Table 3 Index values about safety pre-warning safety of F company

PI	PIV	PI	PIV	PI	PIV	PI	PIV	PI	PIV	PI	PIV	PI	PIV
V_1	24.0	V_5	95.0	V_9	8.0	V_{13}	79.0	V_{17}	4.0	V_{21}	44.0	V_{25}	60.0
V_2	0.6	V_6	3.8	V_{10}	68.0	V_{14}	92.0	V_{18}	10.0	V_{22}	102.0	V_{26}	84.0
V_3	2.4	V_7	93.0	V_{11}	75.0	V_{15}	88.0	V_{19}	87.0	V_{23}	380.0	V_{27}	21.0
V_4	120.0	V_8	90.0	V_{12}	50.0	V_{16}	5.0	V_{20}	95.0	V_{24}	74.0	V_{28}	90.0

5.4 Calculation of the Early Warning Power Coefficient and Safety Degree of Supply Chain

According to the above set value, and according to the formulas (5)–(9) calculation method, the index weight values of the supply chain early warning related to the supply chain, as shown in Table 4, are calculated.

5.5 Calculation of Comprehensive Early Warning Degree of Supply Chain

According to the value of the forewarning index weight of the supply chain of the above Table 4, and the calculation method of formula (4) and (10), the calculated value of the early-warning degree related to the supply chain, as shown in Table 5, is calculated.

5.6 F Company Supply Chain Risk Early Warning Security State and Result Analysis

5.6.1 Analysis of Single Index Security Early Warning

Take C_1 (demand forecast accuracy) and C_2 (demand fluctuation amplitude) as an example, in which the values of 5 relational degrees related to C_1 supply chain extenics are K_1 $(C_1) = -0.$ 4286, K_2 $(C_1) = 0.3333$, K3 $(C_1) = -0.$ 2000, K4 = 0.3333, 2000, calculated or directly from the rank type (11) of the security rank. Figure 1 shows that the supply chain warning level of the available C_1 is grade IV, indicating that the accuracy rate of F's supply chain demand prediction is non police level. C_2 supply chain extenics level related 5 correlation degrees are K_1 $(C_2) = -0.9400$, K_2 $(C_2) = -0.9200$, K_3 $(C_2) = 0.2000$, K_4 $(C_2) = -0.1429$, = K_5 $(C_2) = -0.$ 4419, calculated through the rank type (11) of the security level or directly from the Fig. 1, and the level of the supply chain early warning level belongs to grade III, said The fluctuation of supply chain demand of Ming F company belongs to light police level, which indicates that there are still more problems in supply chain fluctuation. By analogy, it can also easily get other security level and state types of other supply chain warning indicators.

5.6.2 Comprehensive Security Early-Warning Analysis

As shown in Fig. 2, the formulas (10) and (11) are calculated. The relative safety level and state type of the F supply chain inspection index are $K_j = 4$ $(P_0) = -0.$

Table 4 Safety pre-warning index weight coefficients

PI	ω_i	PI	ω_i	PI	ω_i	PI	ω_i	PI	ω_i	PI	ω_i	PI	ω_i
C_1	0.0418	C_5	0.0179	C_9	0.0437	C_{13}	0.0090	C_{17}	0.0247	C_{21}	0.0345	C_{25}	0.0623
C_2	0.0185	C_6	0.0321	C_{10}	0.0364	C_{14}	0.0273	C_{18}	0.0254	C_{22}	0.0436	C_{26}	0.0321
C_3	0.0321	C_7	0.0264	C_{11}	0.0489	C_{15}	0.0309	C_{19}	0.0228	C_{23}	0.0356	C_{27}	0.0563
C_4	0.0328	C_8	0.0365	C_{12}	0.0487	C_{16}	0.0564	C_{20}	0.0324	C_{24}	0.0366	C_{28}	0.0543

Table 5 Calculated values about safety pre-warning degree of F company

Early warning indicators	$K_5(vi)$	$K_4(vi)$	$K_3(vi)$	$K_2(vi)$	$K_1(vi)$
C_1	−0.142 9	−0.040 0	0.043 5	-0.200 0	-0.314 3
C_2	−0.200 0	0.333 3	−0.200 0	−0.333 3	−0.428 6
C_3	−0.441 9	−0.142 9	0.200 0	−0.920 0	−0.940 0
C_4	−0.142 9	0.090 9	−0.076 9	−0.250 0	−0.400 0
C_5	−0.375 0	1.500 0	−0.500 0	−0.750 0	−0.833 3
C_6	−0.073 2	0.055 6	−0.050 0	−0.155 6	−0.240 0
C_7	−0.222 2	0.400 0	−0.300 0	−0.650 0	−0.766 7
C_8	−0.100 0	−0.500 0	−0.750 0	−0.833 3	−0.875 0
C_9	−0.272 7	0.333 3	−0.200 0	−0.733 3	−0.800 0
C_{10}	−0.272 7	0.333 3	−0.200 0	−0.466 7	−0.600 0
C_{11}	−0.444 4	−0.375 0	−0.166 7	0.250 0	−0.166 7
C_{12}	−0.375 0	−0.166 7	0.250 0	−0.166 7	−0.375 0
C_{13}	−0.866 7	−0.866 7	−0.866 7	−0.866 7	−0.866 7
C_{14}	−0.080 0	−0.600 0	−0.800 0	−0.866 7	−0.866 7
C_{15}	−0.142 9	0.200 0	−0.400 0	−0.600 0	−0.760 0
C_{16}	−0.937 5	−0.916 7	−0.875 0	−0.750 0	−0.050 0
C_{17}	−0.428 6	0.333 3	−0.200 0	−0.600 0	−0.800 0
C_{18}	0.250 0	−0.166 7	−0.615 4	−0.642 7	−0.657 5
C_{19}	−0.187 5	0.300 0	−0.350 0	−0.566 7	−0.740 0
C_{20}	−0.050 0	−0.500 0	0.750 0	−0.833 3	−0.900 0
C_{21}	−0.371 4	−0.153 9	−0.022 2	0.023 3	−0.371 4
C_{22}	−0.142 9	0.200 0	−0.640 0	−0.700 0	−0.808 5
C_{23}	−0.222 2	0.166 7	−0.125 0	−0.461 5	−0.720 0
C_{24}	−0.297 3	−0.037 0	0.040 0	−0.133 3	−0.350 0
C_{25}	−0.200 0	0.333 3	−0.310 3	−0.411 8	−0.487 2
C_{26}	−0.272 7	−0.058 8	0.066 7	−0.200 0	−0.680 0
C_{27}	−0.700 0	−0.580 0	−0.300 0	0.750 0	−0.343 8
C_{28}	−0.444 4	−0.285 7	0.666 7	−0.333 3	−0.600 0
$K_j(R0)$	−0.315 2	−0.068 1	−0.216 4	−0.350 7	−0.494 6

0681, and the relevant inspection indexes are no alarm safety level, which shows that the inspection index of the supply chain of F company is more reasonable. But by formulae (10) and (11), $K_j = 3\ (P_0) = -0.\ 2164$ can be found. It is found that the security state of the F supply chain has a tendency to change from the non alarm level to the light alarm level. This also suggests that the optimization and adjustment of the early warning index should be more closely concerned, and the attention of the early warning model results is needed more carefully.

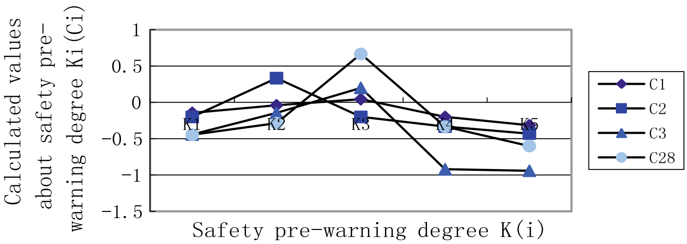

Fig. 1 Indicators save pre-warning1

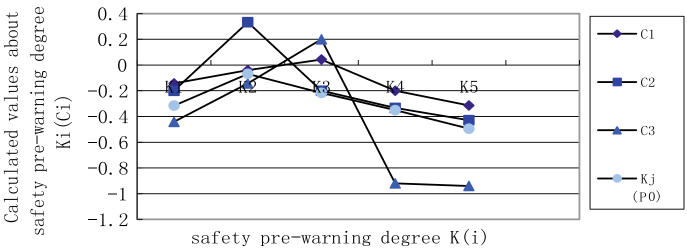

Fig. 2 Indicators save pre-warning

6 Conclusion

The supply chain risk early-warning model based on extenics is an organic combination of supply chain detection management and extension decision theory, which provides new ideas for improving the risk early warning capability of supply chain, evaluating the security state of supply chain system and effectively early-warning. Improving the predictability and robustness of the supply chain can better eliminate the uncertainty of supply chain risk.

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Estimating Regional Water Resources Carrying Capacity Based on Big Data Analysis of Demand and Supply

Xiaoli Chen

Abstract The shortage of water resources is a common concern at present, a comprehensive model, therefore, is needed to analyze and predict the water resources carrying capacity in a region. The system dynamics model is established to systematically analyze the inner relationship between water demand and supply, and the BP neural network model is used for estimating and forecasting the regional water resources carrying capacity. A case study in Shan Dong indicates that the comprehensive model could play a rather good practical role and give a reference to water-policy decision maker.

Keywords Water resources · Carrying capacity · System dynamics model · Neural network

1 Introduction

Water resource is the basic foundation for the survival of mankind and the development of social and economic, however, we are facing the problem of water shortage and the environmental decline [1], therefore, we need to assess the carrying capacity of water resources in a region [2, 3]. For this purpose, we need to give full consideration to social and economic factors [4, 5], draw lessons from the scarcity of water resources in human history, and analyze the conditions for future water resources supply [6, 7]. So as to provide a basis for the formulation of water resources utilization strategy.

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2 Model Development

In order to objectively estimate the carrying capacity of water resources, the system dynamics model and BP neural network model are respectively established.

2.1 System Dynamics Model

The system dynamic method is used to study the dynamic situation of water supply and demand, and the system dynamics equation is written to make sure that the consistency of indexes in the BP neural network model.

The supply of water resources mainly include surface runoff, underground runoff, water reproduction by using science and technology and diversion of water resource. By the further analysis, we can find that surface runoff is decided by surface runoff and channel ecological water requirement, while surface runoff is also affected by the index such as precipitation, underlying surface conditions, evaporation and so on. Underground runoff is mainly decided by underground runoff, degree of groundwater exploitation and conditions of groundwater pollution and so on. Water reproduction by using science and technology mainly includes decline of sewage rate, improvement of repeat utilization, sea water desalination and rainwater collection.

The demand of water resource is mainly composed of economic water demand, ecological water demand and domestic water demand. Economic water demand is mainly including agriculture, industry and tertiary industry, which is effected by the development of economic society. Domestic water demand consists of water consumption of urban and rural residents, which is mainly effected by the change of the population and urbanization rates. Ecological water demand contains animal and plant water consumption (Figs. 1 and 2).

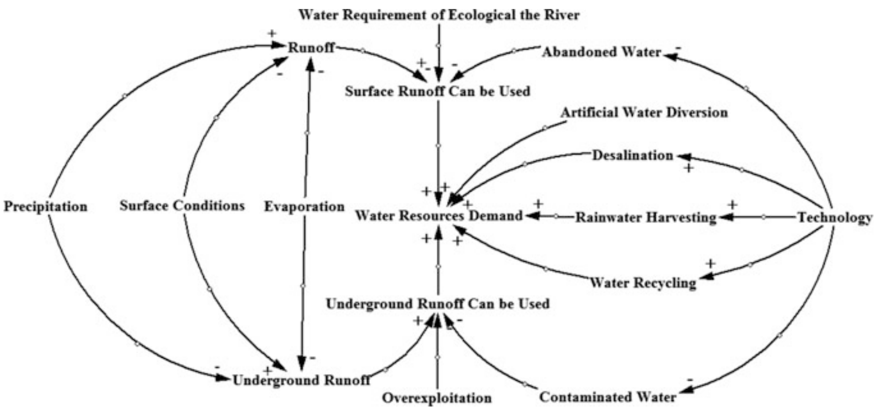

Fig. 1 The casual relationship of water resources demand system

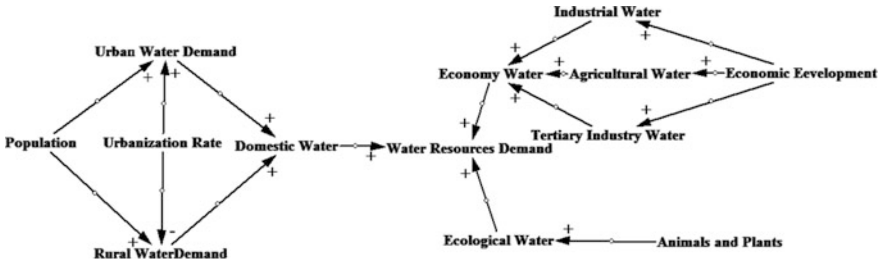

Fig. 2 The feedback mechanism of water resources demand system

2.2 BP Neural Network

The BP neural network is introduced to objectively evaluate the carrying capacity of water resources. This model does not need to determine the subjectivity of weight as other methods, and effectively avoids the subjective judgement of the evaluator. And it is simple with a good nonlinear mapping ability and well applied to the evaluation of water resources carrying capacity.

For a comprehensive evaluation of water resources carrying capacity, combined with the characteristics of regional water resources development and utilization, referring to the ***guidelines for the*** water resources evaluation, nine evaluation indexes were selected:

x_1: Irrigation rate (Irrigated area/Total planting area, %)
x_2: Water Development (Water supply/The total amount of water, %)
x_3: Supply modulus (Water supply/Area, m^3/km^2)
x_4: Supply of Per capacity (Water supply/Total people, m^3/per)
x_5: Consumption of per capacity (The total amount of water/Total people, m^3/per)
x_6: Water pollution rate (Water pollution/The total amount of water, %)
x_7: Agricultural water rate (Agricultural water/Total water, %)
x_8: Industrial water rate (Industrial water/Total water, %)
x_9: Ecological water (Ecological water/Total water, %)

The water resource carrying capacity is divided into three level, level I is the poorest, it shows that the water resources carrying capacity is close to the saturation value; level III shows that water resource supply situation is optimistic, water resources of the region contain big carrying capacity; level II is between these two levels, which shows that the region water resources development and utilization are close to saturation, the supply and demand of water resources, to a certain extent, can meet the economic and social development of local region (Table 1).

After selecting the indicators, a three layers BP neural network is established to evaluate water resources bearing capacity, the network include the input layer, hidden layer and output layer three parts. The number of input layer neurons is eight, the network output levels for I, II, III. On the selection of the number of

Table 1 Grades of the evaluation indexes of water resources carrying capacity

Grade	Index								
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
I	>50	>75	>15	<200	<400	>15	>75	>35	<1
II	50–20	75–50	15–1	200–400	400–800	5–15	65–70	20–25	1–5
III	<20	<50	<1	>400	>800	<5	<65	<20	>5

hidden layer nodes, we use the common Kolmogorov theorem to determine the implied four hidden layer neurons at present.

Put the evaluation indexes as samples, evaluation grade is the output of network, BP network Sum up the complex relationship between the corresponding internal evaluation and assessment level by constantly learning. A comprehensive evaluation of water resources carrying capacity can be carried out.

3 Case Study

Shandong Peninsula is located in 114° 19′−122° 43′E, 34° 22′−38° 23′N, The East is connected to the ocean, between the Yellow Sea and Bohai. The northwest and the north are the northwest plains caused by alluvial deposits in the Yellow River (Fig. 3).

The data is obtained from the official website of China Statistical Yearbook, and the detail data is shown in the website: http://www.stats.gov.cn/tjsj/ndsj, and the first step is to normalize the data to make sure the date is between [0, 1]. The output module is set up as follows (Table 2).

$$\widehat{x} = (x - x_{min})/(x_{max} - x_{min}) \tag{1}$$

Then, the algorithm program is written, and the training samples are used for network training until the accuracy of training is satisfied. The parameter is set by repeated adjustments: number of training is 1000, the goal error of training is 0.0001, the speed of learning is 0.05. The result of training (Table 3).

It can be seen from the grade change that the water resources carrying capacity of Shandong peninsula is decreasing, which means that the development and utilization of water resources in this area have a certain scale, the development potential is gradually declining, and the water supply can still be satisfied. But if the region’s economic and social development is still developing, there will be water shortage. The region should take certain measures to deal with this situation, otherwise water resources will become an obstacle for economic and social development.

Fig. 3 Basic appearance of Shandong Province

Table 2 Learning samples and output modes of water resources carrying capacity evaluation

Learning	Grade of carrying capacity	Output module
1–20	I	[0, 1]
21–40	II	[1, 2]
41–60	III	[2, 3]

The grade change can be vividly seen in the Fig. 4. Which also shows that the trend of grade in this region.

From the prediction results, the carrying capacity of water resources decreases with time. There is no doubt that water sources will have an increasingly significant impact on local people.

Table 3 Prediction of nine index and the evaluation result

	x1	x2	x3	x4	x5	x6	x7	x8	x9	LV.
2015	0.436	0.741	13.98	235.5	307.5	0.182	0.682	0.143	0.028	II
2016	0.446	0.802	13.22	233.1	280.8	0.192	0.67	0.152	0.028	II
2017	0.454	0.513	14.48	233.4	223.4	0.213	0.673	0.168	0.305	II
2018	0.452	1.568	13.65	231.1	380.3	0.134	0.67	0.169	0.204	II
2019	0.431	0.642	14.01	217.1	301.5	0.239	0.668	0.158	0.275	I
2020	0.462	0.768	14.11	241.1	208.2	0.126	0.662	0.168	0.264	II
2021	0.451	0.509	14.27	223	208.1	0.171	0.663	0.16	0.283	II
2022	0.461	0.71	13.8	229.4	420.3	0.163	0.659	0.159	0.319	I
2023	0.442	1.109	15.52	235.2	332.5	0.182	0.659	0.169	0.28	I
2024	0.435	0.753	13.58	231.2	361.4	0.223	0.657	0.157	0.343	I
2025	0.431	0.526	14.79	231.8	283.9	0.258	0.656	0.148	0.285	II
2026	0.445	0.519	14.76	235.2	351.3	0.238	0.652	0.183	0.153	I
2027	0.467	0.72	13.51	225.4	329.2	0.224	0.651	0.168	0.27	I
2028	0.452	1.429	14.51	231.5	375.4	0.215	0.649	0.17	0.258	I
2029	0.443	0.669	13.53	232.8	182.2	0.257	0.648	0.183	0.214	I

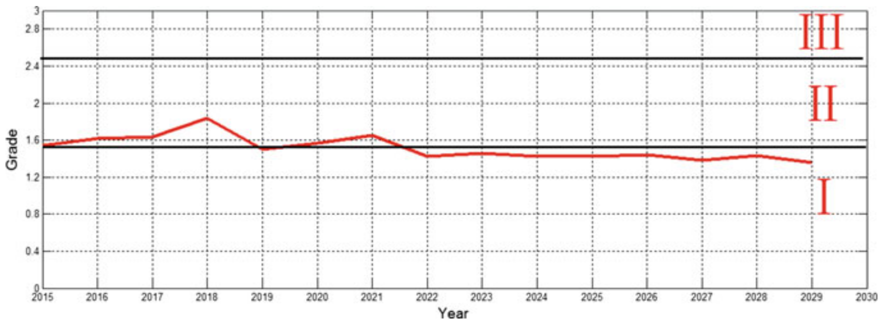

Fig. 4 Grade trend of water resources carrying capacity

4 Conclusion

Combining the system dynamics model with the BP neural network can provide a reference for evaluating and predicting the carrying capacity of water resources in a region.

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Relationship Between Global Warming and Hurricanes Wind Speed Based on Analyzing MODIS Remote Sensing Data

Xiaoli Chen

Abstract Hurricane is a severely destructive weather system, and the global warming, meanwhile, is not a good trend currently. The relationship between global surface temperature and the trend of global temperature change can be derived by using the MODIS remote sensing data. Global temperature change in the next 10 years can be obtained: keep a rise rate of 0.24 K. The main factors of affecting the intensity of hurricane are pressure, humidity and inertial stability. Firstly, the relationship between air pressure and wind speed is established by a linear regression model. Then, the relationship between the humidity and the wind speed is obtained through the analysis of the humidity field in the typhoon area. Since the temperature mainly affects the pressure, the air pressure, therefore, is used as a key factor in the analysis of global hurricane activity and global warming. A case study in the Pacific Northwest shows that global warming will probably cause a 3–5% increase in wind speed for every 1 °C rise in temperature.

Keywords Remote sensing data · Gray forecast · Linear regression · Polynomial fitting

1 Introduction

Both hurricanes and typhoons have a tremendous impact on people's livelihood, agriculture and economy. Global warming can redistribute global precipitation, melt glaciers and permafrost, increase sea levels and urban haze, which not only endanger the balance of natural ecosystems but also threaten human survival [1].

Global warming is likely to have a considerable impact on the total ocean heat up to 10% according to current scientists. Hurricane energy comes from the oceans

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and is therefore also closely linked to climate change. Therefore, studying the relationship between global hurricane activities and global warming has an very important practical significance [2].

2 Model Development

2.1 Data Preparation

First of all, we need to obtain temperature data through the following steps:

(1) Obtain the MODIS remote sensing image data of 1948–2016 in three cities from $30^\circ W \sim 30^\circ E$ https://ladsweb.nascom.nasa.gov/data/search.html. Download MODIS surface temperature data of this area with a resolution of 1 km × 1 km.
(2) We choose batch processing due to the large amount of data based on the use of MRT image cropping and projection conversion.
(3) Select the available data from the processed data, merge the monthly data, and obtain the yearly images to get the average temperature of the surface in a year in the area.
(4) The annual average temperature under different latitudes is integrated to obtain the annual average surface temperature of this latitude.

2.2 FNN Combination Forecast Temperature

In practice, the traditional single prediction method is difficult to obtain satisfactory prediction results. If the various prediction methods are combined, making full use of their useful information will produce better predictions to avoid deficiencies. In this paper, the multi-layer feedforward network is used to combine the forecasting value of the temperature-based $GM(1,1)$ isometric model with the one-step predictive value of the $NARMA(p,q)$ recursive network to obtain the FNN combined model and the FNN combined model. The result is used as the final predictive value [3, 4].

Multi-layer feedforward network combination forecasting model shown in Fig. 1. In this paper, the average annual temperature of 1000 hPa as an example, the basic method and procedure for predicting the global temperature prediction neural network combination are as follows.

In the first stage, the NARMA (p, q) recursive network model with network structure was established based on the data of 1948–1965 and GM (1, 1), And then use the two models to predict the yearly average temperature of 1983–2016 by one-step NARMA (p, q) recursive network model and GM (1, 1). In the second stage, the annual average temperature predicted values of the GM (1, 1) model and

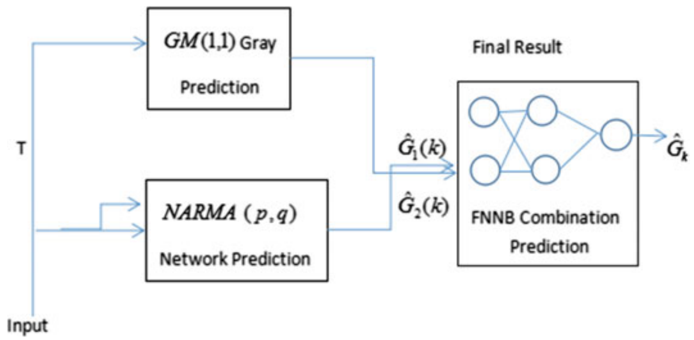


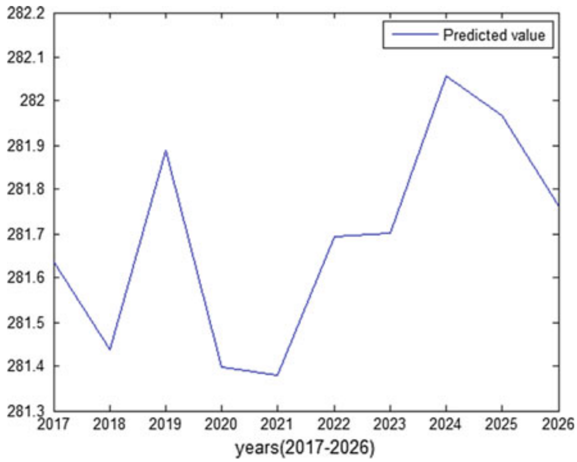
Fig. 1 Flow chart

the NARMA (p, q) recursive network model from 1983 to 1999 are taken as inputs, and the corresponding actual values are used as the output of the network to form the training samples of the network The training selects a combined forecasting network FNN whose network structure is 2-3-1. The network after training to forecast the annual average temperature in 2000–2016 due to the large amount of data. Forecast results in the Table 1 (Fig. 2).

Table 1 Forecast results from 2000–2016

Year	Actual value	$GM(1,1)$ Prediction		$NARMA(p,q)$ Prediction		FNN Prediction	
		Predict value	Relative error (%)	Predict value	Relative error (%)	Predict value	Relative error (%)
2000	281.239	282.842	0.57	281.520	0.1	281.605	0.13
2001	281.386	283.102	0.61	282.343	0.34	281.921	0.19
2002	281.697	283.134	0.51	282.739	0.37	281.838	0.05
2003	281.382	284.280	1.03	282.564	0.42	281.720	0.12
2004	281.239	282.336	0.39	283.348	0.75	281.914	0.24
2005	281.482	282.158	0.24	281.904	0.15	281.651	0.06
2006	281.429	282.695	0.45	282.048	0.22	281.710	0.1
2007	281.462	282.025	0.2	283.517	0.73	281.969	0.18
2008	281.469	283.636	0.77	282.004	0.19	281.835	0.13
2009	281.517	283.375	0.66	282.193	0.24	282.277	0.27
2010	281.314	283.677	0.84	282.974	0.59	282.861	0.55
2011	281.478	283.448	0.7	282.914	0.51	282.745	0.45
2012	281.345	284.384	1.08	282.133	0.28	282.161	0.29
2013	281.422	284.377	1.05	283.279	0.66	283.026	0.57
2014	281.619	283.393	0.63	282.858	0.44	282.886	0.45
2015	281.608	285.128	1.25	281.777	0.06	282.171	0.2
2016	281.579	282.959	0.49	281.945	0.13	282.142	0.2

Fig. 2 Prediction result of the next 10 years



From the above predictions, it can be concluded that in the 10 years, the global temperature will also rise at a rate of about 0.24 K.

3 Case Study

The available temperature reflects the degree of global warming from the analysis of the degree of global warming and the intensity of global hurricane activity. The wind speed reflects the intensity of the hurricane, and the air pressure is the most important factor that affects the wind speed and has a negative correlation with the wind speed. The relationship between temperature and wind speed is first explored, and combine the linear relationship between wind speed and barometric pressure to establish a model of the relationship between temperature and wind speed. Based on this model analysis, we can approximate find the relationship between global warming degree and global hurricane activity intensity.

The atmospheric pressure data of the *Hurricane Event Center* is selected from 1981 to 2014 in the Northwest Pacific Ocean and the corresponding sea temperature of the region for the year. Scatter plot of the sea surface temperature is shown in Fig. 1. At the same time, we select the regional sea surface temperature The maximum wind speed corresponding to the year hurricane activity, the scatter plot is shown in Fig. 3.

From the Figs. 3, 4, it is obviously that there is a certain of degree of linear relationship between "temperature T/K" and "pressure P/hPa" and "temperature T/K" and "wind speed v/m s^{-1}" Relationship rather than strict linear relationship, there are two ways to find the curve equation: linearization and curve fitting. Curve fitting is an important data processing method [5]. A quadratic curve fitting method

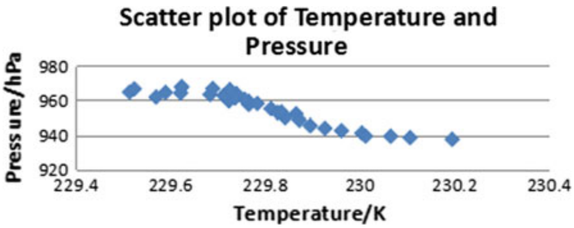


Fig. 3 Scatter plot of temperature and pressure

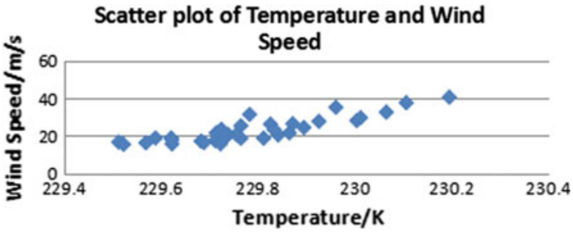


Fig. 4 Scatter plot of temperature and wind speed

based on the principle of least squares is employed to establish the quadratic fitting curve equation and verify the fitting effect of the method by actual data.

From the analysis of the intensity of the global hurricane activity we have concluded that there is a linear negative correlation between the pressure and the wind speed, so adopting a third-order fourth-order fitting curve does not correspond to reality. After the above analysis, the final fitted curve when M = 2, then the temperature as a function of pressure as:

$$y = -21.97 \times x^2 + 1.004 \times 10^4 \times x - 1.147 \times 10^6 \quad (1)$$

R = 0.8869, the fitting degree is well, and the fitting plot is shown below (Fig. 5).

It can be seen that the rising of the sea surface temperature causes the pressure drop in the corresponding area to some extent through the analysis of the relationship between the sea surface temperature in the Northwest Pacific and the

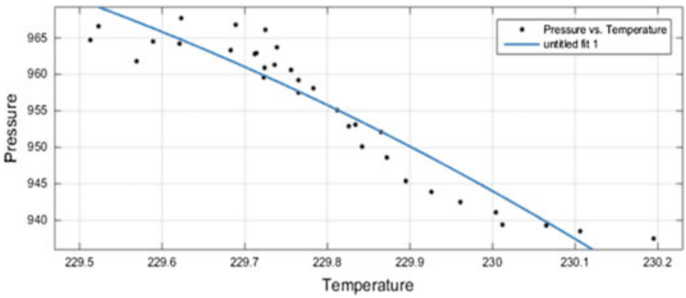


Fig. 5 Fitting plot of temperature and pressure

pressure intensity function of the center of the hurricane and the analysis of the influencing factors on the activity intensity of the hurricane. The reduced influence makes the humidity in the hurricane area increase and the inertial stability increase, which eventually leads to the increase of the wind speed and the increase of the hurricane intensity.

4 Conclusion

The global temperature is still on the rise in the coming decades based on the analysis and forecast of the trend of global warming. As the temperature rises, the pressure of hurricanes in the world will drop to a certain degree, resulting in the pressure of wind and the increase of wind speed. By further analysis of the relationship between temperature and barometric pressure function, a preliminary conclusion can be obtained: For every 1 °C increase in sea surface temperature, hurricane wind speed will increase by 3–5%.

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Systematically Design of Sponge City Road Based on the SWMM Model

Quanlin Chen

Abstract Rainstorm waterlog disasters are becoming more and more frequent in china recently, which brings great harm to the ecological environment and causes an enormous loss of life and property. The concept of "sponge city", therefore, is put forward to solve this environmental issue. The applicability of the low-impact development techniques is introduced to control the rainwater runoffs. Firstly, the concept of sponge city road system design is put forward, and the design idea and principle is also introduced. Secondly, the SWMM model is built and its principles and application steps are described. Finally, a sponge city road systematic simulation experiment is designed on the basis of the actual case to verify that the road system can improve the control of rainwater runoffs, the result shows it is worth developing technology to a certain degree.

Keywords Sponge city · SWMM · Urban road · Runoff

1 Introduction

Sponge city is a city with good elasticity in adapting to environmental changes and responding to natural disasters, its urban underground water system operates like a sponge to absorb, store, leak, and purify rainwater and release it for reuse when necessary [1]. Moreover, the construction of sponge city is based on the principle of ecological priority and under the premise of ensuring the safety of urban drainage and waterlogging, the construction of sponge city can promote the utilization of Rain Water resources and the protection of ecological environment. Urban road is an important place to produce and discharge rain water runoffs, which plays an important role in the prevention and control of urban waterlogging, and it is an important part of sponge city construction.

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2 Sponge City Road System

The idea of the sponge urban road system derived from the view of sponge city, which combines the local climate, hydrogeology and water resources of the city, and synthetically take the urban planning and related planning into consideration. The key point of the system is to select reasonable facilities and technology and design the road networks and all urban roads comprehensively so that the capacity of rain water purification, infiltration, storage and discharge is improved and the hydrological cycle of urban roads are restored.

The main design idea of the system is that: as for the newly built roads, under the condition of ensuring the traffic safety and function, the system adopt the low-impact development technology to carry on the reasonable planning and design in order to prevent waterlogging, environmental pollution and other problems; as for the traditional urban roads, on the foundation of making sure about the traffic safety and function, using the land outside the urban roads, the low-impact facilities and technologies are adopted to solve the problems of urban road drainage, pollution and soon.

There are three design principles: reducing the impervious area of the road to the maximum extent; maintaining the natural hydrological condition; using infiltration and retention to prolong the confluence time and achieve the purpose of wrong peak [2]. The main Application object of low-impact development technology facilities in sponge city roads are shown in Table 1.

Table 1 Main objects of application of low-impact development technology facilities in sponge city roads

Classification	Facility	Installation
Osmosis technology	Permeable cement concrete	Sidewalk, Non-motorized lane, Parking lots, Square and low loaded road
	Permeable asphalt concrete	Driveway
	Sinking green space	Road green belt
	Biological detention facility	Road green belt
	Osmosis pond	Square, Green area
	Seepage well	Green area
Storage technology	Wet pond	Green area, Square
	Rain Water wetland	Green area, Riparian zone
Regulation technology	Regulating pond	Green area
	Grass planting ditch	Both sides of the road
	Permeable pipe	Both sides of the road

3 SWMM Model

3.1 Application Steps of SWMM Model

The first step is to generalize the study region. There is an assumption that the rainfall is evenly distributed in the area. According to the land use situation around the study area, the sub-catchment area is divided, and the location and size of components are determined, including sub-catchment area, joint points, pipes and outlets. (It is also necessary to make sure the location and size of low impact development facilities when adopting sponge city development mode [3, 4]). At the same time, the relationship between each component are definite. Then the second step is to set the properties of objects and determine the parameters. On the one hand, we need to design a series of parameters in sub-catchment area, such as rain gauge, outlets, width, slope, impermeability and so on. Joint points refer to the nodes of drainage system the connecting each part of pipes. Outfalls and joint points are supposed to measure the inner bottom elevation and maximum depth from the surface to the inner bottom. On the other hand, as for the pipes, the maximum depth, length and Manning roughness coefficient should be determined. With regard to the facilities of low impact development, it is essential to determine parameters such as the vegetation coverage fraction, Manning N value, surface slope, porosity, soil thickness, water production capacity, water conductivity and water absorption. Finally, perform the simulation after setting and determining the property parameters of each object, then the result will be displayed [5].

3.2 A Simulation Case

As is shown in Fig. 1, a certain section of road can be designed as study project, whose width is 5 m and length is 200 m, and there is green spaces with an area of 0.029 ha all around. The land has not yet been set up with joint points and outlets. Choose the period from 3: 00 pm to 8: 00 pm on October 27, 2016 as rainfall time.

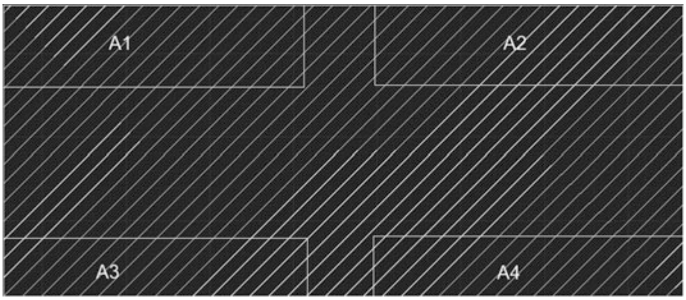


Fig. 1 Layout of the selected road

Table 2 The rainfall process on 27 October, 2016

Time	15:00	16:00	17:00	18:00	19:00	20:00	21:00
Rainfall/mm	0	47.5	87.5	75	42	21	0

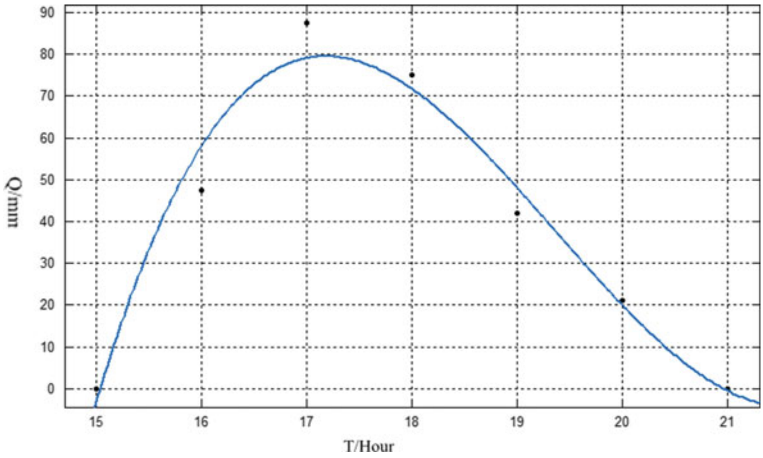


Fig. 2 Rainfall sequence process on October 26

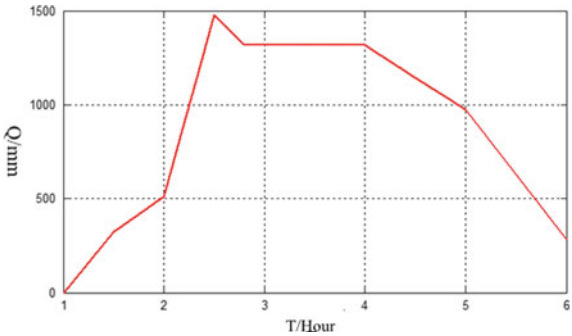
The typical heavy rain and heavy rain events in Zhengzhou from 3 to 8 p.m on October 27, 2016 are chosen as rainfall sequences. The time series of rainfall are shown in Table 2 and Fig. 2.

On the basis of data information, the average annual air temperature in Zhengzhou was 14.3 °C. In October, the evaporation capacity was calculated according to 70 mm, the average temperature was 19.7 °C and the average wind speed was 2 m/s.

The current state of the traditional road surface is simulated. The permeable area is a part of the green belt, the impervious area is the hardened road area, and the impervious area is 0.071 ha, accounting for 71% of the total area. Some unobtainable parameters are set to default values directly in accordance documents.

The output of the simulation is shown in Fig. 3.

Fig. 3 The output result



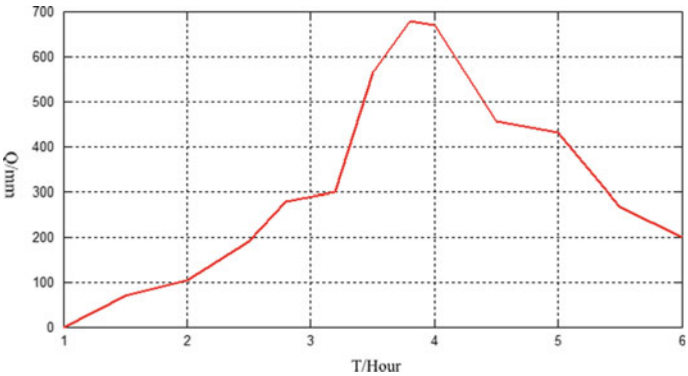


Fig. 4 Simulation result

The flow rate of rain water in the first hour was small and there was not been drained away. Next, the flow rate increased sharply, reaching the peak of 1500LPS after about two and a half hours, then the flow rate decreased steadily, and the rain was slowly discharged ultimately.

First of all, add biological retention zones like rain water gardens, ecological tree ponds with permeable pavements, sunken green spaces, grass trenches, rain water wetlands and other low-impact development facilities to the whole region with an area of 0.1 ha, of which low-impact development facilities occupies an area of 0.05 ha. Then, the road surface is paved with permeable materials, with an area of 0.035 ha. Most of the road surface is set to permeable ground in the experiment, however, it can't meet this requirement in practical application, this part of error is taken into account and set the permeability as 95%.

The parameters of each component are set up and simulated according to the actual situation in this area by referring to a great deal of literature at home and abroad and the typical parameters in SWMM user manual. The simulation result is shown in Fig. 4.

The rainfall was relatively small in the first hour, increasing slowly, and it began to increase rapidly after 3.2 h. It reached a peak of about 680LPS around 3.8 h, the flow started to sharply decrease in two stages after the peak flow.

4 Conclusion

As what has been discussed above, a conclusion can be derived that the peak flow rate can be significantly reduced after the adoption of sponge city road system, it is about half of that before experiment during this experiment, and the time when the peak appears, moreover, can be delayed by about 45 min. It is shown that the design of spongy urban roads can effectively improve the control of rain water runoff, which is beneficial to the protection of the ecosystem of urban roads.

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Research on the Best Booking Strategy for Air Tickets Based on Big Data Analysis

Lei Yang and Xiaoquan Wang

Abstract Airlines apply revenue management methods to formulate price sales strategies that allow ticket prices to change dynamically. Research on the best booking strategy for air tickets can help travelers to choose a reasonable booking time and reduce travel expenses. This article, from the perspective of passengers, collects more than 140,000 ticket price records from the Internet and applies a variety of big data visualization technology to study the fare variation rules and the best booking strategy for a specific airline on the premise of travel time. The study found that when the travel date is given, the cheaper tickets can be purchased about 25 days in advance; when the booking date is given, the ticket price changes show periodic characteristics, and the ticket price peak usually appears on Friday.

Keywords Big data · Ticket booking · Visualization technology

1 Introduction

The rapid development of China's high-speed rail business has brought pressure on the air passenger transportation. For long-distance travel (1500–2000 km), however, taking a plane is still the best choice for most people. In the current fast-paced environment where time is money, the advantage of aviation tools has become increasingly apparent. According to the data released by the National Bureau of Statistics of China, in 2016, there were 490 million people traveling by plane, with an average of 1,717 km per flight, which is equivalent to the distance from Beijing to Chengdu [1]. Traveling by plane has become commonplace.

The widespread use of the Internet promotes the aeronautical e-commerce booming. In the online ticket sales market, the OTA (Online Travel Agency) giant has built strong market position. In 2015, Ctrip.com's market share of online ticket

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sales reached 32.4%, while Qunar reached 34.1%. At the same time, major airlines have also laid out their online direct sales channels to reduce agency fees (such as Air China and China Southern Airlines). Online ticket sales make ticket prices more transparent and ticket booking easier. Take Ctrip.com, which has a relatively high market share, as an example. Input the departure city and arrival city, you can check the fare of the ticket from the current date to the next few months. However, historical prices cannot be found on these network platforms, so it is not possible to know the historical price trends of flights on a particular date.

No doubt, any passenger wants to buy a cheap airline ticket for departure day. Insider suggested that if the itinerary has already been made, one month or so in advance booking, you can buy the cheapest ticket. In other words, the sooner, the cheaper. Is this really true? Ticket prices are affected by many factors, such as the number of remaining seats, fuel prices, etc. Each airline dynamically adjusts ticket prices in accordance with private and complex pricing systems and hidden variables (e.g., remaining seats) in order to maximize revenue, thus making the change of air ticket price has tendency, volatility and randomness.

From a macro perspective, the frequency of passengers traveling by air is not high, and passengers are unlikely to observe for a long time when they purchase air tickets online. Throughout the major air ticket sales platforms, historical prices do not show, pre-sale prices are often subject to change. Due to various uncertainties and information asymmetry, passengers can only see a rough price situation and then make a choice by the seat of their pants, it is difficult to buy at the lowest point of the ticket price. How to buy a cheap ticket with a fixed departure date? Is it cheaper to book sooner? Is there a trend in the change in ticket pre-sale prices? As the departure date approaches, is the ticket price rising or falling? It is of great significance that booking strategy research can help travelers choose the best purchase time and save travel expenses.

2 Related Research

Currently, the domestic OTA (Online Travel Agency) is represented by Ctrip. Its online platform provides ticket price inquiries, air ticket bookings and other services, but does not provide forecast information for future ticket prices. The major airlines' direct-sale platforms are similar to those of OTA, but discounted air tickets such as member air tickets and mileage tickets are introduced. Niche platforms such as Aiflygo can inquire about the historical price before the plane takes off. When it comes to foreign ticket price forecasting platforms, it is represented by Farecast and Yapta. Farecast has 200 billion flight data records. Its forecasting system uses 12,000 price records in 41 days as a sample, which can save an average of 50 US dollars per ticket. However, Farecast was acquired by Microsoft in 2008, and the provider of its price data information, ITA Software, was acquired by Google, making the forecasting function officially closed in 2014.

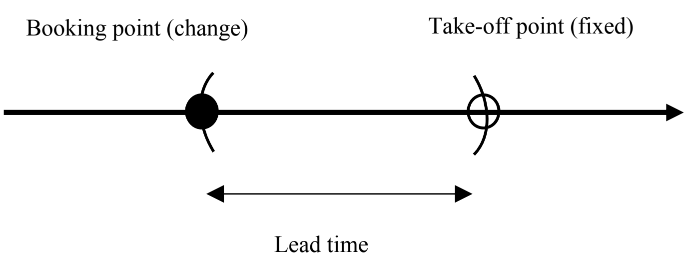
The domestic and international studies on air ticket prices are mostly from the perspective of airlines, i.e. sellers, and they focus on pricing strategies. However, there are not many studies on fare prediction from the perspective of passengers. Etzioni O, Tuchinda R et al. combined Ripper, Q-learning, and time-series algorithms to propose a multi-policy data mining algorithm, Hamlet, to construct a predictive model [2]. Groves et al. used system feature extraction techniques based on machine learning and combined basic user-provided domain knowledge to improve the performance of machine algorithms [3]. Domestic research on air tickets focuses on issues such as pricing strategies and sales strategies, such as literature [4–6]. There are few studies on forecasting ticket prices, and many use time-sequence analysis methods. For example, Gu Zhaojun et al. used the time series algorithm to predict the change trend of ticket prices by taking the time before the flight as a variable [7]. Hua Yiqun and Cao Jian introduced the fuzzy time series into ticket price forecasting [8]. Wang Xing et al. proposed a multi-phase sequence change estimation framework for ticket price sequence characteristics [9]. This article defines the research problem as ticket price under the scene of fixed take-off point and changing booking points, and analyzes it through various visualization technologies, and tools.

3 Problem Description

First define the relevant concepts in the research question:

Take-off point (target point): The date the user travels by air.
Booking Point (Observation Point): The date the user ordered the ticket online.

Lead time: The number of days between the user's online booking date and the departure date (excluding the day of departure). The maximum lead time in this study is 44 days.



Taking the departure day 2018-4-14 as an example, Fig. 1 depicts the change in ticket prices within 44 days of the departure date. It can be seen that with the approach of the take-off day, the ticket prices are constantly changing. How to

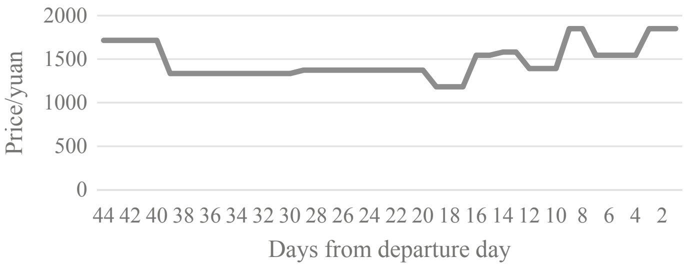
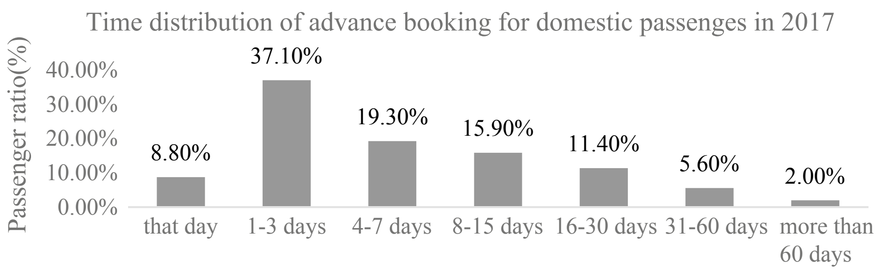


Fig. 1 Change in price 44 days before departure at 2018-4-14

choose the booking point to buy a more favorable ticket will be the focus of this article.

In the study of this paper, the take-off point (target point) is fixed, that is, the date when the user travels by plane is determined, and the booking point (observation point) is uncertain, that is, the user can book a ticket at any time before the take-off day. To improve operability, the maximum lead time for booking points is 44 days, because according to statistics, more than 90% of domestic passengers book tickets within 30 days in advance, and more than 45% of passengers book flights within 3 days of the lead time [10]. Therefore, it is universal and research significance to use 44 days as the boundary for analysis. At the same time, taking into account the high cost of ticket refunds and various affiliated terms for discounted tickets, the user only has one ticket booking opportunity, which is consistent with the reality.



Data Sources China Airlines Index

4 Empirical Research

4.1 Data Collection and Processing

This study selects the route from Beijing to Guangzhou. There are two reasons for choosing this route: One is that the route has a long distance and the price change is obvious. Second, the route has a total of 62 flights (Some flights may be temporarily cancelled, so the value is slightly floating), and more data can be collected.

Data Collection Method: Data was collected daily from Ctrip.com using reptile software Octopus. First create a custom task, and then observe the characteristics of changes in the destination URL, find the law of change, enter the target URL list in Octopus software. Since Ctrip's web page uses Ajax technology, that is, it does not need to reload the entire web page, only part of the content of the web page is updated. Therefore, it is necessary to set Ajax lazy loading and select an appropriate timeout period. In this article, the timeout period is set to 2 s. In addition, due to the large number of flight records in the web page, the scroll bar needs to be dragged down to display the flight information completely. Therefore, the "rolling page" needs to be set during collection, which is mainly to set the scrolling times and duration after the page is loaded. Next select the information to be collected, and delete unnecessary fields (such as takeoff airport, arrival airport, punctuality rate, etc.), start acquisition, and export the data after the collection is completed. Some of the collected results are shown in Fig. 2.

Data collection scope: From April 14, 2018 to June 5, 2018, record their price information from 1 day before takeoff to 44 days before takeoff respectively. For example, when April 14th, 2018, is the take-off point, the price will be recorded once a day from March 1, 2018 to April 13, 2018 as observation points (Table 1).

Data processing methods: With the approach of the take-off point, especially on the day before departure, a certain flight ticket may be sold out. At this time, we choose to ignore this tuple.

Field1	Field2	Field3	Time1	Time2	Field14	Field17
Southern Airlines	CZ3166	Planned model:32L(middle)	6:30	9:50	¥740	39% off economy class
Eastern Airlines	MU3576	Planned model:32L(middle)	6:30	9:50	¥960	50% off economy class
Eastern Airlines	MU5181	Airbus A330-300(large)	7:15	10:40	¥940	49% off economy class
Southern Airlines	CZ9224	Airbus A330-300(large)	7:15	10:40	¥1,220	64% off economy class
Southern Airlines	CZ3116	Airbus A330-200(large)	7:30	10:50	¥740	39% off economy class
Eastern Airlines	MU3019	Airbus A330-200(large)	7:30	10:50	¥960	50% off economy class
Air China	CA1351	Boeing777-300ER(large)	7:35	10:55	¥1,030	54% off economy class
Shenzhen Airlines	ZH1351	Boeing777-300ER(large)	7:35	10:55	¥1,910	100% off economy class
Hainan Airlines	HU7805	Boeing787-9(large)	8:15	11:25	¥1,440	75% off economy class
Southern Airlines	CZ3108	Planned model:33W(large)	8:30	11:50	¥740	39% off economy class

Fig. 2 Data collection results (partial)

Table 1 Data item details

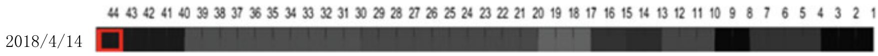
Item	Detail	Sum
Take-off point (target point)	2018.4.14–2018.6.5	53 days
Booking point (observation point)	44 days before departure	44 days
Daily records	62 daily flight records	62
Total	A total of 144,584 records (53 * 44 * 62 = 144,584)	

4.2 Data Analysis

Use MATLAB and other software tools for visual analysis of data. First, taking Air China CA1301 as the research object, we explored the change rule of airline ticket prices when the booking points changed. Then, we took Air China CA1301 and China Southern Airlines CZ3102 as targets, changing the booking points (unchanged take-off points) and the take-off points (unchanged booking points) respectively, to study the cyclical pattern of ticket price changes. Finally, the integrity of all flights is observed by the box plot.

4.2.1 Ticket Price Changes as Booking Points Change

In Fig. 3, each row represents changes in the price of a ticket at a specific point of departure. Each column represents the time interval between the point of booking and the point of departure and is getting closer and closer to the point of departure from left to right. The color of the gray bar indicates the price level. The darker the color, the higher the price.



Take the first line of Fig. 3 as an example, the first line indicates that the take-off point is April 14, 2018, the first gray bar marked with a red box on the left indicates the price of the ticket that was observed 44 days before the take-off point.

By analyzing Fig. 3, we can find the following rules:

(a) Starting around the 9th day of departure, which is 9 days before the plane took off, ticket prices tend to increase. Starting from the column with the number 9 in the figure, the color of the block is deepened, even reaching the deepest.

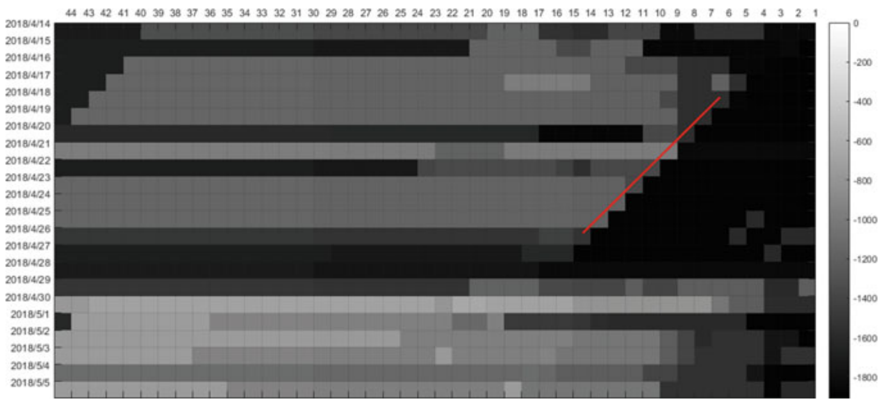


Fig. 3 Changes in ticket price of Air China CA1301 when ticketing points change

(b) The price of the ticket is relatively low around 25 days before the plane took off. Corresponding to Fig. 3, the area is lighter in color, indicating that there is a relatively high possibility of buying a relatively cheap ticket near this date.
(c) Price adjustments happen on the same day.

An interesting line with an inclination of about 45° can be found in the figure, which shows that the adjustment of the prices occurred on the same day. This is not hard to understand. From the perspective of the row, the date increases day by day, so the advance N day of the previous row and the advance N + 1 day of the subsequent row correspond to the same date. In addition, holidays or weekends tend to increase prices, such as 2018/4/14, 2018/4/15, 2018/4/21, 2018/4/22, 2018/4/28, 2018/4/29. The color is relatively deeper.

4.2.2 Periodic Analysis of Ticket Price Trends

Is the change in ticket price cyclic? What is the price change between last Friday and next Friday? Now take the week as a cycle to observe the cyclical changes in ticket price by drawing calendar thermograms.

(a) Periodic analysis of ticket price as booking points change

Still taking Air China CA1301 as the research object, given the take-off point, the ticket price 44 days before the departure point will be plotted as a calendar thermograms. As shown in Fig. 4a, the figure shows the price change of Air China CA1301 flight on April 14, 2018, 44 days before its takeoff. The ticket booking points are from 2018-3-01 to 2018-4-13. That is, the gray bar marked with the first red box in the figure indicates that the price of Air China CA1301 is 1,716 yuan that was ordered on March 1, 2018 and took off on April 14, 2018. By analogy, the second gray bar indicates the price of Air China CA1301 is 1,716 yuan that was ordered on March 2, 2018 and took off on April 14, 2018. Similarly, Fig. 4b shows the price change of Air China CA1301 flight on April 15, 2018, 44 days before its takeoff. The ticket booking point are from 2018-3-02 to 2018-4-14.

From the calendar thermogram of Fig. 4, it can be found that when the booking point changes, there is no significant periodicity in the ticket price. The darker color in the lower right corner of the calendar thermogram shows that as the departure date of the plane approaches, the price of the ticket is relatively high.

(b) Periodic analysis of ticket price as take-off points change

The object of study is Air China CA1301, given the booking point, to observe if there is a cyclical change in the price of the ticket when the take-off date changes. Figure 5a shows the ticket price for Air China CA1301 from 2018-5-11 to 2018-6-13 that was ordered on April 29, 2018. That is, the gray bar marked with the first red box in the figure indicates that the price of Air China CA1301 is 1,716 yuan that was ordered on April 29, 2018 and took off on May 11, 2018. By analogy, the second gray bar indicates the price of Air China CA1301 is 1,030 yuan that was

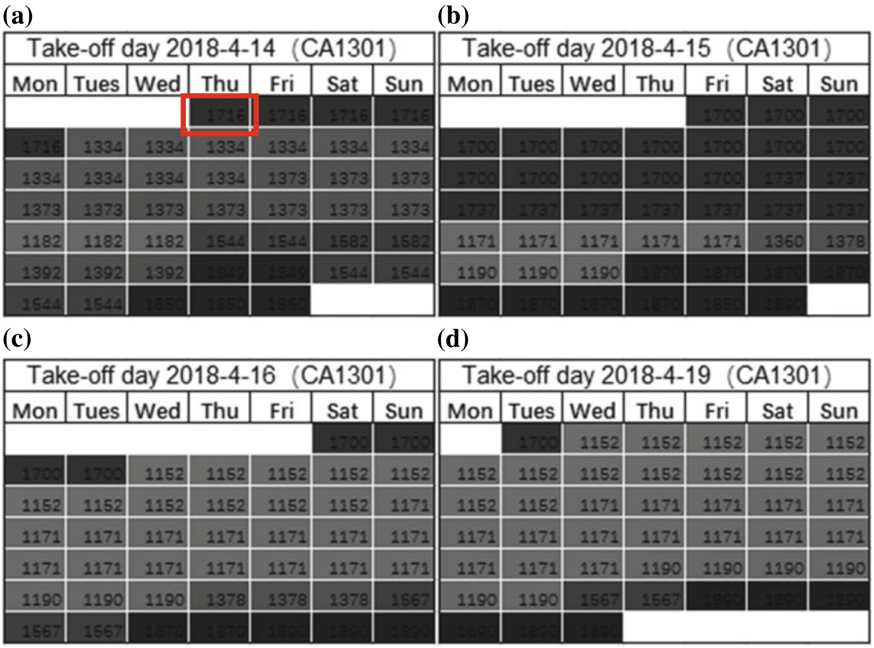


Fig. 4 Calendar thermogram of Air China CA1301 ticket price when the booking points change

ordered on April 29, 2018 and took off on May 12, 2018. Similarly, Fig. 5b shows the price of the airline ticket for Air China CA1301 on April 30, 2018. The take-off points are from 2018-5-11 to 2018-6-14.

In Fig. 5, significant periodic features can be seen. The gray bar color corresponding to the column on Friday is significantly darker than other dates, and the top-down color tends to be lighter, indicating that the price of Air China CA1301 taking off on Friday is higher, at the same time, with the increase in the interval between the booking point and the take-off point, the ticket price has slightly decreased. The gray bar color corresponding to the Sunday column shows a deepening trend, indicating that as the interval between the booking point and the departure point increases, the ticket price will gradually increase. In addition, similar colors from Monday to Thursday of the same week indicate that the price gap is not large.

Next, take China Southern Airlines CZ3102 as the research object, draw a calendar thermogram and observe whether there are similar periodic laws. As shown in Fig. 6, similar to the previous results, the gray bar corresponding to the Friday column has a darker color, and at the same time, the color of the gray bar is similar between Monday to Thursday in one week, which means that the price is quite the same. The gray bar corresponding to the Saturday column is lighter and the price is relatively low.

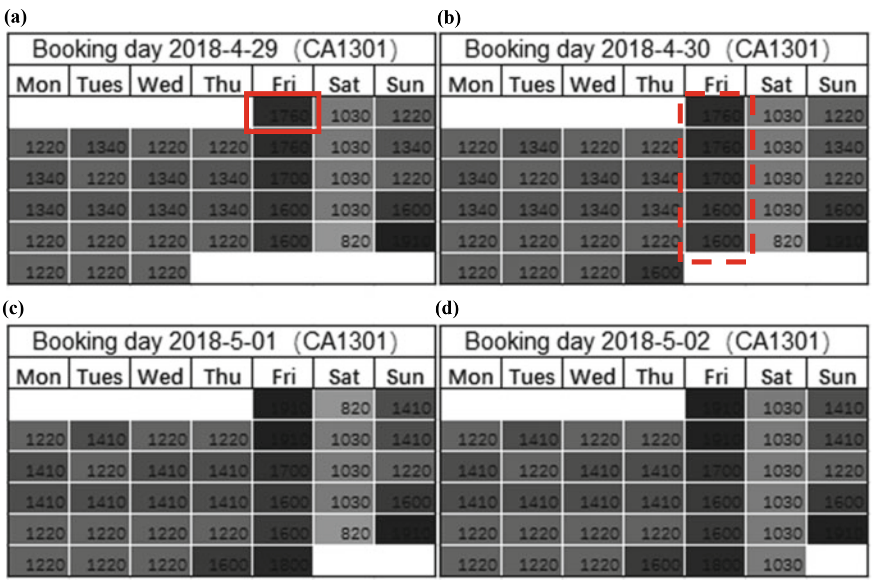


Fig. 5 Calendar thermogram of Air China CA1301 ticket price when the take-off points change

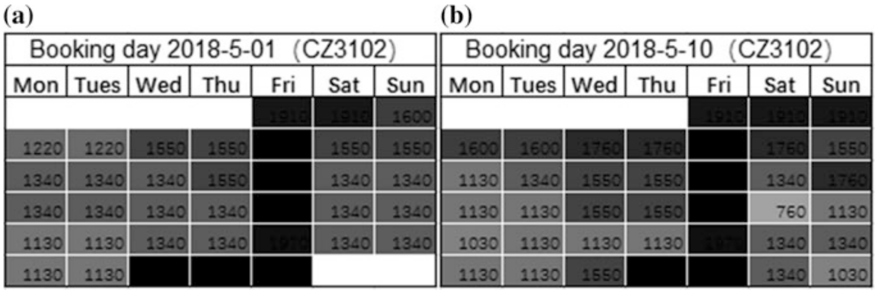


Fig. 6 Calendar thermogram of China Southern CZ3102 ticket price when the take-off points change

4.2.3 Study on the Overall Characteristics of Ticket Price

The price data of all flights observed every day is plotted as a box plot, as shown in Fig. 7.

In the box plot of Fig. 7, the above figure shows that when the take-off point is 2018-5-11, the boxes from left to right indicate the price of the ticket when the booking points are from 2018-3-28 to 2018-4-14. The figure below shows that when the take-off point is 2018-5-13, the boxes from left to right indicate the price of the ticket when the booking point is 2018-3-30 to 2018-4-15. The box reflects the

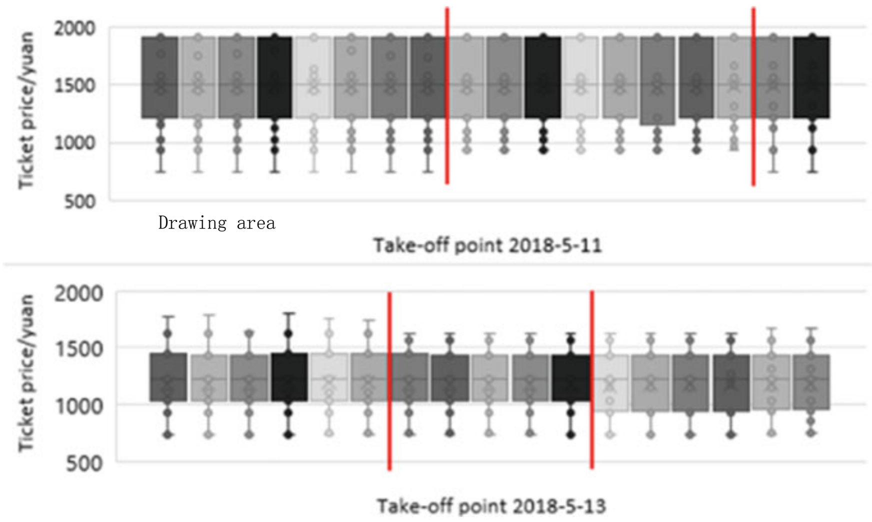


Fig. 7 Box plot of ticket price

maximum, minimum, median, and upper and lower quartile values of the ticket price during the day. The discrete points in the box represent the ticket price values for all flights during the day, and some of the data are coincident.

It can be seen from Fig. 7 that the ticket price has a typical stage characteristic. During the period, the ticket price is relatively stable and has a small fluctuation. This shows that the change in ticket price is not gradual, but it remains stable within a certain period of time, and after a certain point of time changes, it continues to maintain stability in the new stage. The length of the stage is as short as 5 days or so and it is as long as 10 days.

5 Conclusion

This article sums up the research issues as the take-off point is determined, the booking points are changed, so as to explore the changes in the ticket price as the ticketing points approach the take-off point. And apply a variety of data visualization methods, tools for the corresponding analysis.

For the study of this paper, we propose the following strategies for booking tickets:

First, there is a higher likelihood of getting cheaper tickets around 25 days before the plane takes off.

The study found that ticket prices do not simply show an upward trend, so it is not cheaper to buy earlier. And there are more likely to buy cheaper tickets during the 25 days before the plane takes off. About 9 days before the plane took off, the ticket price began to increase significantly. At this time, the possibility of a drop in ticket prices is extremely low. If passengers are at this node, they should purchase it as soon as possible.

Second, avoid traveling on Friday.

The price of flights departing on Fridays is usually higher than other dates, so when selecting a trip point, you can try to avoid Friday and stagger the price peak.

Third, travelers do not have to check ticket prices frequently.

Ticket prices have a phased nature, not always changing, but often stabilizing at a certain stage. Therefore, travelers do not have to compete for many seconds, nor do they need to frequently observe price changes. Especially when it is far from the departure day, the ticket has a longer duration in the corresponding phase, and the frequency of checking the price can be appropriately reduced. And about 25 days before the plane takes off, it should be focused.

Ticket prices are affected by many factors, and the pricing strategies of major airlines are also different. At the same time, since the major ticket sales platforms do not display historical data externally, data collection is also a lasting and trivial task. This article aims to provide some ideas and methods for studying ticket prices and booking strategy. More precise research remains to be further explored.

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The Influence of Boundary-Spanning Search on Organizational Ambidexterity Capacity: An Empirical Research in the Chinese Context

Dingding Xiao, Fei Han and Baolong Wang

Abstract Open innovation system has been identified as a key competency for sustained success in the competitive market. More and more firms prefer external heterogeneity resources to remedy resource endowment and capability structural defects. The study focuses on the questions of whether or not the boundary-spanning search (BSS) affects the organizational ambidexterity capacity (OAC) and how it is influenced. Based on the sampling investigation of 338 firms in China, we use structural equation model to explore influential mechanisms of BSS behaviors on the OAC. The main results are shown as following: First, the BSS behavior of firms can be divided into two dimensions–organizational and technological boundary spanning–which can be further divided into (1) technology-driven and market-driven BSS, (2) generic technology-oriented and product technology-oriented BSS. Secondly, the different dimensions have variant influences on OAC. Technology-driven and generic technology-oriented BSS have positive influences on exploratory capabilities, while market-driven, generic technology-oriented and product technology-oriented BSS have positive influence on exploitative capabilities. Thirdly, the research breaks through the theoretical assumption of the OAC and finds that the OAC is not absolutely exclusive; the exploratory capabilities have significant positive impact on exploitative capabilities. The conclusions expand the perspective and dimension of organization search theory, which enrich the empirical studies about organizational ambidexterity in the context of emerging economy.

Keywords Exploitative capability · Exploratory capability · Organizational boundary spanning · Technological boundary spanning

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1 Introduction

In the dynamic environment, firms need to contain the ambidexterity capacity of exploiting the existing knowledge and exploring the potential knowledge to adapt to the non-continuous changes in technology and market environment [1]. Since March's proposal of two basic activities of "exploration" and "exploitation", the scholars have extended them to organizational learning [2], strategic management [3], innovation management [4] and other research fields. They reach a general consensus that the building of ambidexterity capacity, which consists of explorative and exploitative capabilities within an organization, does help overcome core rigidity and competence traps thus enhancing the sensitivity to environmental change [5]. However, due to the differences in organizational structures, thinking modes and cultures required by the two activities, they have the general, consecutive and nested tension relation [6], resulting in facing a choice between the two trade-offs and paradoxes. "How to coordinate the tension between the exploration and exploitation and effectively enhance the organizational ambidexterity" becomes the focus of scholars and business managers.

To break this dilemma, scholars found a solution within the organization and strived to achieve an internal balance of ambidexterity capacity [7]. Through organizational, context and leadership ambidexterity modes, we help firms effectively manage both current needs as well as assist them in adapting to environmental changes. Jansen [5] claims that the organization can use three ways to coordinate these tensions, namely accepting, decomposing and resolving. This solution is based on the dual mechanism of exploration and exploitation and its breakthrough lies in the use of external resources to coordinate the organizations' internal contradictions [8], especially in organizations with limited resources and capabilities. The use of external technology resources to enhance the technological capacity also becomes the inevitable choice for the firm to integrate itself into an open innovation system [9]. And, the boundary-spanning search (BSS) is the logical starting point for its identification, acquisition and integration of external innovation resources. However, the existing studies of BSS are only at the theoretical level and fail to answer the questions of "whether BSS can improve the technological capacity", or "whether the different dimensions of BSS have diverse effects on exploratory and exploitative capabilities." This topic especially lacks theoretical and empirical tests in the emerging economy context.

Based on these gaps, we examine 338 sample firms in China to explore influential mechanisms of BSS behaviors on the OAC and the relationship between the exploratory and exploitative capabilities. This study also contributes to existing literature in the following aspects: First, it defines the dimensions and contents of firms' BSS behavior in the Chinese context. Second, it theoretically demonstrates the logical relationship between BSS and OAC and empirically tests the influence of different dimensions of the BSS on the ambidexterity capacity. Lastly, it breaks through the theoretical assumption of ambidexterity capacity relationships given by March [1], and empirically tests the relationship between the exploratory and exploitative capabilities.

2 Theoretical Perspective

Under the background of open innovation, organizations face affluent external innovation resources. Consequently boundary-spanning search becomes the focus of scholars' attention at home and abroad [10]. They analyze BSS from the perspectives of single attributes of time, technology and geography in terms of boundary-spanning search [11]. Laursen and Salter [10] propose that the fundamental objective of BSS is to seek heterogeneous knowledge or technology, and measures BSS behavior by the degree of depth and breadth. Sidhu [11] looks into BSS from three dimensions of supply, demand and market, corresponding to knowledge involving suppliers, customers and competitors. Other scholars divide the search activity into a technological knowledge and a professional knowledge search according to the characteristics of the knowledge [12].

Though the current studies cover search boundaries of internal and external, home and cross-border, the depth and breadth, we still find it a little confusing on boundary spanning typology [13]. There is still a gap with regard to clear measurement of BSS behavior, whether it's by use of objective index system or subjective one. It seems unlikely that we can achieve a universal standard of dimension classification and measurement, but it is worthwhile reconciling the different definitions within an integrated framework. Such an effort not only reduces the ambiguity to interpret the BSS behavior, but also provides guidance for future research, especially on the relationship between BSS and ambidexterity capacity. Moreover, existing studies mostly are being concentrated on the firms from developed countries, and less in the context of emerging economy or a region in transition, there is obvious distinction in the characteristic of BSS behavior and ambidexterity capacity of organizations due to their lower technology level and innovation capability.

Since firms, universities and other research institutions have essential differences in the organizational attributes and social functions, there are obvious variations in terms of the targets, ways and contents of BSS. On one hand, firms can search different target objects or knowledge sources. They collaborate with other institutions to conquer what they cannot handle alone; they build good relationship with suppliers and consumers to get feedback timely; they also keep an eye on their competitors to track latest market trends. On the other hand, firms demands different types of knowledge. They need to reserve the pre-competitive technology within certain industry to develop dynamic capability; they desire to obtain generic technology of inner- and inter-industry for improving the innovation capacity; they are also eager to be aware of knowledge about product design and process optimization to sustain competitive advantage. In short, firms search various external organizations for different kinds of technology, which gives us an insight that we can try to clarify BBS behavior from two perspectives: knowledge source (i.e. which kind of target object) and knowledge attributes (i.e. which kind of technology). So, we call them organizational boundary and technological boundary spanning respectively.

3 Research Hypotheses

3.1 Subdivision of Boundary-Spanning Search Dimensions

From the perspective of organizational boundary spanning, firms can conduct search activity through diversified, multi-level knowledge sources [14]. The knowledge spillovers, search, and creation in an emerging market are a dynamic and reciprocal process [15]. In the context of transition, firms face more severe situation than before due to the rising labor costs and economic slowdown. Thus, firms are turning to external sources to introduce product and process innovations. Some leading firms generally choose university-industry collaboration, in which universities and research institutes become the main source of external knowledge. These firms aspire to enhance technology capabilities substantially, which we classify into a technology-driven BSS. Meanwhile, other firms with less technology capabilities often keep in touch with their major suppliers and clients to build good "guanxi" so that they can timely get the suggestion and feedback about production design and process optimization. They also have a frequent visit to industry association and other intermediary, through which they adjust innovation strategy dynamically. We call this type market-driven BSS.

From the perspective of technological boundary spanning, not like the case in developed countries, lots of Chinese firms lack enough capability of industrial technology to fully absorb pre-competitive technology. They are being satisfied with acquiring generic technology, even product and process technology. Thus, we propose only two kinds of BSS behavior in terms of technological boundary spanning search which aims at pursuing generic technology and product technology respectively in the Chinese context. Mostly, Universities and public laboratories focus on basic research, applied research and technology infrastructure, to provide the basis of generic technological support for business firms. Firms that focus on product design and development, which devote themselves to transforming and integrating generic technology into proprietary technology, contribute to the back-end technology [16]. Therefore, the following is hypothesized:

H1:BSS behavior can be denoted by two dimensions named organizational and technological boundary spanning. It can be further divided into technology-driven and market-driven BSS, generic technology-oriented and product technology-oriented BSS respectively in the Chinese context.

3.2 BBS and OAC

3.2.1 The Relationship Between Organization Boundary-Based BSS and OAC

Technology-driven BBS mainly refers to the search for science and technology sources across organizational boundaries. The search objects include universities, research institutes, commercial laboratories and other research subjects [10]. Due to the diversification of knowledge acquisition in the open innovation system, acquiring heterogeneous knowledge via external search is the critical choices for firms. By researching the openness of the firms, Wu [17] finds an inverted U-shaped relationship among the cooperative openness, external resource technology, and complementary assets acquisition, which means there is a certain "critical point" in the use of external resources from partner. Meanwhile, Chen [9] find that enhancing the external search breadth and depth can significantly promote organizational STI (science, technology, innovation) and DUI (doing, using, and interacting) innovation performance. And the search orientation has different effects on the knowledge source selection, and capability structure optimization.

Thus, technology-driven BSS becomes the critical path of firms' access to the core technological advantages, which in turn have a defining impact on an organization's technological capacity and structural integrity. Christine suggest that in certain search and access of key technologies, the cooperation with universities will reduce transaction costs and technological barriers. Schoenmakers and Duysters [18] find that relative to corporate patents, patents of public R&D institutions have a higher reference frequency, and more easily spawn a major innovation, especially those across professional fields. Stettner and Lavie [19] reveal that exploring via externally oriented modes such as acquisitions or alliances, while exploiting via internal organization, enhances these firms' performance. These analysis shows that universities and research institutes provide diverse knowledge sources for firms' innovative activities, especially in the presence of Chinese firms' weak technological capability. Technology-driven BSS will help meet the different demand levels and positively impact the firms' exploration and exploitation capability. Therefore, the following is hypothesized:

H2-1: Technology-driven BSS will be positively related to firms' exploratory capabilities.
H2-2: Technology-driven BSS will be positively related to firms' exploitative capabilities.

Market-driven BSS is the search behavior of market information across organizational boundaries, and its main targets are market information exchange subjects including suppliers, competitors, trade associations, professional meetings, etc. [10]. Timely feedback from the market and user information is the necessary step to create new knowledge and products. The market-driven BSS helps firms to systematically process the dispersed market information and acquire more valuable ideas, and also expands potential partnerships, thereby increasing the creation of market opportunities for new products and technology. Wei and Wu [20] propose that local search and nonlocal search are balanced by jointly considering the breadth and depth of geographic search, and that the optimal balance depends on industry dynamism. Kim and Inkpen [21] find that diversification of alliance members attributes introduce cutting-edge technological information for the alliance. The participation of chambers of commerce and suppliers provide complementary market information for the firms' innovative activities and thereby the firms can have a better understanding of customer needs and competitors' actions. They can be encouraged to continuously explore new technologies and develop new products.

Regarding the impact, such search behavior will face the subjects of more diversification attributes, thus becoming the important R&D source for new technologies and products [22]. He and Wong [23] hold the view that the organizational change and technological innovation depend on not only the capability to integrate internal and external technological information, but also the capability to reach customers, products and other market information. Sidhu [11] maintain that under fixed technological capacity, when the external environment is changed, firms' search practice and innovation output will also change, and timely tracking information of market dynamics is the typical manifestation of firms' innovation process. Thus, market-driven BSS enriches the way to access critical external information, achieves the effective connection of dynamic market information and firms' development strategies, and plays a significant role in promoting firms' technology and service innovation. Therefore, the following is hypothesized:

H2-3: Market-driven BSS will be positively related to firms' exploratory capabilities.
H2-4: Market-driven BSS will be positively related to firms' exploitative capabilities.

3.2.2 The Relationship Between Technology Boundary-Based BSS and OAC

According to Tassey [24], technology can be divided into basic technology, generic technology and product technology based on the perspective of the process, and there is a huge difference among the three types of technology concerning the supply subject, application field and properties. Based on the analysis of the Chinese firms' technological capability structure, this paper proposes that most firms are searching for generic and product technology. The developed countries pursue the inter-industrial generic technology and product generic technology in high-tech fields, thus taking the mission-oriented pre-competitive R&D strategy. The developing countries want to upgrade the inner-industrial generic technology in traditional manufacturing, and they pursue the diffusion-oriented generic technology strategies. For firms, generic technology change means changing technological paradigms. Firms judge customer needs and technology trends, improve the existing technology gradually. But in the case of varieties of technology paradigm, reform of generic technology will become the dominant way thus determining the development path of the leading industrial technology.

Meanwhile, the second innovation of key generic technology is an important opportunity to achieve technological transition in underdeveloped countries. Take Taiwan's Industrial Technology Research Institute for example. Their systematic study of generic technology provides the technological foundation for Taiwan's semiconductor industry, which not only contributes to the global technological leadership of Taiwan but its technology spillover has also led to the rapid development of the Pearl River Delta electronics manufacturing. In short, the generic technology gives birth to the new energy, new materials and other strategic emerging industries. It improves the firms' technological capabilities of exploring new technologies and exploiting old knowledge, and creates the basic conditions for the enhancement of overall innovative capabilities of the firms and industries. Therefore, the following is hypothesized:

H3-1: Generic technology-oriented BSS will be positively related to firms' exploratory capabilities.
H3-2: Generic technology-oriented BSS will be positively related to firms' exploitative capabilities.

Product technology is the sum of specialized technology, operating experience and technology in the production of a certain product, which has strong private property, and its application is limited to a certain type of product, and it becomes the core competitiveness of a firm in a period of time. Nerkar [25] proposes that a great original innovation depends on the effective integration of basic technology and emerging technology, while the in-depth exploitation of existing technology will bring gradual production process improvement. The breakthrough innovation requires more basic knowledge, and the public research institution is an important way to acquire such knowledge. In summary, the two kinds of search behavior have different effects on the firms' technological capabilities. The product technology-oriented search focuses more on sophisticated proprietary technology, whose goal is to optimize the existing production processes and improve current production technologies, but it has little impact on industrial technology development path, which means fewer enhancements of firms' exploratory capabilities. Therefore, the following is hypothesized:

H3-3: Product technology-oriented BSS will be positively related to firms' exploratory capabilities.

3.3 The Relationship of Organizational Ambidexterity Capacity

According to March's [23] concept definition, exploratory and exploitative activities have significant differences in resource, structure, and culture, so they are at the two end positions of organizational innovation continuum. With further study, Gupta [26] and other scholars question the absolute dichotomy between exploration and exploitation and say that the tension constraints can be solved by ambidexterity, for example, by constructing an ambidextrous organization to coordinate the tension; by the introduction of external resources to coordinate the excessive competition over limited organizational resources [27];by developing the dynamic capabilities to promote sensibility to the external environment [28]. Meanwhile, punctuated and ambidexterity equilibrium model provide theoretical bases to resolve the tension between exploration and exploitation and the further research on the ambidexterity affirm the premise of their mutual influence.

Take the new product development for example. The ambidexterity capabilities can coexist and promote each other and both self-renewal through the learning behavior within the organization and among organizations [29]. Rothaermel and Deeds [30] find that new product development takes the exploratory innovation alliance as a starting point, and take the exploitative alliance's completing product marketing process as the terminal point. McMillan [31] propose that exploration efforts lead to science outcomes, and that both exploration and exploitation efforts have a positive impact on technological outcomes. Rosenbloom [32] considers the organization's technological capabilities growth path as alternating intermittent phenomenon, thus ensuring a continuous process of exploitation, use of existing technologies, as well as search for the next generation of technology. According to the above studies, the OAC has broken the absolute split and the relationship between the two fails to reach a unified conclusion. With the merging with the absorptive capacity theory and dynamic capabilities theory, the tension will be more effectively addressed and its positive effect on organizational performance will be further verified. Therefore, the following is hypothesized:

H4: The firms' exploratory capabilities will be positively related to firms' exploitative capabilities.

4 Research Design

4.1 Sample and Response

Adopting the random principle, we can improve the sample' representativeness, making research results more accurate and reliable, and the appropriateness of population determination and sample selection is the key to data quality. Therefore, a number of various industry-based surveys can provide more stable conclusions [33]. The requirement of the sample firms was to engage in certain technological innovative activities, including electronic, pharmaceutical, chemical and other industries. Based on the above criteria, we chose the provinces with a higher level of technological and economic development, namely Shandong, Guangdong, and Zhejiang as the collection areas. We require the development managers or technological directors to fill out the questionnaire, which is able to fully reflect and determine the reasonableness of the items, and to provide objective and credible data base.

Following the approach of Bagozzi and Yi [34], the study seeks to ensure the sample size of 200 or more. In view of the data availability and timeliness, this study chooses four channels to collect the questionnaire (Table 1). The questionnaires were distributed from September to December 2012. We have distributed 1934 questionnaires, and a total of 338 surveys were completed, which represents a response rate of 17.48%.

4.2 Measures

The exploratory and exploitative capability. As the dependent variable, previous research adopted the measurement of high operability with different perspectives. The indicators include the depth and breadth of the patent search, the number of research projects, or involving R&D with external alliance. The innovative capabilities can be distinguished according to the degree of relevant indicators that characterize the level of exploratory and exploitative capabilities [18]. Compared with the objective indicators, the scale has the advantages of generalizing, comprehensiveness, easy-operation, and can characterize and measure the latent variables. He and Wong expand the content of firms' exploratory and exploitative strategies, and the former strategy includes four measure items, namely 'introduce new generation of products', 'extend product range' etc., while the later includes 'improve existing product quality', 'improve production flexibility' etc. In line with

Table 1 Questionnaire for distribution and collection

Distribution ways	Distribution number	Collection number	Collection rate (%)	Valid number	Valid rate (%)
On-spot distribution in the firm	84	46	54.76	41	48.81
Distribution via government agency	750	170	22.67	132	17.6
Distribution via friends	800	193	24.13	148	18.5
Distribution via email	300	23	7.67	17	5.67
Total	1934	432	22.34	338	17.48

Jansen [4], our scale contains items such as 'find and utilize the latent chances in market', 'introduce improved products and services in existing markets', 'makes gradual improvements for existing products or services'. Our measure has a comparable reliability score with Cronbach alpha of 0.828 and 0.891, respectively.

The boundary-spanning search. Due to vary boundaries and goals, the BSS behavior is different in the position of organizational innovation activities on a continuous spectrum, resulting in differences in the impact on capability and performance [35]. Rosenkopf and Nerkar [36] measure organizational knowledge search activities across the boundary of organization and industry by calculating the number of target organizations' citation of patents within and outside of the organization as well as the industry. Sidhu [11] divide the BSS into three dimensions,the supply dimension includes the new knowledge pertaining to the input and output of the technology in the organizations, and the demand dimension includes the knowledge about the search for external market structure, market segment, product use, alternative, customer preferences, need, etc., and the space dimension includes the skills of different areas and operational experience knowledge. To measure the BBS, we use the 7-points scale developed by Laursen and Salter [10] and Rosenkopf and Nerkar [36]. The scale consists of 17 items, such as 'exchange technology development information with public research institutions' and 'participate in the key generic technology projects sponsored by the government agencies' etc. The Cronbach alpha values are 0.934, 0.793, 0.849 and 0.900, respectively.

5 Empirical Analysis

5.1 Descriptive Statistics

Prior to the initial model building, in addition to the analysis of the distribution of the sample size, reliability and validity, there is the need for a brief description of sample characteristics and correlativity. We used SPSS for each variable descriptive statistical analysis, getting the variables' mean, standard deviation, and correlations (see Table 2).

5.2 Discriminant Validity

This paper further constructed pairwise matching detection model, thereby testing the discriminant validity of the various dimensions. As shown in Table 3, the detection model consisting of each pair of variables went through two-step testing procedures of constraint and unconstraint, respectively, and marked by $\chi 2$ and $\Delta\chi 2$ values accordingly. Seen from the results, six pairs of models' unconstrained model

Table 2 Descriptive statistics and correlations

Variables	Mean	Standard deviation	1	2	3	4	5	6
1. Technology-driven BSS	4.44	1.29	1.000					
2. Market-driven BSS	4.65	1.24	0.412^{**}	1.000				
3. Generic technology-oriented BSS	5.57	0.85	0.272^{**}	0.353^{**}	1.000			
4. Product technology-oriented BSS	5.61	0.91	0.181^{**}	0.216^{**}	0.141^{**}	1.000		
5. Exploratory capabilities	5.26	1.011	0.192^{**}	0.145^{**}	0.013	0.038	1.000	
6. Exploitative capabilities	5.23	1.086	0.151^{**}	0.097^{*}	0.056	0.043	0.648^{**}	1.000

Note $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$,the same hereafter

Table 3 Testing result of discriminant validity of BSS

Matching detection	Constrained model χ^2	Unconstrained model χ^2	$\Delta\chi^2$
1. SS & MS	87.36	64.58	22.78^{***}
2. SS & GT	94.28	83.45	10.83^{***}
3. SS & PT	101.34	94.83	6.51^{***}
4. MS & GT	93.66	82.97	10.69^{***}
5. MS & PT	96.47	83.15	13.32^{***}
6. GT & PT	86.27	74.16	12.11^{***}

$\chi 2$ values are less than constrained one, indicating that there is no perfect correlation between pairwise relations, but high discriminant validity. Therefore, under the premise of dividing the BSS into two dimensions of organization and technology, our further subdividing BSS into technology-driven (SS) and market-driven (MS) ones, generic technology-oriented (GT) and product technology-oriented (PT) ones have the theoretical and empirical rationality, thus verifying H1.

5.3 Testing and Hypothesized Model

5.3.1 Structural Model Fitting Degree

To test the hypothesized model, AMOS was used to analyze the initial calculation, and initial fitting results were shown in Table 4. From the perspective of fitting results, $\chi 2$ of the initial structural model is 348.047 (df = 215); $\chi 2/df$ value was 1.619; RMSEA coefficient was 0.071, less than 0.10; NFI, GFI coefficients were

Table 4 Fitting result of initial structural model

Path	Path coefficient	S.E.	C.R.	P
Exploratory capabilities <— Technology-driven BSS	0.367	.039	3.926	***
Exploratory capabilities <— Market-driven BSS	0.037	.028	1.306	0.192
Exploratory capabilities <— Generic-technology-oriented BSS	0.452	.050	1.052	***
Exploitative capabilities <— Technology-driven BSS	0.016	.037	0.153	0.278
Exploitative capabilities <— Market-driven BSS	0.254	.026	0.547	***
Exploitative capabilities <— Generic-technology-oriented BSS	0.196	.046	1.430	*
Exploitative capabilities <— Product-technology-oriented BSS	0.308	.046	0.182	***
Exploitative capabilities <— Exploratory capabilities	0.088	.059	1.019	***
$\chi 2$ 348.047	RMSEA 0.071		CFI 0.927	
df 215	NFI 0.895		GFI 0.884	
$\chi 2/df$ 1.619	TLI 0.915			

0.895 and 0.884, less than 0.9. Except $\chi 2/df$, RMSEA, CFI, TLI and other indicators had reached the acceptable range; the rest fit indices were not fit within the acceptable range, indicating that the fitting effect of the model was not ideal. Only a few models are able to fit successfully through one operation, which is more common in analytical model. The reason for this may be that the constructed conceptual model itself has some problems or the data obtained by surveys are deviated. Therefore, it's necessary to revise the initial model and to detect whether its fitting indicators can reach the standard model.

According to the fitting results, this study made the following two amendments. First, we used the modified index MI and increased the correlation between the residuals. Generally, when a = 0.05, it is appropriate to modified the path parameters of MI > 3.84. Second, we fine-tuned the model by adding or deleting the path relationship of the variables according to the test result of the path coefficient in the initial model test.

For the paths failing to pass the significant test in initial fitting, we first fixed the pathway of "market-driven BSS → exploratory capability," and "technology-driven BSS → exploitative capabilities", and further adjusted and modified the model to achieve the best fitting effect. In the modified model, the overall fitting coefficient and path coefficients between the variables were significantly improved, so the revised structural equation model eventually deleted the above two paths. Meanwhile, on the basis of the simplified model, we amended the residual relationship between variables by increasing the residual covariance relationship to

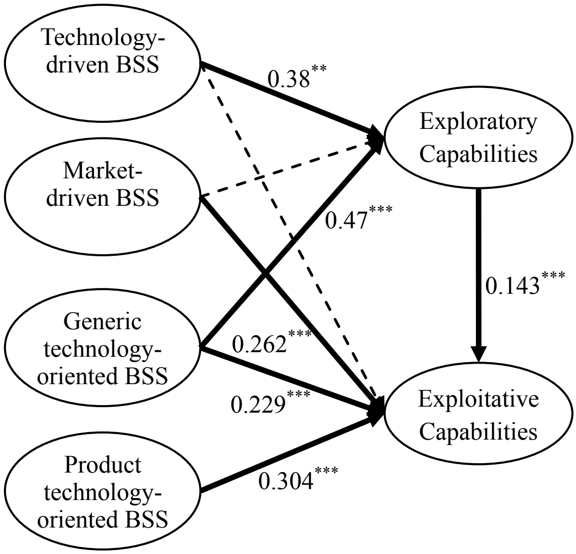

Fig. 1 Final structural model of the impact of BSS on OAC

eliminate the wind age of the simulation gradually. Finally, we refit the revised model and obtain the optimal fitting results (Fig. 1).

5.3.2 Hypothesis Testing

From the perspective of organizational dimension, the path coefficients of technology-driven and market-driven BSS on organizations' exploratory and exploitative capabilities were 0.38, 0.262 ($P < 0.01$; $P < 0.001$), so hypotheses H2-1, 2–4 were verified. BSS is an important measure to implement the external knowledge source strategy, an effective integration of inner knowledge of different research units with different attributes and to a certain extent, it reflects and deepens open innovative theory [37]. Consistent with Laursen and Salter [14] the research requires Chinese firms to cooperate with the external institutions of universities, suppliers, customers, etc., and according to the subjects' attributes and type of knowledge provided, the institutions can be divided into technology-driven and market-driven ones. The classification considers all aspects of the functional characteristics of the supply chain involved in technological subjects. Its innovation lies in the combination of dimension segmentation and content targeting, highlighting the different influences of internal and external factors on the firms' technological capability enhancing process.

Seen from technological dimension, the integration of different levels of technological knowledge is conducive to improve firms' technological innovative capabilities based on firms' own development phase and innovative strategies. The path coefficients of generic technology-oriented BSS on organizations' exploratory and exploitative capabilities were 0.47, 0.229 and both achieved the significant level of 0.1%, so the hypotheses H3-1, 3-2 were verified. The path coefficient of product-technology-oriented BSS on organizations' exploitative capabilities was 0.304 ($P < 0.001$), so hypothesis H3-3 was verified. Similarly to Rosenkopf and Nerkar [36], the result also verifies that technology boundary-based BSS is positively related to the firms' technological capabilities. However, we subdivide the dimensions of the search, and enrich and detail the existing research of BSS. The results deepen the conclusions of Sidhu [11] about the relationship between organizational search and performance. It locates the technology, which the firms need and subdivide the capability so as to find the solution to performance improvement in the realistic context.

Since March [1] ,the scholars have fully discussed the relationships between exploratory and exploitative theoretically and claimed that the two have balanced or coupled interaction, but there are only few empirical studies. The path coefficient of exploratory and exploitative capabilities was 0.143 and had the significance ($P < 0.001$), which supported hypothesis H4. In this study, firms' exploratory capabilities promoting its exploitative capabilities has been verified, but the reverse effect has not been supported by the theory, which is closely related to the current situation of low technological capacity of Chinese firms. In this case, the radical innovation seldom achieved even through long-term accumulation of technology, and most firms only innovate by the gradual improvement of the existing technology.

6 Discussion

This paper discusses the impact mechanism of organization boundary-based BSS and technology boundary-based BSS on the firms' exploratory and exploitative capabilities. Below, we discuss the implications of the study.

6.1 Managerial Implications

Open innovative system contains a wealth of innovative resources. For firms in developing countries, the use of external resources to enhance innovation capability is a necessary path to build core competitiveness, so how to effectively search and integrate the needed target knowledge and cooperative partners becomes the primary concern for firms. Compared with the developed countries, Chinese firms' technological capacities are relatively low, so they cannot absorb the basic research achievements from public research institutions, but linger on the level of technology-based innovation [38]. The technology-driven units represented by universities, research institutes, and the market-driven units represented by suppliers, competitors, business associations become important sources of firms for technological and market information.

Apart from demonstrating the external innovative resource role in promoting the firms' technology capabilities, this paper further analyzes the matching problem of two types of subjects, target knowledge and different levels of capabilities. In order to improve the exploratory capabilities, firms should use the cutting-edge knowledge from research institutions to remedy technology disadvantage. Such kind of knowledge is mainly basic knowledge or generic knowledge on the upstream technology supply chain. As to the exploitative capabilities, firms should pay more attention to the market-driven technology and timely master the product demand information, such as suppliers, customers, etc. to have the gradual improvement of the process of designing, manufacturing and researching. This conclusion reveals the matching problem of different search activities and capability levels and provides references for firms to choose cooperative partners, locate technology category and improve capabilities.

Based on the research findings of dynamic capability theory, organization focusing on similar technology search helps to enhance exploratory capabilities, which means to build "first-order capabilities" through local search, and through BSS and external integration, the exploitative capabilities can be fostered, i.e. to build the "second-order capabilities" of the "first-order capabilities" [39]. The conclusion of this paper verifies the impact of BSS on OAC and further identifies the level difference of different types of BSS on technological capabilities, which is the deep extension of organizational search and organizational learning theories.

6.2 Limitations and Suggestions for Further Research

This paper strictly follows the logic of scientific research, but due to time and condition limitations, there are still some limitations, which should be improved in future studies as follows: First, considering the collecting speed and sample size, we chose the firms from Shandong Province, Guangdong Province and Zhejiang Province for the sample investigation and adopt various collection methods which might influence the validity of this paper to some extent, so the further studies can improve the validity by random sampling. Second, most sample enterprises belong to manufacturing industry and we do not differentiate the industry differences in the analyzing process. The further studies can focus on one industry (software etc.) or make a comparison of the high-tech industry and low-tech industry to get more detailed and meaningful results.

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Research on Logistics Distribution Routing Optimization Based on Ant Colony Algorithm

Taking Shun Feng Logistics in Nan Gang District of Harbin as an Example

Xiao Xi Zhang

Abstract Logistics distribution is the core of logistics, and the optimization of vehicle routing problem is the key to logistics path optimization. Choosing a reasonable delivery route is of great significance for improving the efficiency of logistics distribution and reducing logistics cost. In view of the choice of logistics distribution route, first of all, introduce the traveling salesman problem (TSP problem), introduce the ant colony algorithm and build its mathematical model. Secondly, the important parameters in the ant colony algorithm are tested and analyzed, and the reasonable range of value is determined. Finally, taking the logistics of Nan gang District of Harbin as an example, the use of Matla B simulation results show that the scheme can optimize the logistics distribution route and improve the delivery efficiency.

Keywords Ant colony algorithm · Logistics distribution · TSP problem · SF logistics · Matlab simulation

1 Introduction

In recent years, with the economic globalization and the deepening of China's economic system reform, modern logistics distribution has gradually become the core industry requirement to promote the development of our country's economy. The quality of logistics distribution plan determines the efficiency of logistics distribution to a large extent. In October 2016, the office of the State Council issued the opinion on the policies and measures to promote the healthy development of the logistics industry. It pointed out that the efficiency of logistics distribution should be improved, the competitiveness of logistics enterprises increased, and the policy

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support for the logistics industry was strengthened so as to promote the healthy and efficient development of the logistics industry. Therefore, in order to optimize the logistics transportation route and choose a reasonable distribution plan, it is necessary to study the optimization of logistics distribution route.

In academic circles, the study of solving the optimization of logistics distribution path has attracted extensive attention of many researchers at home and abroad, such as mathematics, computer communications, and so on. Among them, foreign comparisons are representative: Dantzig and Rmaser [1] proposed the optimization of logistics distribution path for the first time in 1959. The problem is quickly aroused by experts from various disciplines such as world operations research, logistics science, combinatorial mathematics and other related people, and become the front of operations research and combinatorial optimization. Along problems and research hot spots; In 1989, Willard [2] applied the tabu search method to vehicle routing optimization for the first time. By designing a repetitive virtual logistics center, the vehicle routing optimization problem was transformed into a traveling salesman problem, and the 2-opt method was used to solve the vehicle routing optimization scheme. In 1995, the research progress and development of vehicle routing problems were discussed in eighth volumes published in the book "operations research and management science manual", which was published by Desrosiers [3]. In 2008, Donati [4] and other ant colony algorithms were used to study vehicle routing problem with vehicle speed varying with time. In contrast, the domestic research on this aspect is relatively backward in the early 1990s, but it has been developed in the early 1990s, but there are also some research results on the optimization of vehicle distribution path. It is more representative: in 2001, Chen [5] proposed a hybrid operator in genetic algorithm to improve the ant colony algorithm and proved the algorithm to be effective by solving the TSP problem. In 2006, Lang [6] reviewed the latest progress of the vehicle routing optimization problem in the distribution vehicle optimization scheduling model budget method. In 2012, Wang [7] and so on proposed improved ant colony algorithm and introduced heuristic factor and parameter adaptive adjustment. In 2013, Li [8] and so on pointed out the superiority of ant colony algorithm in solving the problem of large nonlinear system optimization, and improved the basic ant colony algorithm according to the characteristics of the logistics vehicle scheduling system and proved the algorithm. The correctness of it. To sum up, the research on the distribution path is mainly qualitative, and the quantitative research mainly focuses on the improved ant colony algorithm itself, and the research on the setting and optimization of the algorithm parameters is very few. Based on the policy of national logistics industry, this paper aims to select the rational distribution route and optimize the logistics distribution path, and tries to introduce the optimization problem of the traveler (TSP problem) to explain the ant colony system model, and verify the parameter value of the ant colony algorithm through the simulation experiment, and determine the selection range of the parameter value. At the same time, taking the logistics of SF in Nangang District of Harbin as an example, the Matlab tool simulation experiment is used to optimize the route. Finally, the aim of this paper is to optimize the logistics distribution path based on ant colony algorithm.

2 Analysis of TSP Problem Based on Ant Colony Algorithm

2.1 TSP Problem Definition and Mathematical Description

The traveling salesman problem (TSP problem) introduced in this paper is a special case of path optimization. In recent years, because of its simplicity and adaptability, the TSP problem has been used as a testing platform for new ideas and methods for solving combinatorial optimization problems. The essence of this is that for n cities, the distance between them is known, and a traveler travels from one city to all the cities, and each city can only pass once, finally back to the starting point, so that the total distance is shortest. The mathematical method is described as: a collection of n cities $C = \{c_{1,}c_{2,}\ldots c_N\}$, the distance between each city is $d(c_{i,}c_j) \in R^+, c_{i,}c_j \in C (1 \le i,j \le N)$.

Objective function: $T_D = \sum_{I=1}^{N-1} d(c_{\Pi}(i), c_{\Pi}(i+1)) + d(c_{\Pi}(N), (c_{\Pi}(1))$.

The smallest city sequence: $\{c_{\Pi}(1), c_{\Pi}(2), \ldots c_{\Pi}(\mathrm{N})\}$, Among them, $\Pi(1)$, $\Pi(2), \cdots \Pi$ (N) is the full arrangement of $1, 2, \ldots N$.

2.2 Overview of Ant Colony Algorithm and Implementation Steps of Solving TSP Problem

2.2.1 An Overview of Ant Colony Algorithm

Ant colony algorithm is a probabilistic algorithm for finding optimal paths. In 90s of last century, Italy scholar M. Dorigo simulated the path selection method of ants searching for food, and then came to an algorithm. As a bionic algorithm, ant colony algorithm has strong robustness. It is easy to integrate with other algorithms to improve the performance of the algorithm. Global optimization has become a powerful tool for solving complex combinatorial optimization problems. In recent years, there are many ways to study path optimization based on genetic algorithm and particle swarm optimization, in which the genetic algorithm has good global search ability, but it has no characteristics of active optimization and has no memory. Although particle swarm optimization can effectively optimize the parameters of the system, its local optimization ability is poor; Therefore, ant colony algorithm is the first choice for path optimization.

To facilitate the description of the ant colony model, first define the following variables:

M Ant number;
n Number of cities;
d_{ij} Distance between (I, j)cities, $i, j = 1, 2, \ldots, n$;

ζ_{ij}	The number of pheromones on the t time path (i, j), $i,j = 1,2,\ldots,n$;
φ_{ij}	The visibility of the path reflects the degree of Enlightenment from the city to the city, $\varphi_{ij} = \frac{1}{d_{ij}}$;
α	The number of pheromones on the t time path;
β	The relative importance of enlightening information;
ρ	Pheromone Volatilization Coefficient;
$\Delta\zeta(i,j)$	The amount of information added to a path (I, J) in a cycle;
$\Delta\zeta_{ij}^{k}$	The pheromone intensity of ant K placed on the edge of L (I, J);
$p_{ij}^{k}(t)$	The probability of an ant turning from a city to a city at a time;
$tabu_k$	The amount of pheromone remained in the path passed by the ants in another iteration;
Q	Taboo table, record the city where ants are walking now, and will not choose cities from the table next visit.

2.2.2 The Steps to Solve the TSP Problem

Based on the above variables, the optimization steps of ant colony algorithm are summarized as follows:

Step 1: parameter initialization

Initialization parameters m, α, β, ρ, Q, Command t = 0, Cycle times Nc = 0, The maximum cycle number is $Nc_{\max}$, The amount of information on each path at the initial time is $\zeta_{ij}(0) = C$ (C is a constant), $\Delta\zeta_{ij}(0) = 0$.

Step 2: construction path

M ants are randomly placed in n cities, and the taboo list of each ant is updated to make the first element the ant's current city.

Step 3: determine the transfer probability

At t, the probability of ant K moving from city to next city is:

$$p^{k}(\mathrm{i},\mathrm{j}) = \begin{cases} \frac{[\zeta(i,j)]^{\alpha} * [\varphi(i,j)]^{\beta}}{\sum_{s \in J_k(t)} [\zeta(i,s)]^{\alpha} * [\varphi(i,s)]^{\beta}} \, if\, j \in J_k \\ 0 \qquad\qquad\qquad\qquad otherwise \end{cases}$$

At the same time, the j is put into the taboo table of ant K, so cycle, until all the ants complete the tour of the n city; J_k indicates that the next step can allow access but not access to the logistics point;

Step 4: determine the path length

Calculate the travel path length $L_k(k = 1,2,\ldots m)$ of each ant, and record the current optimal traversal sequence and path length.

Step 5: pheromone update

After all ants find a legal path, they update the information:

$$\zeta_{ij}(t+1) = (1-p)\zeta_{ij}(t) + \sum\nolimits_{m} \zeta_{ij}^{k}(t, t+1) \tag{2}$$

$$\triangle\zeta_{ij}^{k}(\mathrm{t}, \mathrm{t}+1) = \begin{cases} \frac{Q}{L_k} & \textit{If the ant passes}(i,j) \\ 0 & \textit{otherwise} \end{cases}$$

Among them, Q indicates that the trajectory of ants is normal (101000). L_k indicates the length and the path of the ant K in this tour.

Step 6: to each side (i,j), $\Delta\zeta_{ij} = 0$, $Nc = Nc + 1$.

Step 7: judge whether Nc reaches $Nc_{\max}$, if $Nc \leq Nc_{\max}$, then turn to Step 2; otherwise, go to step 8;

Step 8: output results. The optimal solution of this experiment is output.

Based on the description of the model above, the operation flow chart of the ant colony algorithm is compiled, as shown in Fig. 1.

3 Optimization and Analysis of Parameter Setting of Ant Colony Algorithm

From the above mathematical model, we can see that if the parameter is not set properly, it will lead to slow solution and poor quality of the solution. Therefore, the determination of reasonable parameter values will help to improve the convergence speed and global optimization ability of the algorithm. In the ant colony algorithm, there are mainly three parameters that affect the performance of the algorithm, that is, pheromone elicitation factor α, expected heuristic factor β and pheromone volatilization coefficient ρ. Based on this, this paper mainly analyzes and tests the three parameters of alpha, beta and Rho, and then determines the reasonable value.

3.1 Pheromone Elicitation Factor Alpha and Expectation Heuristic Factor Beta Analysis

Pheromone heuristic factor alpha reflects the intensity of the information accumulated by ants in the process of movement to the leading role of the following ants. It also reflects the intensity of the ants' effect on the random factors in the path search: the greater the alpha value, the stronger the amount of information accumulated for the path selection of the succeeding ants. The possibility of ants to choose the previous path is greater, the ant cooperation is strengthened and the convergence speed is quicker, but the search randomness is weakened, the search space becomes smaller and the algorithm is easily trapped in the local optimal,

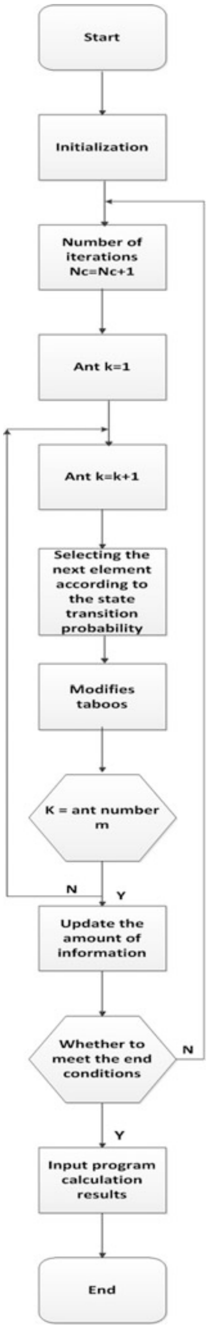

Fig. 1 Flow chart of the running program of ant colony algorithm

which will reduce the global search ability of the algorithm, and when the alpha value is too low, the search speed will be reduced, which will lead to the algorithm difficult to find. The global optimal solution [9], the general alpha value range is 0.5–5.

Beta reflects the strength of the ant's path length to the ants' guiding role in the course of the movement. The greater the beta value, the stronger the guiding role of the heuristic information to the ants' path selection, the faster the algorithm converges, but it weakens the randomness of the ant colony in the optimal path search, and the algorithm is easy to fall into the local optimal, and when the beta value is too small It will make the ant quickly fall into local optimum, greatly reducing the global optimization ability of the algorithm [9], the value of the general beta is 1–5.

In this paper, the effect of alpha and beta on the performance of ant colony algorithm is discussed. When taking beta = 5, the alpha is {0.5, 1, 2, 5}, and the other default values are: n = 15, m = 22, Q = 100, Nc = 200, P = 0.1. The data used in the experiment are derived from the Eil51 city problem, and the data are detailed in Appendix 1. The results of the experiment are shown in Table 1.

When the alpha = 1 is taken, the beta is {1, 2, and 5}, and the other default values are n = 15, m = 22, Q = 100, Nc = 200, and Rho = 0.1, and the TSP problem data used in the experiment is derived from the Eil51 city problem. The results of the experiment are shown in Table 2.

The experimental results show that if the fast convergence performance of the ant colony algorithm is increased and the accuracy of the search process is required, the combination of alpha and beta values should be selected at the same time. Therefore, based on the experimental results, the parameter values in this paper are selected as: alpha = 1, beta = 5.

Table 1 Simulation results of combination of alpha and beta algorithms

Pheromone concentration influence parameter A	Heuristic information influence parameter B	Optimal path length
0.5	5	458.382479
1	5	447.001731
2	5	459.590417
5	5	465.767435

Table 2 Simulation results of combination of alpha and beta algorithms

Pheromone concentration influence parameter A	Heuristic information influence parameter B	Optimal path length
1	1	481.415788
1	2	461.263149
1	5	447.001731

3.2 Numerical Analysis of Pheromone Volatiles

The size of Rho is directly related to the global optimization ability and convergence speed of the ant colony algorithm. In general, the number of [0, 1] and 1- Rho represent the degree of the pheromone's retention, which indirectly reflects the strong and weak relationship between the ants. The greater the value of Rho, the more volatile of the path pheromone, the less the residual pheromone on the path, the smaller the attractiveness to the subsequent ants, the weakening of the collaboration, and the reduction of the convergence speed. The smaller the value of Rho, the greater the value of the retention coefficient 1- Rho, the longer the retention time of the pheromone, the greater the possibility of the search of the previously searched path. The positive feedback function of this algorithm is strengthened, although it can speed up the convergence speed, it will reduce the randomness and search ability of the algorithm [10]. The value of pheromone Volatilization Coefficient in this paper is set to {0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9}, and the other default values are n = 15, m = 22, Q = 100, Nc = 200, and the TSP problem data used in the experiment are derived from the Eil51 city problem. The results of the experiment are shown in Table 3.

In order to select the pheromone volatility 1- Rho in ant colony algorithm, we must consider the two performance indexes of global search ability and convergence speed, and make a reasonable choice according to the two performance indexes. Based on the above experimental results, the pheromone volatilization coefficient is set to 0.5.

The selection of parameter values directly affects the global convergence and solving efficiency of the ant colony algorithm. By analyzing and setting up three important parameters, such as information Su Qifa factor alpha, expected heuristic factor beta and pheromone volatilization coefficient rho, the parameter selection value is determined, and then the convergence speed and global search of the algorithm are improved. The effect of ability provides a parameter basis for improving the efficiency of path optimization.

Table 3 Simulation results of pheromone volatilization coefficient P algorithm performance

Pheromone volatilization coefficient rho	Optimal path length
0.1	448.317777
0.2	453.848623
0.3	446.568507
0.4	455.270271
0.5	445.624177
0.6	448.123656
0.7	454.123656
0.8	448.317777
0.9	448.384141

4 Case Verification—Take Harbin Nan Gang District Shun Feng Logistics Distribution Route as an Example

As the capital city of Harbin, Heilongjiang is the largest commercial center in the north of Northeast China. The modern logistics industry in Harbin started late. According to the statistical yearbook of Harbin, after 2014, the freight transportation was mainly carried by civil aviation, its total amount reached 38 thousand tons, and up to 43 thousand tons [11] in 2015, and the transport volume of goods increased year by year. Although the logistics industry in Harbin has some advantages compared with other cities in the province, there is still a big gap compared with other provincial capitals. In 2014, the freight volume of Zhengzhou reached 22802 tons, and the freight volume of Hangzhou reached 293 million 350 thousand tons, and the freight volume of Guangzhou reached 965 million 530 thousand tons [12]. In the same year, the total freight transport volume of Harbin reached 101 million 690 thousand tons. From this, we can see that the development level of logistics industry in Harbin is still low. In April 2017, the Heilongjiang Ministry of Commerce issued the implementation opinion of Heilongjiang Province on promoting the development of trade and logistics industry, and pointed out that promoting the construction of express logistics park to promote the rapid and healthy development of the express industry in the province. In May of the same year, the Harbin Municipal Committee held the demonstration meeting of "Harbin logistics industry" "development plan of 13th Five-Year", and discussed the development plan of Harbin logistics industry. Therefore, based on the policies of Heilongjiang and Harbin, it is of great practical significance to optimize the logistics distribution route and improve the distribution efficiency in Harbin.

4.1 Data Selection

On this paper, through the Baidu map coordinate system, a total of 15 SF express delivery points in Nangang District of Harbin are selected. The self extraction of these self extracts is mainly concentrated in the places with large passenger flow around the University, the shopping center, the residential area and so on. Harbin Shun Feng Logistics in the city and the county area of 81 self promotion, and there will be two times a day, 11 a.m. and 6 p.m. after the completion of the loading of goods to their respective distribution, and then notify the customer to the nearest point of view to pick up the goods. This paper focuses on the optimization of the distribution path of 15 express delivery points in the Nan gang District of Shun Feng Logistics in the morning time. A cargo container vehicle from the general distribution point of Nan gang district is sent to the other 14 self lifting points. Each time, only once, after all the self lifting, the cargo is returned to the starting point and does not consider the congestion. The shortest path of the process. Specific data information is detailed in Table 4.

Table 4 Self lifting latitude and longitude coordinates of SF logistics in Nan gang District

Self lifting number	Self lifting name	Latitude and longitude
1	Shun Feng District Department	126.67027, 45.709242
2	Self lifting of Zhongshan Road No. 244 in Nangang District	126.660429, 45.755093
3	Self lifting of No. 145, the Yellow River Road, Nangang District	126.714869, 45.763718
4	The self lifting of No. 62, Yan Xing Road, Nangang District	126.614208, 45.721168
5	The business point of Liaoyang street in Nangang District	126.663753, 45.769298
6	Nangang district collection garden business point	126.644613, 45.689934
7	Qinghua Street business point in Nangang District	126.608173, 45.72269
8	Business point of West Bank of Jianqiao in Nangang District	126.592672, 45.697519
9	Business point of Shenyang street in Nangang District	126.653249, 45.756799
10	The business point of Liaohe District in Nangang District	126.686423, 45.766538
11	The self lifting of SF EXPRESS in Nangang District	126.635195, 45.684517
12	The self lifting of Nangang district business place	126.542173, 45.747582
13	The prosper street of Kazakhstan	126.641739, 45.747731
14	The self lifting of the family District of the Xuefu Road, Heilongjiang University	126.62866, 45.716998
15	The self lifting of the Southern Campus of Harbin Normal University	126.632253, 45.730743

Data source The Baidu map coordinate system [13]

4.2 Data Processing

In order to simplify the calculation of data, this paper takes the distance of two point coordinates instead of the actual distance and transforms the coordinate data. At the same time, it is convenient for data processing. In this paper, we choose the data after the decimal point of latitude and longitude as the coordinate data. As the latitude and longitude across the earth is a 1/360 of a latitude and longitude circle, it is about 111 km. Therefore, the latitude and longitude is converted to the data of rice as a unit, and the specific data are as follows:

Coordinate after conversion = latitude and longitude $*$ 11,000 m[14].

The converted data are shown in Table 5 as follows:

Table 5 Coordinate values after conversion of X, Y data

Self lifting number	Self lifting name	After conversion X	After conversion Y
1	Shun Feng District Department	74399.97	78725.86
2	The Self lifting of Zhongshan Road No. 244 in Nangang District	73307.62	83815.32
3	Self lifting of No. 145, the Yellow River Road, Nangang District	79350.46	84772.70
4	The self lifting of No. 62, Yan Xing Road, Nangang District	68177.09	80049.65
5	The business point of Liaoyang street in Nangang District	73676.58	85392.08
6	Nangang district collection garden business point	71552.04	76582.67
7	Qinghua Street business point in Nangang District	67507.20	80218.59
8	Business point of West Bank of Jianqiao in Nangang District	65786.59	77424.61
9	Business point of Shenyang street in Nangang District	72510.64	84004.69
10	The business point of Liaohe District in Nangang District	76192.95	85085.72
11	The self lifting of SF EXPRESS in Nangang District	70506.65	75981.39
12	The self lifting of Nangang district business place	60181.20	82981.60
13	The prosper street of Kazakhstan	71233.03	82998.14
14	The self lifting of the family District of the Xuefu Road, Heilongjiang University	69781.26	79586.78
15	The self lifting of the Southern Campus of Harbin Normal University	70180.08	81112.47

4.3 Parameter Setting

Through the analysis of the parameters in the previous article, n = 15, m = 22; alpha = 1; beta = 5; rho = 0.5 are selected in this case; the maximum cycle times NC_max = 200; the release of the pheromone Q = 100. The setting of specific parameters is shown in Table 6. The detailed code is shown in annex two.

Table 6 Correlation parameter values of ant colony algorithm

Parameter	Numerical value
α (Information heuristics)	1
β (Expectation inspiring factor)	5
ρ (Number of iterations)	0.5
m (Number of ants)	22
n (Urban scale)	15
Q (Pheromone intensity)	100
Nc (Pheromone volatilization factor)	200

4.4 Path Optimization of Ant Colony Algorithm

The results are as follows: MATLAB simulation results are as follows:
The shortest path (Shortest_Route) is 1-6-11-14-4-7-8-12-15-13-9-2-5-10-3-1.
The shortest path length (Shortest_length) is 49113.73 m.
The shortest path graph and convergence curve are shown in the following figure respectively (Figs. 2 and 3).

It can be found that the average path of the pheromone volatilization is still fluctuating because of the effect of pheromone volatilization, and the global optimization is still carried out, and it does not fall into the local optimal. Therefore, the effect of the ant colony algorithm on the optimization of distribution path is proved.

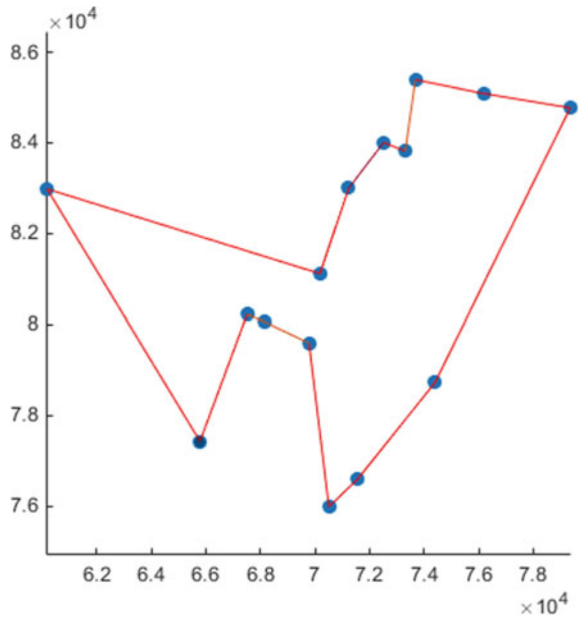

Fig. 2 Shortest path

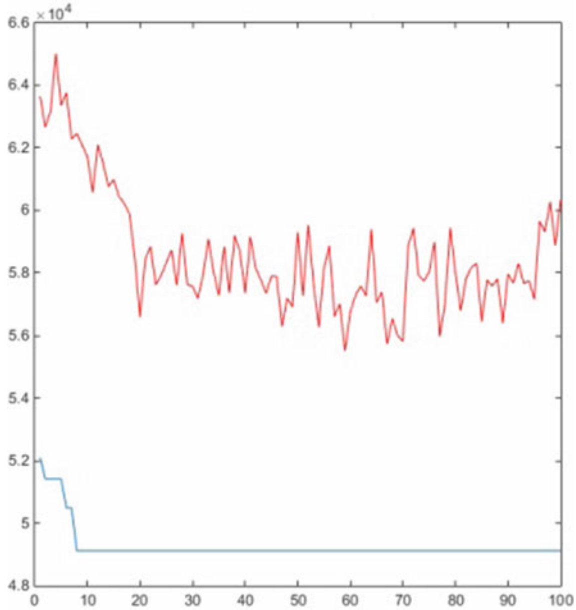

Fig. 3 The average distance and the shortest distance

5 Conclusion

Logistics distribution is an important part of logistics activities. It is the main research direction of this paper to optimize distribution routes and improve distribution efficiency. In this paper, we use ant colony optimization algorithm and experimental simulation to determine reasonable parameter values to study logistics distribution routing optimization problem. Taking the logistics of SF in Nangang District of Harbin as an example, the shortest distribution route was determined by Matlab simulation experiment, which verified the feasibility and efficiency of the ant colony optimization algorithm and parameter value in the previous article. Finally, we achieve the purpose of selecting reasonable distribution routes and optimizing logistics distribution routes.

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A Comparative Analysis of Wages Level of Private Enterprises in 30 Provincial Administrative Regions in China Based on Principal Component Analysis

Shuang Zheng

Abstract Through the analysis of 19 statistical indicators of wages level in different industries in 30 provincial administrative regions, the principal component analysis method is used to compare and analyze the wage levels of private enterprises in different provincial administrative regions in China. A region with a score greater than 0 indicates that private enterprises have a better wage level, and a comprehensive score of less than 0 indicates that private enterprises have poorer wage development. Among them, Beijing's private enterprises have the highest overall wage rate, which is much higher than other provincial administrative regions. The study also found that there is a certain degree of similarity between the level of wages of private enterprises in various regions and their level of economic development.

Keywords Principal component analysis · Private enterprise · Wage level

1 Introduction

The development of private enterprises reflects the economic vitality of a country and region, and it is of great positive significance to many aspects such as employment and economic development in countries and regions. Especially in the current state-owned mixed ownership reform of state-owned enterprises, private companies have played a very important role. The salary level of private enterprises reflects the ability of private enterprises to attract talents and the development of private enterprises. It is of great significance to study the wage levels of the private enterprise.

The study of the development level of private enterprise wages is of great significance in many aspects. Bao Shufang learned from the study of the wage

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regulation of Shanghai private enterprises in the early years after the founding of the People's Republic of China: The wage level of private enterprises has a lot to do with the initial exploration of the party and the government in the field of income distribution. In addition, it also reflects the demands of private enterprise workers in the interests and the complex relationship between the aspect and the country [1]. Wang Yunzhong conducted an analysis of the level of actual labor remuneration of private industrial enterprises and compared them with other relevant factors, and measured the increase in the pay of private industrial enterprises in China [2]. Pan Qifan has conducted in-depth research on the differences in wage levels between domestic and foreign public and private enterprises through literature review methods [3].

There have been many achievements in the study of economic issues through principal component analysis. Wei Jing et al. analyzed and processed relevant data of 15 prefectures and cities in Xinjiang through principal component analysis and other methods, and obtained that comprehensive scores and ranks of the open levels in various regions of Xinjiang [4]. Luo Xiaoxun et al. used the principal component analysis method to conduct a detailed study of theater performance evaluation, through the construction of multi-level index system [5]. Kong Fanbin et al. used principal component analysis to measure and rank industrial scale competitiveness, industrial structure competitiveness, industrial efficiency, industry innovation competitiveness, industrial ecological competitiveness, and comprehensive industrial competitiveness of the Yangtze River Economic Belt along the Yangtze River in 2010–2014. And they also conducted a comparative study [6].

Based on the above studies, this paper is based on data from 30 other provincial administrative regions except Hong Kong, Macao, Taiwan, and Tibet in the "China Statistical Yearbook". And selecting 19 average wages for different industries of statistical indicators, using principal component analysis, the salary level of private enterprises in China is researched in this paper.

2 Problem Description and Mathematical Description

In accordance with the principle of data availability, systematization, scientificity, and objectivity, the 2012 the average wages of employees for sub-regions in Different industries is selected to conduct in-depth research on the issues in this paper. According to the fourth part of the "China Statistical Yearbook (2013)" (hereinafter collectively referred to as the "Yearbook"): Table 4-16 of the employment of employees and wages. (Note: Since 2013 and previous "Yearbook" data can be directly linked with EXCEL, for the convenience of the study, as well as taking into account the timeliness and scientific nature of the data, the data in the 2013 "Yearbook" is selected in this paper.)

According to the classification of the "Yearbook", in the study of the wage level of the private enterprise the average wage level of each industry is selected as the index. They are as follows:

X_1, Average wages for farming, forestry, animal husbandry, and fishery (unit: yuan, the same for each index unit below, no longer listed separately);
X_2, Average wage for mining industry;
X_3, Average wage for manufacturing industry;
X_4, Average wage in water, electricity, heat, gas production and supply industry;
X_5, Average wage in construction industry;
X_6, Average wage in wholesale and retail trade;
X_7, Average wage in transportation, warehousing and postal services;
X_8, Average wage in accommodation and catering industry;
X_9, Average wage in software and information technology services;
X_{10}, Average wage in the financial industry;
X_{11}, Average wage in real estate;
X_{12}, Average wage in rental and business services;
X_{13}, Average wage in scientific research and technical services;
X_{14}, Average wage in water, environmental, and public facilities management;
X_{15}, Average wages in resident services, repairs, and other service sectors;
X_{16}, Average wages in the education sector;
X_{17}, Average wages in health and social work;
X_{18}, Average wages in the culture, sports, and entertainment industries;
X_{19}, Average wages in Public management, social security, and social organization, a total of 19 indicators.

The sample was selected as the data of 30 other provincial administrative districts except Hong Kong, Macau, Taiwan and Tibet.

3 Model Establishment

In the study of this paper, the study of the wage level of the private sector involves 19 indicators, which are denoted by $X_1, X_2, \ldots, X_{19}$ respectively. The 19-dimensional random vector composed of the 19 indicators is $X = (X_1, X_2, \ldots, X_{19})'$.

A new synthesis variable can be formed through the linear transformation of X, which can be expressed with X, satisfying the following formula:

$$\begin{cases} Y_1 = u_{11}X_1 + u_{12}X_2 + \cdots + u_{1-19}X_{19} \\ Y_2 = u_{21}X_1 + u_{22}X_2 + \cdots + u_{2-19}X_{19} \\ \ldots \\ \mathrm{Y}_{19} = u_{19-1}X_1 + u_{19-2}X_2 + \cdots + u_{19-19}X_{19} \end{cases} \tag{1}$$

Among them, $\mathbf{u}_i'\mathbf{u}_i = 1$, that is, $u_{i1}^2 + u_{i2}^2 + \cdots + u_{ip}^2 = 1$. Y_i and Y_j are not related to each other. $(i \neq j, i, j = 1, 2, \ldots, 19)$.

Let the covariance matrix of the random vector $X = (X_1, X_2, \ldots, X_{19})'$ be $\Sigma . \lambda_1 \geq \cdots \geq \lambda_p$ is the eigenvalue of Σ, which $\gamma_1, \ldots, \gamma_p$ is the standard orthogonal eigenvector corresponding to each eigenvalue of the matrix Σ. Then the first i principal component Y_i can be expressed as:

$$Y_i = \gamma_{1i}X_1 + \gamma_{2i}X_2 + \cdots + \gamma_{19i}X_{19}(i = 1, 2, \ldots, 19) \quad (2)$$

where $\mathrm{var}(Y_i) = \boldsymbol{\gamma}_i' \Sigma \boldsymbol{\gamma}_i = \lambda_i$. And $\mathbf{cov}(\boldsymbol{Y}_i, \boldsymbol{Y}_j) = \boldsymbol{\gamma}_i' \boldsymbol{\Sigma} \boldsymbol{\gamma}_j = \mathbf{0} \quad (\boldsymbol{i} \neq \boldsymbol{j})$.

In the following, the model is further analyzed by using SPSS software and the indicator data in this paper.

4 Model Analysis

Firstly, data standardization function of SPSS 21.0 statistical software was used to standardize the data of the 19 indicators in the 30 provincial administrative regions selected in this paper, which will provide the basis for the next step of the principal component analysis.

Selecting standardized data, SPSS 21.0 statistical software is used to calculate the corresponding eigenvalues, variance contribution rates, cumulative variance contribution rates, and factor loading matrix data for each factor. First, view result of the eigenvalue greater than 1 as the principal component analysis result according to the default, and calculate the total variance of the interpretation of each factor, as shown in Table 1.

It is shown from Table 2 that the variance of first 3 principal components accounted for 80.794% of the total variance. It do not satisfy the general requirement of 85% of the cumulative variance contribution rate in the principal component analysis. At this point, change the condition setting to set the number of output factors to 4. At this time, using SPSS 21.0 again for statistical analysis, the results are as shown in Table 2.

From the output of Table 3, we can see that the ratio of the variance of the first four principal components,Y_1, Y_2, Y_3 and Y_4, to the total variance is 85.228%. We select the first principal component Y_1, the second principal component Y_2, the third principal component Y_3 and the fourth principal component Y_4. And the variance of the four principal components accounts for 85.228% of the total variance, that is, basically retains the information of the original indicator, so that the original 19 indicators are converted into 4 indicators, and the number of indicators is greatly reduced. It has played a very good dimension reduction effect.

The factor load matrix obtained by SPSS 21.0 software is shown in Table 3.

By dividing each element of the first column of the component matrix output from the result of the factor analysis module of SPSS 21.0 by the square root of the third eigenvalue. The coefficient of the first i principal component of the principal component analysis can be obtained. The results are shown in Table 4.

Using SPSS 21.0 software to analyze and process the coefficients of each principal component in the principal component analysis in Table 5, the scores of each principal component of 30 provincial administrative regions in China can be

Table 1 Total variance explained

Component	Initial eigenvalues			Extraction sums and squared loading		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	12.577	66.194	66.194	12.577	66.194	66.194
2	1.719	9.047	75.241	1.719	9.047	75.241
3	1.055	5.553	80.794	1.055	5.553	80.794
4	0.842	4.434	85.228			
5	0.628	3.307	88.535			
6	0.471	2.479	91.014			
7	0.420	2.208	93.223			
8	0.281	1.477	94.700			
9	0.223	1.175	95.875			
10	0.166	0.872	96.747			
11	0.154	0.809	97.556			
12	0.129	0.681	98.238			
13	0.097	0.512	98.749			
14	0.085	0.449	99.199			
15	0.058	0.304	99.503			
16	0.040	0.211	99.713			
17	0.029	0.155	99.868			
18	0.016	0.086	99.954			
19	0.009	0.046	100.000			

Extraction method: principal component analysis

Table 2 Total variance explained

Component	Initial eigenvalues			Extraction sums and squared loading		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	12.577	66.194	66.194	12.577	66.194	66.194
2	1.719	9.047	75.241	1.719	9.047	75.241
3	1.055	5.553	80.794	1.055	5.553	80.794
4	0.842	4.434	85.228	0.842	4.434	85.228
5	0.628	3.307	88.535			
6	0.471	2.479	91.014			
7	0.420	2.208	93.223			
8	0.281	1.477	94.700			
9	0.223	1.175	95.875			
10	0.166	0.872	96.747			
11	0.154	0.809	97.556			
12	0.129	0.681	98.238			
13	0.097	0.512	98.749			
14	0.085	0.449	99.199			
15	0.058	0.304	99.503			
16	0.040	0.211	99.713			
17	0.029	0.155	99.868			
18	0.016	0.086	99.954			
19	0.009	0.046	100.000			

Extraction method: principal component analysis

Table 3 Component matrix[a]

	Composition			
	1	2	3	4
X1 Average wages for farming, forestry, animal husbandry, and fishery	0.841	0.294	−0.331	−0.011
X2 Average wage for mining industry	0.313	0.815	0.062	−0.339
X3 Average wage for manufacturing industry	0.948	0.168	−0.094	−0.066
X4 Average wage in water, electricity, heat, gas production and supply industry	0.618	0.273	0.551	−0.070
X5 Average wage in construction industry	0.829	0.167	−0.198	−0.207
X6 Average wage in wholesale and retail trade	0.941	−0.020	−0.152	−0.044
X7 Average wage in transportation, warehousing and postal services	0.907	−0.006	−0.262	0.023
X8 Average wage in accommodation and catering industry	0.909	−0.076	−0.100	0.058
X9 Average wage in software and information technology services	0.809	−0.339	0.266	0.133
X10 Average wage in the financial industry	0.728	−0.033	0.590	−0.053
X11 Average wage in real estate	0.848	0.275	0.147	−0.037
X12 Average wage in rental and business services	0.930	−0.252	−0.075	0.085
X13 Average wage in scientific research and technical services	0.829	−0.368	−0.031	0.029
X14 Average wage in water, environmental, and public facilities management	0.813	0.020	0.003	−0.008
X15 Average wages in resident services, repairs, and other service sectors	0.858	0.001	−0.164	−0.095
X16 Average wages in the education sector	0.866	−0.178	0.056	0.187
X17 Average wages in health and social work	0.880	−0.255	0.097	−0.089
X18 Average wages in the culture, sports, and entertainment industries	0.920	−0.041	−0.030	0.066
X19 Average wages in Public management, social security, and social organization	0.216	0.585	0.009	0.763

Extraction method: principal component analysis
[a]4 components have been extracted

obtained. The variance contribution rate of each principal component accounts for four main components. The proportion of the component variance contribution rate is used as the weight. With Excel, the weighted summary can be obtained for the wage level Y of the 30 provincial administrative regions. The formula is as follows:

$$Y = \sum_{i=1}^{19} \frac{\lambda_i}{\lambda_1 + \lambda_2 + \cdots + \lambda_{19}} Y_i \tag{3}$$

The calculation results are shown in Table 5.

Table 4 Coefficients of principal components

	Y1	Y2	Y3	Y4
X1	0.237	0.224	−0.323	−0.012
X2	0.088	0.621	0.061	−0.370
X3	0.267	0.128	−0.091	−0.072
X4	0.174	0.208	0.537	−0.076
X5	0.234	0.127	−0.193	−0.226
X6	0.265	−0.015	−0.148	−0.048
X7	0.256	−0.005	−0.255	0.025
X8	0.256	−0.058	−0.097	0.063
X9	0.228	−0.258	0.259	0.145
X10	0.205	−0.025	0.575	−0.058
X11	0.239	0.210	0.143	−0.040
X12	0.262	−0.192	−0.073	0.092
X13	0.234	−0.281	−0.031	0.031
X14	0.229	0.015	0.003	−0.009
X15	0.242	0.001	−0.160	−0.103
X16	0.244	−0.135	0.055	0.204
X17	0.248	−0.195	0.095	−0.097
X18	0.260	−0.031	−0.029	0.072
X19	0.061	0.446	0.009	0.832

5 Explain Model Results

Through the analysis of the above model and the study of the results, we can get the following rules:

(1) In the research on the wage level of private enterprises in 34 provincial-level administrative regions of China, the cumulative contribution of the four principal components selected in this paper accounts for 85.228% of the total, indicating that there is a good interpretation effect of principal component analysis method for analyzing this issue.
(2) It can be seen from Table 5 that the private enterprises in Beijing have the highest wage level, and its comprehensive score is 3.24 higher than Tianjin, which ranks second, indicating that the wage level of private enterprises in Beijing is much higher than that of other provincial administrative regions. In Sichuan Province and other 18 provincial administrative regions, the comprehensive scores of are negative, and a negative composite score does not indicate that the private enterprises in the region have negative wages. Can only represent the private sector in the region where wages are low.
(3) By comparing relevant statistical data, it can be seen from Table 5 that the private sector has a higher wage level (in this article, the provincial administrative district with a comprehensive score greater than 0 is defined as the higher wage level of the private sector), the level of development is also good,

Table 5 Principal component scores and comprehensive scores of each region

Provinces	Y1	Y2	Y3	Y4	Y	Rank
Beijing	10.585	0.183	1.815	0.553	7.148	1
Tianjin	5.673	1.982	−1.048	0.707	3.908	2
Zhejiang	4.353	−1.004	0.110	−1.353	2.737	3
Jiangsu	4.145	−0.843	−0.682	−1.043	2.583	4
Chongqing	3.479	1.077	0.817	0.447	2.466	5
Guangdong	4.101	−2.504	−0.850	−0.713	2.409	6
Fujian	3.229	0.320	−1.239	0.236	2.108	7
Shandong	2.504	1.172	−0.325	0.817	1.782	8
Inner mongolia	1.872	2.059	−0.521	0.435	1.416	9
Shanghai	2.233	−4.674	0.689	1.235	1.148	10
Anhui	0.298	0.841	−1.038	0.762	0.249	11
Xinjiang	0.311	1.425	−0.529	−2.316	0.202	12
Sichuan	−0.143	−0.046	0.072	−1.040	−0.141	13
Liaoning	−0.320	0.354	−0.403	0.762	−0.168	14
Hebei	−1.024	0.609	−0.609	1.285	−0.600	15
Guangxi	−1.463	−0.363	−0.395	−1.035	−1.069	16
Hunan	−1.708	0.481	0.108	0.012	−1.080	17
Henan	−1.759	0.011	−0.378	−0.035	−1.186	18
Hubei	−2.046	−0.378	1.476	0.938	−1.265	19
Shanxi	−1.902	−0.234	−0.096	0.058	−1.283	20
Guizhou	−2.484	1.188	3.808	−0.014	−1.326	21
Ningxia	−2.221	0.923	−0.038	−0.172	−1.396	22
Jiangxi	−2.181	−0.318	0.601	−0.891	−1.478	23
Jilin	−2.459	−1.264	−0.016	−0.651	−1.772	24
Qinghai	−3.028	−0.617	−0.648	−0.692	−2.127	25
Shanxi	−3.481	0.739	0.894	−1.431	−2.251	26
Henan	−3.645	−0.332	−0.032	0.666	−2.415	27
Heilongjiang	−3.693	−0.068	0.037	0.597	−2.422	28
Gansu	−4.411	−0.507	−0.425	0.872	−2.951	29
Yunnan	−4.814	−0.213	−1.152	1.009	−3.225	30

indicating that there is a certain correlation between the level of wages in the private sector and the level of economic development, and further research can be conducted on the basis of this article.

6 Conclusion

Through the analysis of 19 statistical indicators of wage levels in different industries in 30 provincial administrative regions, the development level of private enterprises in different provincial administrative regions in China is studied. A region with a score greater than 0 indicates that the wage level of the private sector has developed fairly well, and a region with a combined score of less than 0 indicates that the wage level of the private sector is developing poorly. Among them, the private enterprise in Beijing has the highest comprehensive score of wages, which is much higher than other provincial-level administrative regions. There is a certain degree of similarity between the level of wages of private enterprises in various regions and their level of economic development.

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Study on the Improvement Strategy of Urban Traffic Congestion in Shandong Province Based on Internet of Things

Xiaoli Li, Haifeng Wang and Lijing Yu

Abstract The acceleration of urbanization raise higher challenges to traffic fluency. The contradiction between public travel demand and transportation carrying capacity has become increasingly prominent, and the traffic congestion problem is showing an upward trend. Under the background, the paper combines the current situation of urban traffic in Shandong Province, and integrates related technologies of the Internet of Things, proposes the traffic congestion improvement strategies with the characteristics of information sharing, forecasting intelligence and regulatory integration, provides real-time comprehensive and authoritative information for the traffic, provides theoretical support for optimizing the current status of urban traffic in Shandong Province.

Keywords Internet of Things · Intelligent transportation · Congestion

1 Introduction

Accompanied by the accelerating pace of urban development, urban traffic faces increasing pressure. As one of the provinces with the highest population scale and economic strength, actively using intelligent means to optimize urban traffic and laying track for the overall development of the national economy become extremely urgent for Shandong Province.

From the data presented in Table 1, we can easily see the total population and private car ownership in Shandong Province have shown an upward trend in recent years, especially the increase in the private car ownership; Although traffic mileage and railway mileage have also shown an increasing trend, per capita urban road area has stagnated or even declined. A series of data indicates that the traffic situation in Shandong Province is facing severe challenges in the new era.

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Table 1 Statistics of some indicators of Shandong traffic over the years

Compare items	Years		
	2014	2015	2016
Total population (Ten thousand)	9789.43	9847.16	9949.64
Urban population density (People/km^2)	1426	1452	1502
Private car ownership (unit)	12443277	13911321	15791483
Highway mileage (km)	259514	263447	265720
Railway traffic mileage (km)	4546	4863	4882
Inland navigation mileage (km)	1150	1150	1150
Per capita urban road area (m^2)	25.8	25.8	24.7

Note The data comes from 《Shandong Statistical Yearbook》 (2014, 2015, 2016) [1–3]

For traffic conditions, different studies give different classifications. According to the relevant regulations of "Urban Traffic Operations Evaluation Standards", urban road traffic conditions are basically divided into: smooth, basic, mild, moderate, and severe congestion [4]. According to investigations by relevant departments, Jinan ranked 1st in the "China Block City Ranking" published in January 2018, 18 in Yantai, and 20 in Tai'an. In the investigation of traffic congestion in 294 prefecture-level cities in China, Shandong Province occupies 3 seats in the top 20 provinces. It also shows that the urban traffic in Shandong Province is facing a severe test, and it is urgently needed to scientifically plan and rationally allocate it based on the existing conditions. Under the "Internet +" environment, we will actively play our network advantage and rely on the Internet of Things technology to fully integrate "Intelligent" resources and reduce congestion.

This paper is based on the Reality of urban traffic in Shandong, using the Internet of Things technology, building an intelligent platform and proposes improved strategies for improving the urban traffic congestion in Shandong Province.

2 Internet of Things Technology in Intelligent Transportation

The Internet of Things is widely used in modern intelligent transportation for traffic congestion management and grooming, traffic incident management, regional road network traffic flow organization, road network control and guidance, extraction of traffic flow features, and traffic status discrimination and forecasting. For urban transport, the main application scenarios include the following.

2.1 Intelligent Electronic License Plate

The intelligent electronic license plate refers to the high-precision identification, high-accuracy acquisition, and high-sensitivity technical features of the integrated radio frequency identification technology. An electronic license plate label is installed on the basis of an ordinary license plate, and an RFID electronic license plate is used as a vehicle information carrier. When passing through a section equipped with an authorized RFID reader, data on smart vehicle license plates of each motor vehicle is collected or written. The emergence of intelligent electronic license plates allows vehicles to have an "Identity Card" that uniquely identifies information. This played a role in reducing the number of violations such as decking, counterfeit cards, and license plate alterations.

With intelligent devices and wireless networks, information reading of intelligent electronic license plates can be achieved. At the same time, dynamic information such as vehicle speed and positioning can be obtained. By integrating the reading of other Internet of Things technologies, we can accurately achieve real-time traffic flow statistics. This will provide a basis for traffic forecasting and also provide information support for the work of the relevant law enforcement or management department.

2.2 Electronic Police

The setting up of the electronic police is mainly for the service of the public security organs. The intelligent monitoring system for the transportation industry adopts the most advanced video detection technologies and algorithms to implement video surveillance systems, Red light electronic police system, speeding electronic police systems, security subsystems and other subsystems. Through the system platform which integrated the powerful management functions and information processing functions can integrate various functional subsystems such as illegal processing, information management, media scheduling, central storage, information release, comprehensive inquiry, and emergency command, thus forming a complete intelligent transportation system.

2.3 Intelligent Parking System

The realization principle of the intelligent parking system is based on wireless network communication technology, GPS positioning technology, GIS positioning technology and related mobile terminals and other technologies that are applied to the collection, query, management and prompt information push of the city parking space information, so that the parking information is updated in time, push in time, and strive to achieve the maximum utilization of parking lot resources, the optimization of parking facilities for car owners and the maximization of car park profits.

2.4 Intelligent Bus

The principle of intelligent public transportation is based on on-board GPS devices, cameras and various sensors installed on buses. The intelligent public transportation system can be used for real-time positioning and automatic tracking of vehicles, real-time display and statistics of operational information, history (track) record query playback, image monitoring and operations. Line settings, over speed, cross-border and cross-line alarm, vehicle rollover and collision alarm, illegal door opening alarm function, information notification function and scheduling information display, driving recorder and remote wireless collection, full speed, trajectory curve analysis, vehicle history speed Curves and reports, vehicle comprehensive information query, station management and automatic reporting station functions.

3 The Improvement Strategy of Urban Traffic Congestion in Shandong Province Based on Internet of Things

3.1 Perfect Shandong Traffic Information Sharing Platform

The main body of traffic consists of people, cars and roads. Loss of information from any party will affect the comprehensiveness of real-time traffic information prediction. Under the “Internet +” context, it is particularly important to integrate the Internet of Things technology to obtain full-fledged information and improve Shandong’s traffic information sharing platform.

The content of the information sharing platform is actually a complex of multiple data sources. At present, information about people, vehicles, and roads exists in different databases. The data sharing platform achieves the purpose of sharing by realizing the interconnection, conversion, and sharing of these homogeneous or heterogeneous data. The data stored in the information sharing platform can be divided into dynamic data, static data, and historical data from the type. The dynamic data is obtained through intelligent traffic monitoring systems, such as traffic flow, environmental status information, real-time vehicle information, traffic management information, and road maintenance information. Static information data includes road network basic information, traffic facility distribution information, and the like. Dynamic information and static information become history information after being extracted, transformed, loaded, and refreshed. Because the data formats adopted by these data are not the same, they must also undergo data conversion, reorganization and normalization, and then be stored in the database to form a unified format of data.

3.2 Promotion of Regional Intelligent Parking System Applications

The convenience of parking also has a direct or indirect effect on traffic congestion to a certain extent. With the acceleration of urbanization and the increase of urban population, urban land use is more precious. The reality is a lot more intense residential area parking, public parking spaces are slightly lacking. Especially in public places close to the main arterial line, if the parking is difficult, it will have a direct impact on traffic congestion on the road section.

With the support of Internet of Things technology, the setting of the intelligent parking system can improve the problem of parking difficulties to a certain extent. Each parking space in the intelligent parking lot shall be equipped with a parking space detector to obtain the real-time status information of the parking space and pass it to the data processing terminal through the relevant information transmission system. The terminal system integrated intelligent traffic integrated management system and intelligent electronic license plate information to push free parking space information to the vehicles in the vicinity of the path, and at the same time, the parking space status information is displayed at the entrance of the parking lot and in a conspicuous position. This can reduce the driver's time for finding a parking space and guides the driver to a smooth stop. This has an indirect mitigation effect on the amount of traffic congestion, especially on the critical road sections of the city.

3.3 Improve the Intelligence of Traffic Induction and Guidance System

The induction is a prerequisite in the improvement strategy of urban traffic jams, and the grooming strategy is the key. The phenomenon of urban traffic congestion is an unavoidable event at present, and the occurrence of congestion requires the support of appropriate evacuation strategies to ease traffic. The paper deduces the application of intelligent grooming system with the support of Internet of Things technology.

The intelligence of traffic induction system refers to the convergence of IoT technologies, big data, and GPS positioning technology. It enables data acquisition and timely analysis of vehicles and roads, and provides drivers with real-time information such as traffic safety, weather, and road availability. The implementation of the traffic induction and guidance system mainly combines with the intelligent traffic integrated monitoring system in the intelligent traffic integrated management system, and calculates the traffic flow in real time through wireless sensor technology, electronic license plate information and video data. The results of the calculations are fed back to the road operating status map in a timely manner. At the same time, information is displayed on key road sections such as traffic displays, the Internet, and navigation devices. In this way, traffic participants can obtain road information in time and change routes in time to avoid congestion.

The intelligent principle of the traffic grooming system is: Analyze the abnormal data in the induced intelligent system against the system evaluation model, analyze the cause of traffic jams, and independently adjust the congestion line signal time for signal sections, and extend the congestion direction time; For the absence of traffic light segments, GPS vehicle positioning data acquisition, analysis of the cause of congested road segments, forecast congestion market, push information to the vehicles about to enter the road section, to achieve the purpose of intelligent grooming.

3.4 Building Intelligent Traffic Integrated Management System in Shandong Province

The improvement of urban traffic congestion needs the support of full information. The integration of Internet of Things technology and big data technology collects and analyzes traffic information in real time, and provides behavioral decision support or data reference for traffic participants or managers. The main components and operating mechanism of the system are shown in Fig. 1.

The system is mainly composed of an intelligent traffic comprehensive monitoring system, an intelligent traffic comprehensive analysis system, an intelligent

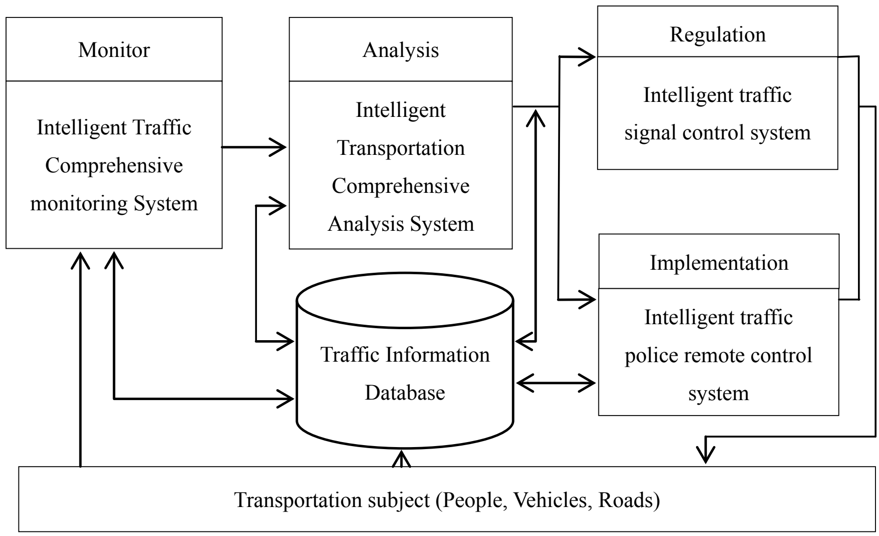

Fig. 1 The operational mechanism of intelligent transportation integrated management system in Shandong Province

traffic signal control system, an intelligent traffic warning remote control system, and a traffic information database. The operating mechanism of the system is based on the "Monitor-Analysis-Adjustment-Implementation" mechanism. Its operation object is the main body of traffic.

The intelligent traffic comprehensive monitoring system is a prerequisite for the successful operation of the intelligent traffic integrated management system. The subsystem automatically monitors event data and traffic flow data according to different road conditions under the support of video surveillance data and microwave wireless technology and provides data support for the intelligent traffic comprehensive analysis system.

The main responsibility of the intelligent transportation comprehensive analysis system is to perform cluster analysis on the data pushed in the previous stage and obtain the current road operation status. For normal flow data storage, alarms need to be issued for abnormal data; congested road sections need traffic signal control to push information to intelligent traffic signal control system; for accidents, illegal road sections information must be pushed to intelligent traffic police remote control system to implement decision making.

The premise of the implementation of the intelligent traffic signal control system is to achieve full coverage of the traffic signal control point, from the original regional traffic signal point to the provincial traffic signal control surface. Traffic on all surfaces must be under the centralized control of the traffic control center, and the abnormal data of the analysis results can be combined with the intelligent traffic grooming system to regulate and control work.

The main purpose of the intelligent traffic control remote control system is to promote the remote control of the traffic police. With advanced technology, it helps in the smart regulations of traffic accidents and the timely handling of traffic accidents. Relying on the Internet platform, it can quickly handle traffic accidents and prevent traffic accidents from escaping. Make the traffic police want to be smart, fast and accurate.

4 Conclusion

The promotion of smart cities provides hardware and technical support for solving the current status of urban traffic congestion. With the support of Internet of Things technology, it improves the traffic information sharing platform, promotes the application scope of regional intelligent parking systems, and improves the intelligence of traffic grooming systems and the intelligent traffic integrated management system. The promotion can relieve the current situation of urban traffic congestion. To a certain extent, it can improve the overall control and information service level of urban traffic in Shandong Province. It will provide strong technical support for intelligent analysis of traffic information and changes in traffic management models.

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Inventory Lot-Sizing Optimization with Supplier Selection Under Uncertain Environment

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Abstract This paper considers inventory lot-sizing optimization with supplier selection (LS-SS) problem under uncertain environment where the demand of products, the supplier-dependent transportation costs and the quality level of products are all known but not exactly. These uncertain quantities are modeled by using uncertainty theory which has been proved to be more suitable to model uncertain quantities than probability theory and fuzzy theory in some situations. An uncertain integer linear programming model is presented and then converted to equivalent crisp model and is solved with a genetic algorithm. Finally, a numerical example is show to illustrate the effectiveness of the proposed algorithm.

Keywords Inventory · Lot-sizing · Supplier selection · Uncertainty theory · Genetic algorithm

1 Introduction

Inventory lot-sizing optimization with supplier selection (LS-SS) problem is a decision-making optimization problem that has attracted much attention in the field of logistics and supply chain management in recent years [1]. The goal of this problem is to decide what products to order in what quantities with which suppliers in which periods.

This problem consists of two subproblems: inventory lot-sizing problem and supplier selection problem. The problem of inventory lot-sizing is to determine the optimal production quantity or purchasing quantity of the product in each period in a multi-period situation. The problem of supplier selection is to determine the best supplier of the product in a multi-supplier situation. With the increasing importance of supply chain management, few papers [2–5] take a combined look at the above

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two problems and proposed a LS-SS model. The enterprise decision-making in real life is always contained with multi-product, multi-period and multi-supplier. Therefore, the LS-SS model has strong practical significance and high research value.

Few researchers [1, 6, 7] noticed the stochastic and recognitive uncertainties in this model and developed the LS-SS model under uncertain demand and costs. Purohit et al. [1] proposed an integer linear programming model under non-stationary stochastic demand. Rezaei and Davoodi [6] considered demand and inventory costs as fuzzy numbers and formulated the LS-SS problem as a fuzzy mixed integer programming. However, the requirement of large sample size and strong subject knowledge to build suitable distribution function or fuzzy membership function restrict the applicability of probability theory and fuzzy theory in LS-SS problem. In fact, neither probability theory or fuzzy theory is suitable for uncertain quantities when the sample size is too small (even no-sample) [8]. Therefore, it is necessary to seek a more applicable mathematical theory to model uncertainty.

In order to model uncertainty, the uncertainty theory was founded by Liu [9] in 2007 and refined by Liu [10] in 2010. In recent years, it has been widely used in the field of science and engineering [11–14]. It has not been found that the uncertainty theory is used in LS-SS problem. For this reason, an uncertain integer linear programming model is proposed in this paper.

The remainder of this paper is organized as follows. In Sect. 2, some basic concepts and results of uncertainty theory are introduced. In Sect. 3, a LS-SS model based on uncertainty theory is presented and converted to equivalent crisp model. In Sect. 4, a genetic algorithm is presented to solve this model. In Sect. 5, a numerical example is shown to illustrate the effectiveness of the proposed algorithm. Finally, in Sect. 6, conclusions and suggestions for future research are provided.

2 Uncertainty Theory

As mentioned before, uncertainty theory was founded by Liu in 2007 and refined by Liu in 2010. There are three fundamental concepts in this theory: uncertain measure, uncertain variable and uncertain distribution. Interested readers may refer to papers [8–10] for more details. Some useful definitions and theorems of uncertainty theory are outlined as follows:

Definition 1 (Liu [9]) Let Γ be a nonempty set, and let A be a σ-algebra over Γ. Each element of $A$is called an event. A set function M is called an uncertain measure if and only if it satisfies the following four axioms:

Axiom 1 (*Normality*) $\mathcal{M}\{\Gamma\} = 1$;

Axiom 2 (*Monotonicity*) $\mathcal{M}\{A\} \leq \mathcal{M}\{B\}$ whenever $A \subseteq B$;

Axiom 3 (*Self-Duality*) $\mathcal{M}\{A\} + \mathcal{M}\{A^c\} = 1$ for any event A;

Axiom 4 (*Countable Subadditivity*) $\mathcal{M}\{[U_i A_i\} \le \sum_1^\infty \mathcal{M}\{A_i\}$ for any countable sequence of events $\{A_i\}$.

Definition 2 (Liu [9]) Let Γ be a nonempty set, and let A be a σ-algebra over it. If M is an uncertain measure, then the triplet (Γ, A, M) is called an uncertainty space.

Definition 3 (Liu [9]) Uncertain variable n is defined as a measurable function from an uncertainty space (Γ, A, M) to the set of real numbers R. That is, for any Borel set B, we have: $\{\gamma \in \Gamma | \xi(\gamma) \in B\} \in A$.

Definition 4 (Liu [9]) Let ξ be an uncertain variable. Then the expected value of n is defined as below provided that at least one of the two integrals is finite:

$$\mathrm{E}[\xi] = \int_0^\infty \mathcal{M}\{\xi \ge x\}dx - \int_{-\infty}^0 \mathcal{M}\{\xi \le x\}\mathrm{d}x \tag{1}$$

Theorem 1 (Liu [9]) *Let ξ be an uncertain variable with regular uncertainty distribution Φ and inverse uncertainty distribution Φ^{-1}. Then the expected value of the uncertain variable ξ with regular uncertainty distribution Φ is:*

$$\mathrm{E}[\xi] = \int_0^1 \Phi^{-1}(\alpha)\mathrm{d}\alpha \tag{2}$$

Theorem 2 (Liu [9]) *Let ξ, η be uncertain variables with regular uncertainty distribution Φ_1, Φ_2, respectively. Then for any real numbers a and b, we have:*

$$\mathrm{E}[a\xi + b\eta] = a\mathrm{E}[\xi] + b\mathrm{E}[\eta] \tag{3}$$

Theorem 3 (Liu [9]) *Assume $f(x, \xi_1, \xi_2, \ldots, \xi_n)$ is strictly increasing with respect to $\xi_1, \xi_2, \ldots, \xi_m$ and strictly decreasing with respect to $\xi_{m+1}, \xi_{m+2}, \ldots, \xi_n$, and $g_j(x, \xi_1, \xi_2, \ldots, \xi_n)$ are strictly increasing with respect to $\xi_1, \xi_2, \ldots, \xi_k$ and strictly decreasing with respect to $\xi_{k+1}, \xi_{k+2}, \ldots, \xi_n$* for *$j = 1, 2, \ldots, p$. If $\xi_1, \xi_2, \ldots, \xi_n$ are independent uncertain variables with regular uncertainty distributions $\Phi_1, \Phi_2, \ldots, \Phi_n$, respectively, then the uncertain programming*

$$\begin{cases} \min \mathrm{E}[\mathrm{f}(x, \xi_1, \xi_2, \ldots, \xi_n)] \\ s.t. \\ \mathcal{M}\{g_j(x, \xi_1, \xi_2, \ldots, \xi_n) \le 0\} \ge \alpha_j, \quad j = 1, 2, \ldots, p. \end{cases} \tag{4}$$

is equivalent to the crisp mathematical programming:

$$\begin{cases} \min \int_0^1 f\big(x, \Phi_1^{-1}(\alpha), \ldots, \Phi_m^{-1}(\alpha), \Phi_{m+1}^{-1}(1-\alpha), \ldots, \Phi_n^{-1}(1-\alpha)\big) \mathrm{d}\alpha \\ s.t. \\ g_j\big(x, \Phi_1^{-1}(\alpha_j), \ldots, \Phi_k^{-1}(\alpha_j), \Phi_{k+1}^{-1}(1-\alpha_j), \ldots, \Phi_n^{-1}(1-\alpha_j)\big) \le 0, \quad j = 1, 2, \ldots, p. \end{cases} \tag{5}$$

Theorem 4 (Liu [9]) *Let* ξ *be a normal uncertain variable* $N(e, \sigma)$ *with regular uncertainty distribution* Φ *and inverse uncertainty distribution* Φ^{-1}. *The inverse uncertainty distribution of normal uncertain variable* ξ *is*:

$$\Phi^{-1}(\alpha) = e + \frac{\sigma\sqrt{3}}{\pi} \ln \frac{\alpha}{1-\alpha} \tag{6}$$

3 Mathematical Modeling

Based on the existing research results and uncertainty theory, an uncertain integer linear programming model is presented and then converted to equivalent crisp model in this section. The objective function of this model is the total costs (TC) which is formulated as the sum of net purchase costs, ordering costs, holding costs and transportation costs in all periods. The constraints of this model are formulated as demand constraint, storage capacity constraint, quality level constraint, supplier capacity constraint and transportation ability constraint. The uncertain demand, uncertain transportation cost and uncertain quality level are all represented as uncertain variables. The following notations are used to formulate this model.

3.1 Notations

Indices:	
i	index of products $(i = 1 \ldots I)$
j	index of suppliers $(j = 1 \ldots J)$
t	index of periods $(t = 1 \ldots T)$
Parameters:	
p_{ij}	net purchase cost of product i from supplier j
o_j	ordering cost for supplier j
h_i	holding cost of product i per period
c_{ij}	capacity of supplier j in production of product i per period
m_i	minimum acceptable quality level of product i
v_j	vehicle capacity of supplier j

(continued)

(continued)

w_i	occupied space by product i in warehouse or vehicle
W	total storage capacity
d_{it}	uncertain demand of product i in period t
g_j	uncertain transportation cost for supplier j per vehicle
f_{ij}	uncertain quality level of product i offered by supplier j
Φ_{it}	uncertainty distribution of uncertain variable d_{it}
G_j	uncertainty distribution of uncertain variable g_j
F_{ij}	uncertainty distribution of uncertain variable f_{ij}
α_1	confidence level that the demand constraint is satisfied
α_2	confidence level that the storage capacity constraint is satisfied
α_3	confidence level that the quality level constraint is satisfied
Decision variables:	
x_{ijt}	number of product i ordered from supplier j in period t
y_{jt}	binary integer: 1, if the order is given to supplier j in period t, 0, otherwise
z_{jt}	number of vehicles required by supplier j in period t

3.2 Objective Function

Net purchase costs:

$$\sum_i \sum_j \sum_t p_{ij} x_{ijt} \tag{7}$$

Ordering costs:

$$\sum_j \sum_t o_j y_{jt} \tag{8}$$

Holding costs:

$$\sum_i \sum_t h_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik} \right) \tag{9}$$

Transportation costs:

$$\sum_j \sum_t g_j z_{jt} \tag{10}$$

Therefore the objective function of this model is formulated as follow:

$$\min \mathrm{E}\left[\sum_i \sum_j \sum_t p_{ij}x_{ijt} + \sum_j \sum_t o_j y_{jt} + \sum_i \sum_t h_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik}\right) + \sum_j \sum_t g_j z_{jt}\right] \tag{11}$$

3.3 Constraints

Demand constraint:

$$\mathcal{M}\left\{\sum_{k=1}^{t}\left(d_{ik} - \sum_j x_{ijk}\right) \le 0\right\} \ge \alpha_1 \quad \forall i, t \tag{12}$$

Storage capacity constraint:

$$\mathcal{M}\left\{\sum_i w_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik}\right) \le W\right\} \ge \alpha_2 \quad \forall t \tag{13}$$

Quality level constraint:

$$\mathcal{M}\left\{\sum_{k=1}^{t} \sum_j (m_i - f_{ij}) x_{ijk} \le 0\right\} \ge \alpha_3 \quad \forall i, t \tag{14}$$

Supplier capacity constraint:

$$x_{ijt} \le c_{ij} y_{jt} \quad \forall i, j, t \tag{15}$$

Transportation ability constraint:

$$\sum_i w_i x_{ijt} \le v_j z_{jt} \quad \forall j, t \tag{16}$$

Binary and non-negativity constraints:

$$y_{jt} = 0 \text{ or } 1 \quad \forall j, t \tag{17}$$

$$x_{ijt} \ge 0 \quad \forall j, t \tag{18}$$

3.4 Uncertain Programming Model

The resulting uncertain integer linear programming model looks as follows:

$$\begin{cases} \min \mathrm{E}\left[\sum_i \sum_j \sum_t p_{ij} x_{ijt} + \sum_j \sum_t o_j y_{jt} + \sum_i \sum_t h_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik}\right) + \sum_j \sum_t g_j z_{jt}\right] \\ s.t. \\ \mathcal{M}\left\{\sum_{k=1}^{t}\left(d_{ik} - \sum_j x_{ijk}\right) \le 0\right\} \ge \alpha_1 \quad \forall i, t \\ \mathcal{M}\left\{\sum_i w_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} d_{ik}\right) \le W\right\} \ge \alpha_2 \quad \forall t \\ \mathcal{M}\left\{\sum_{k=1}^{t} \sum_j (m_i - f_{ij}) x_{ijk} \le 0\right\} \ge \alpha_3 \quad \forall i, t \\ 0 \le x_{ijt} \le c_{ij} y_{jt} \quad \forall i, j, t, \\ y_{jt} = 0 \, or \, 1 \quad \forall j, t \\ \sum_i w_i x_{ijt} \le v_j z_{jt} \quad \forall j, t \end{cases} \tag{19}$$

3.5 Equivalent Crisp Model

Taking advantage of Theorems 1–3, Eq. 11 is equivalent to Eq. 20.

$$\begin{aligned} \min & \sum_i \sum_j \sum_t p_{ij} x_{ijt} + \sum_j \sum_t o_j y_{jt} \\ & + \sum_i \sum_t h_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} \int_0^1 \Phi_{ik}^{-1}(1-\alpha) \mathrm{d}\alpha\right) \\ & + \sum_j \sum_t z_{jt} \int_0^1 G_j^{-1}(\alpha) \mathrm{d}\alpha \end{aligned} \tag{20}$$

Similarly, Eqs. 12–14 is equivalent to Eqs. 21–23.

$$\sum_{k=1}^{t}\left(\Phi_{ik}^{-1}(\alpha_1) - \sum_j x_{ijk}\right) \le 0 \quad \forall i, t \tag{21}$$

$$\sum_i w_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} \Phi_{ik}^{-1}(1-\alpha_2)\right) \le W \quad \forall t \tag{22}$$

$$\sum_{k=1}^{t}\sum_{j}\Big(m_i - F_{ij}^{-1}(1-\alpha_3)\Big)x_{ijk} \le 0 \quad \forall i, t \tag{23}$$

Finally, the mathematical model 19 can be transformed into its equivalent crisp model as shown in 24.

$$\begin{cases} \min \sum_i \sum_j \sum_t p_{ij}x_{ijt} + \sum_j \sum_t o_j y_{jt} \\ \quad + \sum_i \sum_t h_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} \int_0^1 \Phi_{ik}^{-1}(1-\alpha)\mathrm{d}\alpha \right) \\ \quad + \sum_j \sum_t z_{jt} \int_0^1 G_j^{-1}(\alpha)\mathrm{d}\alpha \\ s.t. \\ \quad \sum_{k=1}^{t} \left(\Phi_{ik}^{-1}(\alpha_1) - \sum_j x_{ijk} \right) \le 0 \quad \forall i, t, \\ \quad \sum_i w_i \left(\sum_{k=1}^{t} \sum_j x_{ijk} - \sum_{k=1}^{t} \Phi_{ik}^{-1}(1-\alpha_2) \right) \le W \quad \forall t, \\ \quad \sum_{k=1}^{t} \sum_j \Big(m_i - F_{ij}^{-1}(1-\alpha_3)\Big)x_{ijk} \le 0 \quad \forall i, t, \\ \quad 0 \le x_{ijt} \le c_{ij}y_{jt}, \quad \forall i, j, t, \\ \quad y_{jt} = 0 \text{ or } 1, \quad \forall j, t, \\ \quad \sum_i w_i x_{ijt} \le v_j z_{jt}, \quad \forall j, t. \end{cases} \tag{24}$$

In this paper, the d_{it} is assumed to be a normal uncertain variable $N(e_{it}^d, s_{it}^d)$, the g_j is assumed to be a normal uncertain variable $N(e_j^g, s_j^g)$, and the f_{ij} is assumed to be a normal uncertain variable $N(e_{ij}^f, s_{ij}^f)$, then according to Theorem 4, the sign of integration and the inverse distribution functions in model 24 can be transformed into flows:

$$\int_0^1 \Phi_{ik}^{-1}(1-\alpha)\mathrm{d}\alpha = \mathrm{e}_{ik}^d \tag{25}$$

$$\int_0^1 G_j^{-1}(\alpha)\mathrm{d}\alpha = e_j^g \tag{26}$$

$$\Phi_{ik}^{-1}(\alpha_1) = e_{ik}^d + \frac{\sqrt{3}s_{ik}^d}{\pi}\ln\frac{\alpha_1}{1-\alpha_1} \tag{27}$$

$$\Phi_{ik}^{-1}(1-\alpha_2) = e_{ik}^d + \frac{\sqrt{3}s_{ik}^d}{\pi}\ln\frac{1-\alpha_2}{\alpha_2} \tag{28}$$

$$F_{ij}^{-1}(1-\alpha_3) = e_{ij}^f + \frac{\sqrt{3}s_{ij}^f}{\pi}\ln\frac{1-\alpha_3}{\alpha_3} \tag{29}$$

4 Genetic Algorithm

Genetic algorithm (GA) is a random search and optimization algorithm based on biological natural selection and genetic mechanism. The algorithm provides a general framework for solving complex system optimization problems. With strong robustness, GA is independent of the type and optimization function of the problem. In recent years, it has been widely used in function optimization, combinatorial optimization, production scheduling and supply chain management. For the first time, Rezaei and Davoodi applied this algorithm to the LS-SS problem and obtained good results.

Unlike traditional search algorithms, the idea of GA is to start with a random set of initial solutions, each feasible solution of the problem is represented as an chromosome, called individual, and a set of individual are called population. The population iteratively evolve through three operators: selection, crossover and mutation. The selection operator selects a certain number of individuals as the parent of next generation from the current population according to individual fitness. The crossover and mutation operators are responsible for generating new individuals. The fitness of a individual is measured by fitness function, which depends on the value of objective function. After several generations, the algorithm converges to the best individual, which is probably the optimal solution or suboptimal solution of the problem.

Based on the above analysis, this paper choose GA to solve the above mathematical model. The Solving steps and details of GA are given below.

4.1 Solving Steps

Step 0: Parameter setting. Set the length of chromosome (L), the size of population (N), the maximum generation number (G), the crossover probability (P_c) and the mutation probability (P_m). Also, set the current generation counter $t = 0$.

Step 1: Randomly generate N feasible solutions. These N feasible solutions are encoded as N chromosomes, and form the initial population P_t.

Step 2: Calculate the fitness of each individual in P_t according to the value of objective function. Rank all individuals in P_t from large to small according to fitness.

Step 3: Select N individuals by using selection operator from P_t to form the parent population Q_t of next generation P_{t+1}.

Step 4: Generate P_{t+1} by using crossover operator with probability P_c and mutation operator with probability P_m.

Step 5: Calculate the fitness of each individual in P_{t+1} according to the value of objective function. The smaller the value of the individual's objective function, the higher the individual's fitness. Rank all individuals in P_{t+1} from low to high according to fitness. Set $t = t + 1$.

Step 6: Repeat the step 3 to step 5 until $t = G$.

Step 7: Return the best individual in P_t, which is the optimal solution of this model.

4.2 Encoding

The encoding operation represents the feasible solution of the problem as a vector, called chromosome. There are two common used encoding methods including binary encoding and real-number encoding. The former is suitable for smaller solution space and the latter is suitable for larger solution space. The solution space of this model is $I \times J \times T$, which is a large space. In this reason, this paper take each chromosome as a integer vector by length $I \times J \times T$, which contains the value of each x_{ijt} (see Fig. 1).

4.3 Selection Operator

The selection operator selects N individuals from P_t to form the parent of next generation. The detailed steps for this operator are as follows.

Step 1: Set $Q_t = \varnothing$, and current individual index $c = 1$.

Step 2: Randomly generate two numbers r_1, r_2 between 1 and N. If $r_1 < r_2$, then add the individual r1 to Q_t. If $r_2 < r_1$, then add the individual r2 to Q_t. Set $c = c + 1$.

Step 3: Repeat the step 2 until $c = N$.

Step 4: Return Q_t.

x_{IJT}	x_{IJT-1}	$\cdots$	x_{ijt}	$\cdots$	x_{112}	x_{111}

Fig. 1 Chromosome encoding

4.4 Crossover Operator

The crossover exchanges two partial chromosomes with each other in a certain way to form two new individuals. This operation is an important feature of GA that distinguishes it from other evolutionary algorithms. It is the main method of generating new individuals and therefore plays a key role in GA. The detailed steps for this operator are as follows.

Step 1: Set the current individual indexes $s_1 = 1$, $s_2 = N$.

Step 2: Randomly generate a number r between 1 and N. If $r < P_c$, then go to the next step. Otherwise, skip to step 5.

Step 3: Assume that the chromosome of individual S_1 in Q_t is C_1 and the chromosome of individual s_2 in Q_t is C_2. Create two chromosomes D_1, D_2. Randomly generate a number r between 0 and 1. Set k = 1. Do:

$$\begin{aligned} D_1[k] &= r \times C_1[k] + (1-r) \times C_2[k] \\ D_2[k] &= (1-r) \times C_1[k] + r \times C_2[k] \\ k &= k+1 \end{aligned}$$

while $k < L$.

Step 4: If $D1$ satisfies the constraints, save $D1$ as individual s_1. If $D2$ satisfies the constraints, save $D2$ as individual s_2.

Step 5: Set $s_1 = s_1 + 1$ and $s_2 = s_2 - 1$.

Step 6: Repeat the step 2 to step 5 until $s1 \geq s2$.

Step 7: Return Q_t.

4.5 Mutation Operator

The mutation operator replaces certain gene values in the chromosome with other gene values to form a new individual. This operator is an auxiliary method to generate new individuals. But it is an essential operator which determines the local search ability of the genetic algorithm. The crossover operator and mutation operator cooperate to complete the global search and local search for the search space. The detailed steps for this operator are as follows.

Step 1: Set the current chromosome index $s = 1$.

Step 2: Randomly generate a number r between 1 and N. If $r < P_m$, then go to the next step. Otherwise, skip to step 5.

Step 3: Assume that the chromosome of individual s in Q_t is C. Randomly change the value of $C[k]$ for each k between 1 and L.

Step 4: If C satisfies the constraints, save C as individual s.

Step 5: Set $s = s + 1$.

Step 6: Repeat the step 2 to step 5 until $s = N$.

Step 7: Return Q_t as next generation P_{t+1}.

5 Numerical Example

In this section, a simple case example and a Real Parameter Genetic Algorithm are used to illustrate procedure of the proposed model. This paper considers a scenario with three products ($I = 3$), four periods ($T = 4$) and five suppliers ($J = 5$). The program was written in C and run on Windows 7 with a total run time of 931.18 s. The data and results of this example are shown below. The uncertain demand of each product in each period are shown in Table 1. The holding cost, occupied space and minimum acceptable quality level of each product are show in Table 2. The ordering cost, vehicle capacity and uncertain transportation cost for each supplier are show in Table 3. Other parameters are show in Table 4. The decision of this example are show in Table 5, 6 which indicate what products to order in what quantities with which suppliers in which periods. The results of model by GA, including the length of chromosome (L), the population size (N), the maximum generation number (G), the rate of mutation operation ($P1$) and the rate of crossover operation ($P2$) are show in Table 7.

Table 1 d_{it}

d_{it}	$t = 1$	$t = 2$	$t = 3$	$t = 4$
$i = 1$	N(15.09, 18.93)	N(27.41, 13.44)	N(23.97, 16.08)	N(14.14, 10.35)
$i = 2$	N(36.59, 17.02)	N(28.30, 17.75)	N(10.68, 13.72)	N(32.77, 11.82)
$i = 3$	N(25.12, 12.49)	N(25.29, 14.36)	N(23.26, 17.10)	N(16.95, 11.07)

Table 2 h_i, w_i and m_i

	h_i	w_i	m_i
$i = 1$	2.17	3.51	0.73
$i = 2$	8.72	1.74	0.76
$i = 3$	7.78	4.29	0.71

Table 3 o_j, v_j and g_j

	o_j	v_j	g_j
$j = 1$	155.76	6.85	N (58.56, 28.55)
$j = 2$	190.54	8.50	N (45.35, 13.43)
$j = 3$	125.89	9.02	N (57.51, 29.31)
$j = 4$	167.49	8.91	N (57.30, 29.16)
$j = 5$	122.97	8.14	N (51.21, 29.79)

Table 4 Other parameters

	i	j				
		1	2	3	4	5
p_{ij}	1	18.66	14.84	18.07	10.55	19.57
	2	17.86	16.55	13.99	18.77	16.20
	3	12.56	13.28	10.45	13.36	17.69
c_{ij}	1	9	19	7	14	6
	2	19	17	17	15	6
	3	8	10	16	9	12
f_{ij}	1	$N(0.89, 0.07)$	$N(0.88, 0.08)$	$N(0.71, 0.02)$	$N(0.72, 0.02)$	$N(0.81, 0.08)$
	2	$N(0.76, 0.05)$	$N(0.80, 0.06)$	$N(0.85, 0.05)$	$N(0.82, 0.05)$	$N(0.84, 0.06)$
	3	$N(0.83, 0.07)$	$N(0.81, 0.07)$	$N(0.76, 0.03)$	$N(0.79, 0.07)$	$N(0.71, 0.07)$
$W = 246.94$						
$\alpha 1 = 0.60$. $\alpha 2 = 0.82$, $\alpha 3 = 0.74$						

Table 5 x_{ijt}

x_{111}	3	x_{141}	13	x_{221}	9	x_{251}	4	x_{331}	8
x_{112}	0	x_{142}	0	x_{222}	13	x_{252}	3	x_{332}	15
x_{113}	0	x_{143}	8	x_{223}	16	x_{253}	4	x_{333}	12
x_{114}	8	x_{144}	0	x_{224}	0	x_{254}	2	x_{334}	12
x_{121}	17	x_{151}	2	x_{231}	10	x_{311}	0	x_{341}	5
x_{122}	11	x_{152}	1	x_{232}	14	x_{312}	0	x_{342}	0
x_{123}	16	x_{153}	4	x_{233}	1	x_{313}	0	x_{343}	3
x_{124}	0	x_{154}	5	x_{234}	11	x_{313}	4	x_{344}	0
x_{131}	0	x_{211}	8	x_{241}	12	x_{321}	8	x_{351}	8
x_{132}	3	x_{212}	0	x_{242}	0	x_{322}	5	x_{352}	9
x_{133}	0	x_{213}	0	x_{243}	2	x_{323}	4	x_{353}	8
x_{134}	3	x_{214}	13	x_{244}	0	x_{324}	0	x_{354}	2
$TC = 14,141.58$									

Table 6 y_{jt} and z_{jt}

	j	t			
		1	2	3	4
y_{jt}	1	1	0	0	1
	2	1	1	1	0
	3	1	1	1	1
	4	1	0	1	0
	5	1	1	1	1
z_{it}	1	4	0	0	10
	2	13	10	12	0
	3	6	11	6	9
	4	10	0	5	0
	5	6	6	7	4

Table 7 Results of model by GA

TC	Iteration 1	Iteration 100	Iteration 300	Iteration 400	Iteration 500	Iteration 600
	15,084.36	14,552.77	14,311.58	14,212.90	14,141.58	14,141.58
$L = 60$						
$N = 200$						
$G = 600$						
$P_c = 0.3$, $P_m = 0.4$						

6 Conclusion

In this paper a inventory lot-sizing optimization with supplier selection problem under uncertain environment is solved with uncertainty theory and a genetic algorithm. The proposed model does not require large sample size or strong subject knowledge. Therefore, it has strong operability and guiding significance. The results of numerical example in this paper show that the proposed algorithm is effective.

As this study is the first one that formulate LS-SS problem using uncertainty theory, the proposed model can be extended with some modifications to the complicated inventory and supply chain models, i.e. models with discount, back-ordering costs, service level, etc. Besides, with the popularity of intelligence algorithms, such as simulated annealing algorithm, neural network and tabu search, another future direction is to find more suitable intelligent algorithms for this problem.

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Maximizing Profit in Word-of-Mouth Promotion with Incremental Chance Model in a Social Network

Xiaojie Sun and Zuxiong Tan

Abstract WOM promotion can be an effective marketing strategy in social networks. Initiating from a set of influential seed customers, many other individuals can be activated to purchase the product due to WOM effects. In this paper, we study the problem of finding optimal nodes in a social network that could maximize the profit in such a viral marketing campaign. We adopt the incremental chance model to characterize the information diffusion process, which considers the complete influence. To solve this model, we design a framework of greedy algorithms that achieves a trade-off between optimality and complexity. Finally, numerical experiments are performed to demonstrate the effectiveness and efficiency of our algorithms.

Keywords Social networks · Viral marketing · Influence diffusion · Incremental chance model · Greedy algorithm

1 Introduction

The social network of interactions among a group of individuals plays an important role in the spread of ideas, information and influence. Such phenomena can often be observed in real life, when a product or an opinion wins sudden widespread popularity through word-of-mouth effects. For instance, ridesharing products such as Uber, DiDi, and the shared bicycle ofo, have achieved widespread usage largely through referrals, rather than direct advertising. By giving some free or discounted privileges to the selected group of influential individuals, the product or service will

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be widely accepted. For companies, this viral marketing method is an effective strategy to help them save promotion costs [1–3].

The problem of profit maximization can be traced back to the research of influence maximization (IM), which focuses on selecting a set of seed individuals in a social network to make a piece of information spread as wide as possible, in hope of activating the remaining individuals. Domingos and Richardson [4, 5] are the first to study influence maximization as an algorithmic problem, but their models are probabilistic, not describing diffusion influence. Afterwards, Kempe et al. [6] design two stochastic models, namely the independent cascade model and the linear threshold model, to characterize the information propagation process, then apply greedy algorithms to solve the problem. After that, the IM problem arouses great attention and the two models became the classical diffusion models that many further studies are based on [7, 8]. However, several other studies try to explore more accurate diffusion models. Even-Dar et al. [9] believe that at each time step, each person changes his opinion by choosing one of his neighbors randomly and adopting their opinion, thus propose the probabilistic voter model. Zhu et al. [10] propose the CTMC-ICM, which introduces the theory of Continuous-Time Markov Chain (CTMC) into the Independent Cascade Model (ICM). Recently, Qin et al. [11] experimentally demonstrate that IC cannot model accurately for the structure of information diffusion and thus propose the Three Steps Cascade Model. Yang et al. [12] point out in order to better capture the characteristics of real-world networks, the influence maximization-cost minimization model (IM-CM) should be adopted. Besides, Ni et al. [13] assume all nodes in the network will be ultimately influenced, so they propose the incremental chance model to characterize the complete influence.

In real life, the situation described in incremental chance model can be more often observed than before. Due to the emergency of more practical product or more efficient service, everyone in social networks may be affected. For example, people who went shopping in traditional stores ago first choose to shop online today, making the brick-and-mortar shopping style obsolete. Moreover, in the digital age, the WOM effect of purchase behaviors tend to achieve complete influence, making the commodity market greatly revolutionize. Thus, when considering the WOM effect in viral marketing, we adopt Ni's [13] model. Nevertheless, the model still has its restriction. When it represents the chance of product adoption, it only considers social effect, but not price. However, in a viral marketing, there is possibility that an individual who gets influenced by social acquaintances may not necessarily adopt a product for monetary concerns. For example, iPhone seems to create bigger buzz than any other smartphones, but its global market share fall behind Huawei and Samsung these years. It's partly due to the fact that iPhone's price is much higher than its counterparts. On the contrary, many online products account for a small market share in the beginning, but they are quickly sold out when the price is substantially dropped. Thus, price should also be considered in WOM promotion. Inspired from the reality, we introduce the factor price in the incremental chance model.

The problem of optimizing influence diffusion in social networks can be studied from various aspects. In recent decades, related literature has been growing. Qin et al. [11] and Chen et al. [14] maximize the number of ultimately influenced nodes by seeding a certain number of nodes. Long et al. [15] minimize the number of seeded nodes to achieve expected influence. Ni et al. [13, 16] minimize the complete influence time. Furthermore, some researchers consider the problem of achieving the maximum influence with the minimum cost [12, 17]. However, for a company, profit should be most emphasized in a real viral marketing, rather than influence diffusion. If a company intends to put influence maximization as its priority, it can set price as zero, or lower than cost. Obviously, it is not a wise strategy. This strategy cannot generate any profit for the company though it achieves great influence. Therefore, to be more rational, we should invert our effort to study how to maximize the profit.

However, the literature on profit maximization in social networks is far less than that on IM problem. In existing works, many researchers still use IC or LT model [7, 8]. Lu et al. [7] extend LT model to incorporate both prices and valuations, then employ hill-climbing heuristics to solve it. Tang et al. [8] adopt the IC model and combine the benefit of influence spread with the cost of seed selection to achieve maximum profit. Moreover, some studies also apply different methods in this field. Hartline et al. [18] formulate profit maximization as a NP-hard problem, but the models they propose satisfy probability distribution, not characterizing the influence diffusion. Chen et al. [19] assume agents follow the Bayesian Nash equilibrium and calculate maximum revenue in analytical methods. Besides, Xu et al. [20] conduct an empirical research to identify valuable customers for maximum profit, which includes collecting related data from SNS and mining influential users. Of all current studies, Zhou's [21] work is most similar to us. He proposes a novel model to characterize the diffusion process and designs a heuristic algorithm to seed appropriate customers. However, his model doesn't consider the price, which is rather an important factor in WOM promotion. Also, he doesn't make a pricing strategy, only think of seeding. In our work, we sensibly incorporate both price and social effects in our model, and strategically consider pricing and seeding.

In this paper, we focus on the problem how to make optimal seeding and pricing strategies in WOM promotion so that the profit is maximized. We employ the incremental chance model in [13] in the belief that the product or service will be ultimately adopted by all individuals in a social network. To be closer to reality, we extend the model by introducing the monetary factor. To reduce the expensive computing cost for the exhaustive search, we propose three heuristic methods and a balance parameter in greedy algorithms. Further, numerical experiments are performed to show that our modified greedy algorithms are able to trade off between computational complexity and solution performance. Finally, we investigate how price, target size and diffusion time affect profit.

To sum up, the main differences between our work and previous studies can be listed as follows: (1) We apply the incremental chance model to characterize influence diffusion in WOM promotion. The classical model proposed several years ago cannot accurately characterize diffusion influence in real life nowadays. The increasingly connected society we live in constantly brings about revolution to commodity markets, so complete influence is more often observed in WOM promotion. In this sense, the incremental chance model is preferable. Besides, to be more applicable in viral marketing, we incorporate monetary concerns in our model. (2) We make both seeding and pricing strategies. In order to spread information more efficiently, it is necessary to seed appropriate users, especially when the budget is limited. However, decision makers also have pricing power which is directly related to profit, so they should also consider how to make the optimal pricing strategy. (3) Our object is to achieve profit maximization, rather than influence maximization. Researches on IM problem are rather mature and systematic. Comparatively, literatures on profit maximization are still few, but bring more practical advice to viral marketing. Therefore, we focus on how to get the maximum profit through optimal seeding and pricing strategies.

The remainder of this paper is organized as follows. Section 2 briefly introduces some preliminaries of social networks and the modified incremental chance model. In Sect. 3, we describe the profit maximization problem in detail. Section 4 describes a framework of greedy algorithms for solving the problem. Next, numerical experiments are performed in Sect. 5 to show the performance of our proposed algorithms. Finally, conclusions are drawn in Sect. 6.

2 Social Network and Incremental Chance Model

A social network can be modelled as a graph that represents a group of individuals and their relationships. In our paper, we denote it as an indirected graph G-(N, E, W), where N is a set of nodes representing individuals, E is a set of edges meaning the connection between pairs of people, and W is the weight function to quantify their relationships. Since G is an indirected graph, for any pairs of node i and node j, edge (i, j) and edge (j, i) are the same. We can call node j a neighbor of i if edge (i, j) exists, and the set of i's neighbors is denoted as N(i).

The incremental chance model was especially proposed to characterize the diffusion of complete influence [13]. In this model, all nodes have two states: active and inactive. The nodes in active state means she has been influenced, vice versa. Obviously, the influencing process is progressive, that is, inactive nodes can turn active but the opposite will never happen. At each time step, the influenced degree of node j satisfies probability distribution:

$$P_t^j = \frac{\sum_{i \in N_t^a(j)} W(i,j)}{\sum_{i \in N(j)} W(i,j)} \tag{1}$$

where $N_t^a(j)$ is the set of j's active neighbors at time t, then $\sum_{i \in N_t^a(j)} W(i,j)$ quantifies the influence of active neighbors on j, while $\sum_{i \in N_t^a(j)} W(i,j)$ represents the influence of all neighbors on j. For an active node j at time t, the influence chance of p_t^j is defined as 1. At first, several nodes are targeted and set to be active, namely seeding process. After the influence diffusion triggered by these seeds, all nodes in the social network will ultimately turn active with probability 1.

However, the original incremental chance model only considers the social effect, ignoring the price, which is an important factor in the marketing campaign. On one hand, price affects people's purchase decision. On the other hand, it is directly related to profit. Thus, we need to do some modifications. Considered the fact that price plays a negative effect when people make their purchase decision, we propose our improved model as follows:

$$P_t^j = \max\left\{0, \frac{\sum_{i \in N_t^a(j)} W(i,j)}{\sum_{i \in N(j)} W(i,j)} - p\right\}, p \in [0,1] \qquad (2)$$

where p denotes the influence of price on node j and we set its value between 0 and 1. In a WOM promotion, an active node represents an individual who purchases the product. Note that $\frac{\sum_{i \in N_t^a(j)} W(i,j)}{\sum_{i \in N(j)} W(i,j)}$ is nondecreasing, as long as time is long enough, the state of all nodes will be active. That is, everyone in the social network will ultimately adopt the product, namely the complete influence is achieved.

3 Profit Maximization Problem in a Word-of-Mouth Marketing

WOM marketing has been increasing popular these years, especially when social media gets more widely use. It aims to promote the brand in limited time, attracting as many people as possible to purchase their products. Enlightened from real life, influence maximization (IM) problem has gained much attention. Since then, these IM studies have inspired WOM marketing a lot, such as: select individuals who have frequent interactions with a lot of people [13, 20], seed target nodes sequentially [22], or they provide optimal strategies when facing with incomplete information [16, 19]. However, the ultimate aim of WOM marketing campaigns is getting profit, not pursuing influence. In this sense, we should divert our attention from IM problem to profit maximization.

In our paper, we focus on the following problem. For a given social network, how to select target influential nodes and how to set price for products to obtain the maximum profits. Notably, profit here is not only referred to the final profit when achieving complete influence, it also points to the profit before that state. The reason why we pursue maximum profit at all times is, floating capital is rather crucial to company operations. Once coming across capital shortage, the company will have difficulty carrying on their businesses, leaving the so-called optimal profit turn into an illusion. That is also why so many startups end up with failures. They have innovative ideas and a bright prospect, but they are also plagued by capital deficiency during operation, which directly results in their misfortune. Therefore, it is essential to investigate the whole process of complete influence and seek the maximum profit all the time.

In order to investigate the maximum profit at time t, we should figure out how many people purchase the product. Considered that the diffusion process needs to take a certain time, although node j has the probability of being influenced when $P_t^j > 0$, it may not adopt the product within a limit of time.

Obviously, the number of active nodes is related to the influence time. Also, it is affected by the target size and product price. Thus, we can mathematically use $\beth(T, S, p)$ to denote the total number of purchasers at time t. Finally, we can derive our optimization objective:

$$\max_{S,p} \mathrm{E}[R] = \max_{S,p} \mathrm{E}[\beth(T, S, p) * p] \tag{3}$$

4 Framework of Greedy Algorithms

Unfortunately, it is difficult to get the optimal solution of a profit maximization problem. One reason is that, the analytic representation of profit function is too difficult to obtain. So here, we employ the stochastic simulation method and estimate the expected profit. Another reason is that usually a real social network contains huge numbers of individuals, which takes lots of time to find the optimal solution. To solve such a NP-hard problem, Kempe et al. [6] first employed greedy algorithms, which is an efficient approach to avoid the brute-force search [23]. In the greedy algorithm, nodes are selected one by one until constraints are destroyed. To target these nodes efficiently, they also set a criterion, that is, only if a node out of the target set brings the most improvement in the value of the objective function, can it be put as a seeded member. And once the node is added to the target set, it will never be driven out. Note that although the greedy algorithm provides a feasible approach, for large-scale social networks, however, its computational cost is still very high.

To further reduce the computational cost, many methods are proposed to improve the greedy algorithm, like Degree Discount algorithms [14], SCG algorithms [24], K-means algorithms [25], etc. In our paper, we introduce a parameter r to modify the traditional greedy algorithm. In detail, first we determine r nodes at

Table 1 The modified greedy algorithm framework

```
Input: G, k, r, h;
Output: S , p;
S=∅;
T=0;
while t < k
  R=∅;
  c=0;
  while c < r
     i_c = arg max_{i∈N\(A∪R)} h(S, i);
     R = R ∪ {i_c};
     c= c + 1;
  i_t = arg max_{i∈R} (E[R ∪ i] − E(R));
  S = S ∪ {i_t};
  t = t+1;
return S, p;
```

once, and then compute the change of the value of objective function for adding such r nodes for every search. Compared with the traditional greedy algorithm, which selects the node one by one, our modified algorithm achieves a trade-off between solution performance and computational complexity [13].

The framework of our modified greedy algorithm is presented in Table 1. For a given social network G, we just need to input the target size k, a parameter r and the heuristic function h, then the algorithm will return S as the target set.

The heuristic function here, denoted as h (S, i), is the value of any combination of a set of nodes S and a node i out of S. It is used to measure the improvement in the value of objective functions when adding a node. For example, for any pair of nodes i and j, the inequality h (S, i) > h (S, j) means, adding node i into the target set can bring more increase in profit than node j.

Because heuristic functions are defined on the basis of a distance network, we first define the graph of it. A distance network contains exactly the same set of nodes with the original social network. The only difference is, distance network is a direct graph. For each pair of nodes that is directly connected in the original social network, there are two directed edges with opposite directions. The weight on each edge (i, j) shows the degree of unfamiliarity between node i and j. Here, we present three definitions of weight function in the distance network:

(1) $W^r(i,j) = \frac{1}{W(i,j)}$;
(2) $W^*(i,j) = \frac{\sum_{l \in N(j)} W(l,j)}{W(i,j)}$;
(3) $W^o(i,j) = max_{(i',j') \in E} W(i',j') - W(i,j)$.

Here,$W^r(i,j)$ is defined as the reciprocal of the weight in the original social network, $W^*(i,j)$ is the variation of $W^r(i,j)$, which is multiplied by a weight $\sum_{l \in N(j)} W(l,j)$, and $W^o(i,j)$ is defined as the sum of a large positive number and the opposite of the weight in the original social network. Note that all these weight functions are ensured non-negative.

Next, we present our definition of the heuristic function. Before defining it, we should consider two key principles. First, the heuristic function should indicate the potential to increase profits after seeding each node. Second, it should be computed efficiently. In this paper, we adopt the heuristic functions named "Maximin Path Length Reduction (MPLR)" and "Shortest Path Forest Weight Reduction (SPFWR)". They are presented as follows:

(1) Maximin Path Length Reduction (MPLR)

$$h_{MPLR}(S, i) = \max_{j \in N0} SP(S \cup \{i\}, j) - \max_{j \in N} SP(S, j) \tag{4}$$

(2) Shortest Path Forest Weight Reduction (SPFWR)

$$h_{SPFWR}(S, i) = \sum_{(l,j) \in Edge(F_{SP}(S \cup \{i\}))} W^*(l,j) - \sum_{(l,j) \in Edge(F_{SP}(S))} W^*(l,j) \tag{5}$$

where $F_{SP}(S)$ is defined as the spanning forest with set of roots S, where each node in the forest is connected to the closest root by a shortest path.

In the strategy "MPLR", given the target set S, we evaluate each pair (S, i) on the basis of the reduction in the maximin path length. For "SPFWR" strategy, it follows the intuition that if adding node i can largely reduce the sum of weights in the shortest path forest, then we seed it.

5 Numerical Experiments

In this section, a number of experiments are performed to show how the modified greedy algorithm trades off between solution performance and computational complexity and how it outperforms the traditional heuristic algorithm. In all following experiments, the total number of nodes is N = 1000, and the diffusion process is simulated for M = 500 times. All experiments are performed on a Core 2 2.90 GHz PC.

We assume our social network as a random graph [26]. To generate such a graph, firstly we set a predetermined connection probability p, which represents the probability that each pair of nodes are connected. When p is close to 1, each node is connected to almost other nodes; while p is small, each of them is connected to only a few others. In this sense, the parameter p also characterizes the density of a graph. Next, we generate a random number $\theta \in [0, 1]$ for each pair of nodes i and j. If $\theta < p$, node i and node j turns directly connected, then a new edge (i, j) is added to the set of edges E. After generating the network, we add as few edges as possible to ensure its connectivity. Without loss of generality, we assign to each edge an integer weight between 1 and 5.

In the first experiment, we investigate how the modified greedy algorithm trades off between computational complexity and solution performance. Without loss of generality, we let p = 0.002 to generate the social network. The influence time T is set to 20 and the seeding number k is set to 8. As is shown in Fig. 1 and Fig. 2, we change the trade-off parameter r from 1 to $|N| - t$, then record profit and runtime respectively. At the same time, we consider different greedy algorithms and different weight functions. From the figures, we can note two extremes of r. One is when r = 1, algorithms run fast but do not bring good results. The other is when $r = |N| - t$, the algorithms perform well but that's at the cost of time consumption. Further, it's not difficult to find, in general, greater r brings more profit. The only

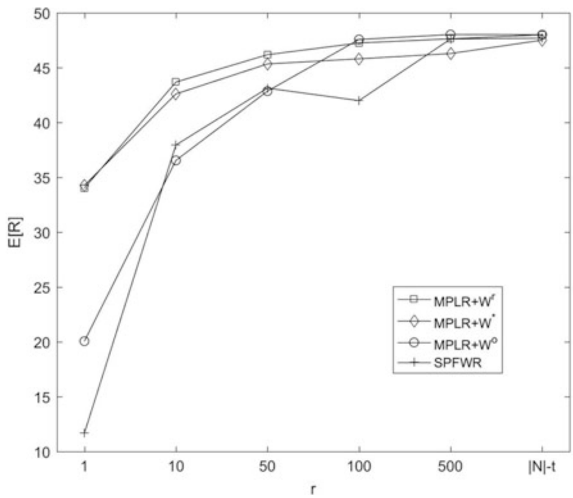
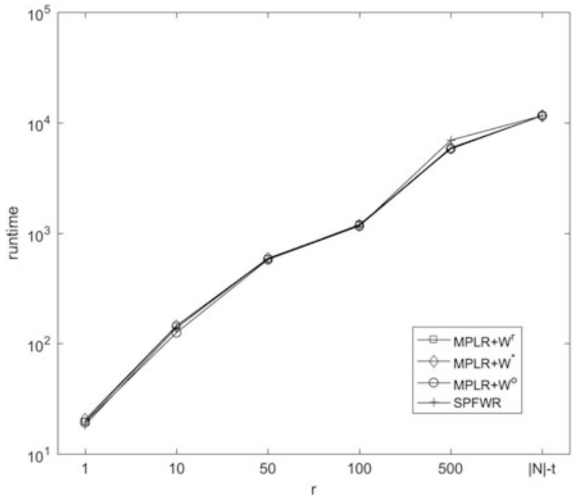


Fig. 1 Profit of the modified greedy algorithm

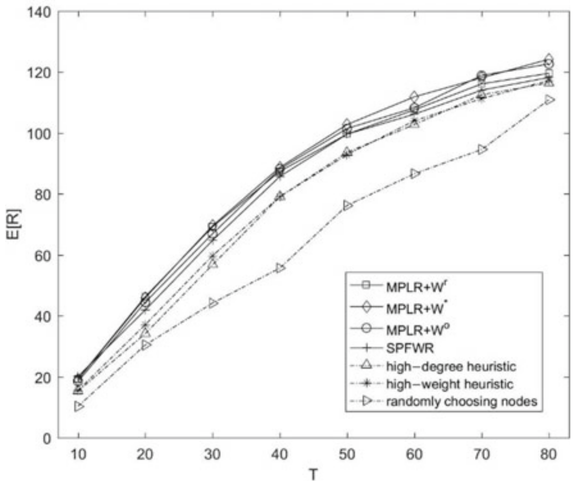
Fig. 2 Runtime of the modified greedy algorithm



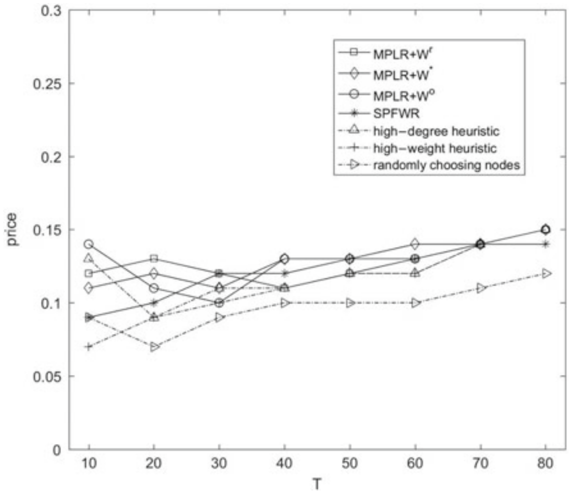
exception is "SPFWR", when r = 100, the profit is a bit less than that when r = 50. That's because the numerical experiment exist a certain of randomness. Anyway, for other cases, profit increases with r. What's more, when combined Fig. 1 with Fig. 2, we can find larger r takes more runtime, but at the same time, it generates a better solution. Overall, the two figures justify the role of parameter r to trade off between optimality and complexity.

In the next experiment, we show the effectiveness of our proposed algorithm. The performance of our proposed algorithms is compared with that of three trivial heuristic methods, named "highly-degree heuristic", "highly-weight heuristic" and "randomly choosing nodes". In this part, we set r = 50, p = 0.002. Then we have two points to consider. One is, since time period and target size would affect the number of influenced people, we should investigate the relations between profit and T, k, respectfully. Another is, one of our goal is to determine the optimal price, so we should also study how price changes with T and k. For the two reasons above, we get our results as shown in Figs. 3a, b and 4a, b. When we study the influence of T on profit and price, we set k = 8. When we study the influence of k on profit and price, we set T = 50. Intuitively, all these figures show our greedy algorithms generate better solutions than trivial methods. In Figs. 3a and 5a, which focus on the maximum profit, we find profit increases with time T and target size k, which is consistent with our cognition. From Figs. 3b and 5b, we can see the optimal price increases just a little bit, which can be seen as almost steady, that means T and k doesn't affect pricing decision a lot.

Fig. 3 Comparison of greedy algorithms with trivial heuristic methods for different time



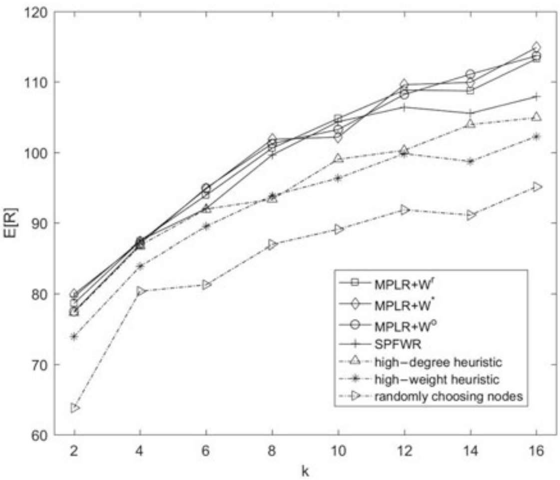
(a) The influence of T on expected maximum profit



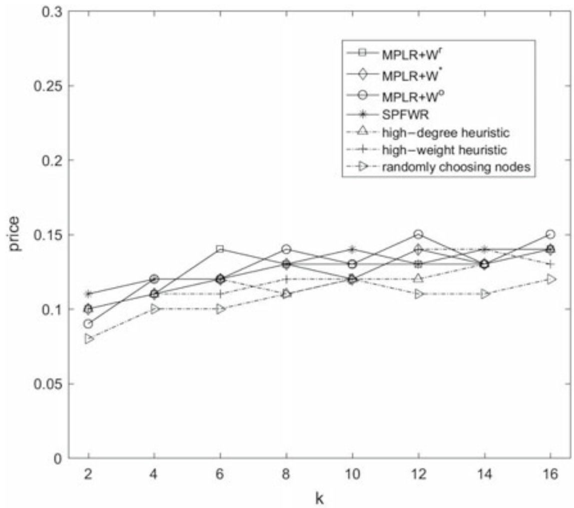
(b) The influence of T on optimal price

The last experiment is performed to study the maximum profit and optimal price under different network structures. We investigate how they change with k under a certain T. In this part, we choose the method "MPLR + W^*" and set T = 50. The results are shown in Fig. 5a, b. By analysing the results, we still find the maximum profit increases with k, no matter what the network structure is. Besides, at the same k, the profit increases with p generally. Except for when p is large enough, the law

Fig. 4 Comparison of greedy algorithms with trivial heuristic methods for different k



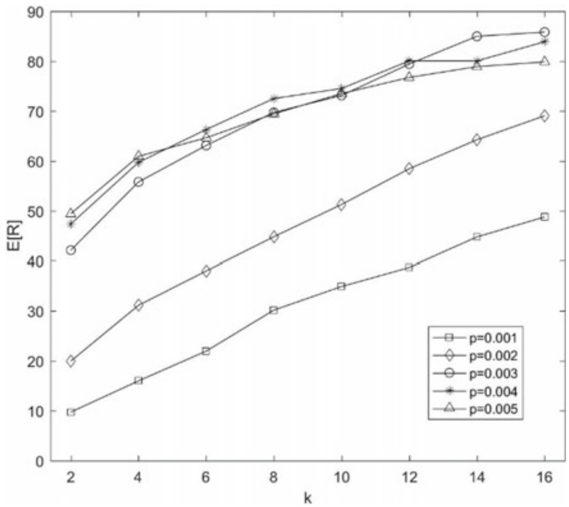
(a) The influence of k on expected maximum profit



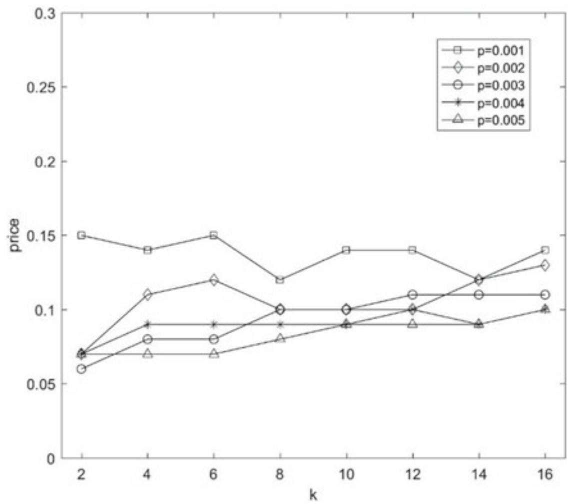
(b) The influence of k on optimal price

is not so obvious, it may for the reason that the influenced diffusion has achieved a saturation state. As for the optimal price, we can see that it still keep steady under each network structure. But when p decreases, it can be higher. That enlightens us when we promote products in niche markets, the price can be set higher; while in a mass market, the price should be low enough and get the scale return.

Fig. 5 Comparison of network structures for different k



(a) The influence of k on expected maximum profit under different network structures



(b) The influence of k on optimal price under different network structures

6 Conclusion

In this paper, we studied a problem on how to optimize profit in a social network. Specially, we focus on the situation where complete influence can be achieved, so we adopt the incremental chance model to characterize influence diffusion process. Due to the limitation of the original incremental chance model, we add the factor price in the model for better applicable to WOM promotion. In order to trade off between optimality and complexity when solving the problem, we introduce a parameter r and modify the traditional greedy algorithms. Finally, a series of numerical experiments are performed to show the effectiveness of our modified greedy algorithms.

Actually, this paper provides several directions for future works. First, in a real marketing campaign, many uncertain factors exist, such as product quality, personal preference, advertising costs, etc. All these uncertainties can be considered in the influence diffusion process. Second, our research just experiments on random network, but there are many other types of social networks, whose experimental results may be different. In real life, for example, a well-adopted opinion in a friend network may not be quickly spread in a stranger network. Therefore, it's worthwhile to study different social networks in a WOM promotion further.

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China's Energy Demand Forecast Based on Combination Model

Jing Cao and Xinpeng Zhou

Abstract This paper presents a combination of GRNN neural network and fuzzy neural network prediction model, based on the energy-related data from 1997 to 2016 to establish a model, and use it for practical applications. The actual forecast predicts that the combined forecast model in the actual forecast Effectiveness. And predict energy demand in the next three years. The results show that the combined forecasting model is superior to the single forecasting model in general, and the combined forecasting model has high forecasting accuracy and strong practicality.

Keywords Energy demand forecasting · GRNN neural network · Fuzzy neural network · Combined forecasting model

1 Introduction

Energy is an indispensable and important material foundation for human survival, economic development, social progress and social civilization. The use, replacement, and development of energy have all contributed to economic growth, social progress, and improvement in people's living standards. This is the material guarantee for the survival and development of the world. Doing a good analysis of energy demand in the future, doing a good job in forecasting energy demand, and providing a scientific basis for the formulation of energy planning and policies will have important theoretical and practical significance for maintaining the sustainable development of China's national economy [1].

The energy demand forecast starts from studying the history and current status of energy consumption in a country, region or specific range. According to its consumption behavior, it summarizes the various factors that affect energy consumption and seeks the relationship between consumption and these factors. According

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to these relationships, the future energy Needs development trends to make an assessment [2]. Therefore, modeling and forecasting energy demand is one of the foundations for formulating development strategies and planning and deployment.

Many experts at home and abroad have conducted a lot of researches on the factors influencing energy demand and energy prediction from the two perspectives of economic theory and engineering technology theory. Representative prediction methods include: LEAP model [3], MARKAL model [4], TIMES model [5], input-output model [6], system dynamics model [7], etc. These research methods are basically solved. The problem of real-time changes in energy trends can better reflect the openness, complexity, and nonlinearity of energy systems. However, these models still have the disadvantages of large variables, complex relationships, and poorly defined parameters. Xing Xiaojun and others used the principal component analysis method to assist the cointegration and error correction model to establish a prediction model of China's energy demand [8]. Li Bo et al. used the three kinds of extrapolation prediction methods such as gray system theory, consumption elasticity coefficient method, and unit GDP energy consumption prediction method to predict the energy demand in Sichuan Province [9]. Song Chunmei divided the total energy demand in China into two parts: the energy demand of the three industry sectors and the energy demand of the residents' lives, and finally used the scenario analysis method to predict [10]. Li Jinlu established a long-term cointegration equation and a generalized differential regression model between energy consumption and the national economy, and made specific predictions on China's future energy demand [11].

Neural network is an emerging mathematical modeling and analysis method in recent years. It has been widely used in signal processing, data compression, fault diagnosis and many other fields. Due to its good function approximation capability, neural networks can be used to predict the relevant data. Wang Xi and Bao Qin established an energy demand model based on wavelet neural network, and its prediction accuracy is higher than the multiple regression model [12]. Fu Jiafeng et al. combined grey forecasting with artificial neural networks to establish a combined energy consumption-forecasting model [13]. Lu Bin et al. used artificial neural networks to predict power loads [14]. Liu Ying et al. used the time series-neural network model to establish the Fujian province energy consumption-forecasting model, and used this model to predict energy consumption in Fujian province over the next 15 years [15]. Zhou Yang and others established the optimized combination model of BP neural network and grey GM, and realized the principle of "minimum combined prediction error in the past period of time" of the optimized combination model [16]. Fu Juan et al. established a clean energy Logistic medium and long-term prediction model based on genetic algorithms. They used this model to predict clean energy demand in 2020 that is consistent with China's energy planning goals [17]. Zong Woo Geem predicted the energy demand of South Korea based on the artificial neural network, and pointed out that the neural network model is superior to the linear regression model and the exponential model [18]. Sun Han et al. conducted a useful exploration on energy demand estimation methods. The energy demand forecasting model based on the support vector regression machine established by China has shown high prediction accuracy for energy demand in China [19].

The above literature also confirms that artificial intelligence algorithms are effective in solving energy system nonlinearity and high dimensional pattern recognition problems. In view of the limited application of intelligent algorithms in the field of domestic energy demand forecasting, this paper introduces the generalized radial basis network algorithm (GRNN) and wavelet neural network algorithm to perform combined model prediction, which overcomes the disadvantages of single model prediction with large errors and can be effective.

2 Factors Affecting China's Energy Demand

Our country is in the process of industrialization, marketization, and internationalization. The economy and society are developing rapidly. In the long run, energy demand is mainly determined by factors such as economic level, energy consumption structure, energy production, industrial structure, population growth, urbanization process, living standards of residents, and technological progress.

2.1 Economic Development Level

The energy industry is a long-term, high-input industry, and its level of development is directly constrained by the level of economic development. Therefore, the level of economic development is a very important factor affecting energy demand. Production requires energy as a support, and economic development will improve living standards, which in turn will affect energy consumption. Energy development promotes economic development. Economic development provides material conditions and economic basis for energy development. Economic growth not only generates energy demand, but also provides a way to meet this demand. This relationship between economic development and energy demand has not disappeared due to the reality of the energy shortage in the world today, but become more compact. Zhang and Ge [20] adopt the co-integration test and error correction model for China's economic growth and energy. The dynamic analysis of the internal compliance of consumption shows that between 1987 and 2010, economic growth was the Granger cause of energy consumption in the long and short term.

2.2 Energy Consumption Structure

The energy consumption structure reflects the proportion of various energy sources in the total energy consumption. China is a country that has with rich coal resources. Coal has always been China's main energy source, which has led to a low energy efficiency and high-energy consumption index in China. Therefore, optimizing energy structure and developing high-efficiency energy can reduce China's coal consumption, which depends on it to reduce energy demand.

2.3 Energy Production

The current global energy consumption is mainly non-renewable energy such as petroleum, coal, and natural gas. This determines that the supply of oil, coal, natural gas and other energy sources within a certain period of time is limited. Energy production and supply have an important material basis for the country's economic development and national political and economic security. China is currently in a period of time with high-speed economic development. The rapid increase in energy demand and the limited energy supply at home and abroad have caused the energy market to be in short supply. In a sense, energy supply determines energy consumption. In the absence of energy supply, energy demanders will also endeavor to search for energy alternatives in order to reduce dependence on energy or improve technology to improve energy efficiency. This will also reduce energy demand to some extent.

2.4 Industrial Structure

With the economic development, the industrial structure is undergoing constant changes. The energy consumption of different industries varies greatly. Changes in the industrial structure will inevitably affect the energy demand. The energy consumption levels of the three industries are not the same, and the energy consumption of the secondary industry is relatively high. Compared with Western developed countries, the rate of second industry in China is still at a relatively high level. China is reducing energy demand by optimizing its industrial structure. As China's secondary industry is the main industry for energy consumption and accounts for about 70% of total energy consumption, the change in the proportion of the secondary industry is the main factor leading to changes in energy demand. Li [21] obtained qualitative analysis and quantitative analysis of data from 1979 to 2009 that the adjustment of the industrial structure can indeed affect energy demand, and the secondary and tertiary industries can have a certain effect on the energy consumption. The primary industry is energy. The demand has no effect.

2.5 Population Growth

Population is the most basic factor in the social system. Energy is the basis for human living. The total population directly affects the total energy consumption, and it also directly affects the per capita possession of energy resources and their utilization. The increase in population directly increases the demand for fuel and energy by-products, which indirectly increases the demand for energy. From the point of view of the industrial structure of energy consumption, the energy consumption that most closely related to people is life consumption. In 2011, the proportion of living energy consumption in total energy consumption was as high as 10.64%. Therefore, changes in the population will have a major impact on energy consumption.

2.6 The Process of Urbanization

Urbanization in China drives the transfer of rural population to the urban population. It also promotes the development of high-energy-consuming industries such as urban construction, housing, and automobiles. The energy consumption of the urban population is much higher than that of the rural population, directly affecting the per capita occupancy and utilization of energy resources. The urbanization process has promoted the construction of large-scale urban infrastructure such as roads, water conservancy, heating, hospitals, and greening, as well as the construction of residential buildings and office buildings, which have greatly increased the overall level of energy demand. According to relevant estimates, the energy demand of the urban population is about 3.5–4 times than that of the rural population. Therefore, the process of urbanization is also one of the factors affecting energy demand.

2.7 Living Standard of Residents

Since the Reform and Opening, China's residents have greatly improved their living standards. The economic development brought about by the improvement of people's living standards and attitudes has brought about changes in people's spending power. This has stimulated the tertiary industries such as transportation, accommodation, catering, and postal services as well as automobiles, electricity, water, and real estate. With the accelerated development of electronic products and medical services, the per capita energy consumption has gradually increased, which in turn has affected the energy consumption demand.

2.8 Technological Progress

Science and technology are primary productive forces. The impact of scientific and technological progress on energy demand is mainly reflected in the following three aspects: First, with the advancement of science and technology, the further development of energy-saving technologies has enabled the energy-saving rate to be greatly increased, thereby saving energy consumption, and secondly, technological progress can improve energy efficiency. The rate of exploitation reduces the consumption in the production and transportation process, and thus yields the same amount of output with lower input. Third, the progress in science and technology makes it possible to develop and use new energy, which leads to a fundamental change in the structure of energy consumption. Fundamentally change the development trend of energy demand. Therefore, the progress in science and technology is also another important factor affecting energy demand.

3 Algorithm Introduction

3.1 Generalized Regression Neural Network Algorithm (GRNN)

The Generalized Regression Neural Network (GRNN) was proposed by American scholar Specht in 1991 [22]. GRNN has a strong non-linear mapping capability and flexible network structure, as well as a high degree of fault tolerance and robustness, and is suitable for solving nonlinear problems. GRNN has stronger advantages over RBF networks in terms of ability and speed of learning. The network eventually converges to an optimized regression surface with a large sample size accumulation, and when the sample data is small, the prediction effect is also good. Therefore, GRNN has been widely used in various fields such as signal process, structural analysis, education industry, energy, food science, control decision system, drug design, finance, and bioengineering.

The number of input layer neurons is equal to the dimension of the input vector in the learning sample. The number of model layer neurons equals the number of learning samples n. Each neuron corresponds to a different sample. The mode layer neuron transfer function is:

$$p_i = \exp\left[-\frac{(X-X_i)^T(X-X_i)}{2\sigma^2}\right] \quad (1)$$

The output of element i is the exponential form of the Euclidean distance function between the input variable and its corresponding sample X. Its function is to calculate the distance between the network input and the weight of the pattern layer, where σi determines the position of the i-th pattern layer. The shape of the basis function, the larger σi, the smoother the basis function, so called the smooth factor. The transfer function of the mode layer node responds locally to the input signal. When the input signal is closer to the center of the transfer function, the mode layer node generates a larger output, so the network has the ability to locally approach.

The summation layer performs a weighted sum on the neurons of all the model layers. The connection weight between the i-th neuron in the model layer and the j-th molecule summation neuron in the summation layer is the i-th output sample Yi The j-th element of the transfer function is:

$$S_{Nj} = \sum_{i=1}^{n} y_{ij} p_i \quad j = 1, 2, \ldots, k \tag{2}$$

The number of neurons in the output layer is equal to the dimension k of the output vector in the learning sample. Each neuron divides the output of the summation layer. The output of neuron j corresponds to the j-th element of the estimation result Y ϒ(X).

$$y_j = \frac{S_{Nj}}{S_D} \quad j = 1, 2, \ldots, k \tag{3}$$

3.2 *Fuzzy Neural Network Algorithm*

The TS fuzzy model is a nonlinear fuzzy inference model proposed by Takagi and Sugeno. Because each rule formed by it adopts a linear equation as a conclusion, the global output of the model has a good mathematical expression, and can be used when dealing with a multivariable system. Effectively reducing the number of fuzzy rules has great advantages [23]. The T-S fuzzy system is defined by the following "if - then" rule form. In the case of the rule Ri, the fuzzy inference is as follows:

$$\mathrm{R^i} : \mathrm{If}\ \mathrm{x_1}\ \mathrm{is}\ \mathrm{A^i_1}, \mathrm{x_2}\ \mathrm{is}\ \mathrm{A^i_2}, \ldots, \mathrm{x_k}\ \mathrm{is}\ \mathrm{A^i_k}\ \mathrm{then}\ \mathrm{y_i} = \mathrm{p^i_0} + \mathrm{p^i_1 x_1} + \mathrm{p^i_2 x_2} + \cdots + \mathrm{p^i_k x_k} \tag{4}$$

Among them, A_j^i is the fuzzy set of the fuzzy system; $p_j^i (j = 1, 2, \ldots, k)$ is the fuzzy system parameter; y_i is the output according to the fuzzy rule, and the input part (i.e., the if part) is fuzzy. The output part (i.e., the then part) is definite, and the fuzzy inference means that the output is a linear combination of inputs.

Suppose that for the input x = [x_1, x_2,…, x_k], the membership of each input variable x_j is first calculated according to the fuzzy rules:

$$u_{A_j^i} = \exp\left(- \frac{\left(x_j - c_j^i\right)^2}{b_j^i} \right) \quad j = 1, 2, \ldots, k;\ i = 1, 2, \ldots, n \tag{5}$$

In the formula, c_j^i, b_j^i are the center and width of the membership function respectively; k is the input parameter number; n is the fuzzy subset number.

Each membership degree is calculated in a fuzzy manner and a fuzzy operator is used as a concatenation operator:

$$\omega^i = \mu_{A_j^1}(x_1) * \mu_{A_j^2}(x_2) * \ldots * \mu_{A_j^k}(x_k) \quad i = 1, 2, \ldots, n \tag{6}$$

Calculate fuzzy model output value y_i based on fuzzy calculation results:

$$y_i = \frac{\sum_{i=1}^{n} \omega^i \left(p_0^i + p_1^i x_1 + p_2^i x_2 + \cdots + p_k^i x_k\right)}{\sum_{i=1}^{n} \omega^i} \tag{7}$$

T-S fuzzy neural network is divided into four layers: input layer, fuzzy layer, fuzzy rule calculation layer and output layer. The input layer is connected to the input vector x_i, and the number of nodes is the same as the input vector. The fuzzy layer uses a membership function to fuzzify the input value to obtain a fuzzy membership value μ. The fuzzy rule calculation layer uses a fuzzy continuous formula to calculate ω. The output layer uses a formula to calculate the output of the fuzzy neural network.

The fuzzy neural network learning algorithm is as follows:

(1) Error calculation

$$e = \frac{1}{2}(y_d - y_c)^2 \tag{8}$$

In the formula, y_d is the expected output of the network, y_c is the actual output of the network, and e is the error between the expected output and the actual output.

(2) Correction of coefficients

$$p_j^i(k) = p_j^i(k-1) - \alpha \frac{\partial e}{\partial p_j^i} \tag{9}$$

$$\frac{\partial e}{\partial p_j^i} = \frac{(y_d - y_c)\omega^i}{\sum_{i-1}^{n} \omega^i * x_j} \tag{10}$$

In the formula, p_j^i is the neural network coefficient; α is the network learning rate; x_j is the network input parameter; ω_j is the input parameter membership degree product.

(3) Parameter Correction

$$c_j^i(k) = c_j^i(k-1) - \beta \frac{\partial e}{\partial c_j^i} \tag{11}$$

$$b_j^i(k) = b_j^i(k-1) - \beta \frac{\partial e}{\partial b_j^i} \tag{12}$$

In the formula, c_j^i, b_j^i are the center and width of the membership function, respectively.

4 GRNN and Fuzzy Neural Network Combined Forecasting Model

4.1 Combination Forecasting Model Introduction

In general, the error rate of a single prediction model will be larger than that of a combined prediction model in practical applications. Therefore, this paper uses GRNN and fuzzy neural network to perform combined forecasting to reduce the prediction error as much as possible and achieve better prediction results. The common form of the combined model is the weighted average of each individual forecasting model. Therefore, the focus of the combined forecasting model lies on the determination of the weighting factor.

4.2 Data Source and Description

In this paper, the combined model is applied to practical applications. At the same time, the effectiveness of the combined forecasting model is tested. The sequence of China's total energy consumption from 1997 to 2016 is selected as a data sample, and the data comes from the website of the National Bureau of Statistics. As can be seen from the data, China's total energy consumption shows a rapid upward trend, especially in 2002–2010, the rate of increase is rapid, and during 2012–2016, the rate of increase has slowed down. Based on the above analysis of the factors affecting the total energy consumption, this paper looks up the data from the National Bureau of Statistics for the period of 1997–2016, and summarizes the data as shown in Tables 1 and 2.

4.3 GRNN Model Prediction

Taking the 19-year historical data of China from 1997 to 2015 as the training sample of network training, the historical data of 2016 was selected as the test sample of network training to construct a GRNN neural network. Since there are few training data, this article adopts cross-validation method training. The GRNN neural network uses the loop to find the best SPREAD. First, because there are few test samples, this paper simulates the test sample 20 times. According to the constructed GRNN neural network, 20 simulation results are obtained, as shown in Fig. 1. Calculate 20 prediction errors, as shown in Fig. 2.

Relying on the constructed neural network model, 20 years of data are input into the neural network, and the results of the 20-year prediction are shown in Table 3. Compared with the actual energy usage, the prediction model can be seen in Fig. 3. The fitting effect is very good.

Table 1 Influencing factors sample data 1

Particular year	GDP (billion)	Urbanization (%)	Total population at the end of the year (ten thousand people)	Second industry contribution rate (%)	Per capita disposable income of urban residents (Yuan)
1997	79715	31.9	123626	59.1	5160.3
1998	85195.5	33.4	124761	59.7	5425.1
1999	90564.4	34.8	125786	56.9	5854
2000	100280.1	36.2	126743	59.6	6280
2001	110863.1	37.7	127627	46.4	6859.6
2002	121717.4	39.1	128453	49.4	7702.8
2003	137422	40.5	129227	57.9	8472.2
2004	161840.2	41.8	129988	51.8	9421.6
2005	187318.9	43.0	130756	50.5	10493
2006	219438.5	44.3	131448	49.7	11759.5
2007	270232.3	45.9	132129	50.1	13785.8
2008	319515.5	47.0	132802	48.6	15780.8
2009	349081.4	48.3	133450	52.3	17174.7
2010	413030.3	49.9	134091	57.4	19109.4
2011	489300.6	51.3	134735	52	21809.8
2012	540367.4	52.6	135404	49.9	24564.7
2013	595244.4	53.7	136072	48.5	26467
2014	643974	54.8	136782	47.8	28844
2015	689052.1	56.1	137462	42.4	31195
2016	743585.5	57.3	138271	38.2	33616

4.4 *Fuzzy Neural Network Model Prediction*

The fuzzy neural network takes 19 years of historical data from 1997 to 2015 in China as a training sample for network training. The historical data of 2016 is selected as a test sample for network training. According to the training sample input and output dimensions to determine the number of network input and output nodes. Since the input data dimension is 9 and the output data dimension is 1, the number of input nodes in the network is determined to be 9 and the number of output nodes is 1. According to the number of network input and output nodes, the number of artificially determined membership functions is 18, and the center, width, and coefficient of the fuzzy membership function are randomly initialized.

According to the fuzzy neural network model, the predicted data are shown in Table 4, and the trends of the fuzzy neural network and actual values are shown in Fig. 4. According to the forecast results, the calculation error range is within a reasonable range. From the test sample data, the prediction result is 44,0031 (ten thousand tons of standard coal), and the prediction error is 0.92%. It can be seen that the prediction effect is very good. This model can predict energy demand.

Table 2 Influencing factors sample data 2

Particular year	Total energy production (10,000 tons of standard coal)	Energy processing conversion efficiency (%)	Research and experimental development (R&D) expenditure (100 million Yuan)	Coal's share of energy consumption (%)
1997	132410	69.2	509.16	71.7
1998	124250	69.4	551.12	69.6
1999	125935	69.2	678.91	69.1
2000	138569.7	69.4	896	68.5
2001	147424.99	69.7	1042.49	68
2002	156277.01	69	1287.64	68.5
2003	178298.78	69.4	1539.63	70.2
2004	206107.73	70.6	1966.33	70.2
2005	229036.72	71.1	2449.97	72.4
2006	244762.87	70.9	3003.1	72.4
2007	264172.55	71.2	3710.24	72.5
2008	277419.41	71.5	4616.02	71.5
2009	286092.22	72.4	5802.11	71.6
2010	312124.75	72.5	7063	69.2
2011	340177.51	72.2	8687	70.2
2012	351040.75	72.7	10298.41	68.5
2013	358783.76	73	11846.6	67.4
2014	361866	73.5	13015.63	65.6
2015	361476	73.7	14169.88	63.7
2016	346000	74	15676.75	62.0

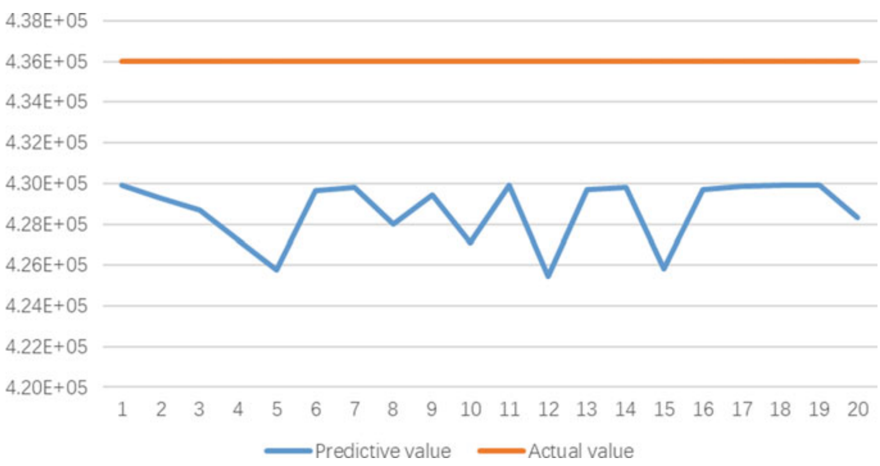

Fig. 1 Trend of test sample forecast results

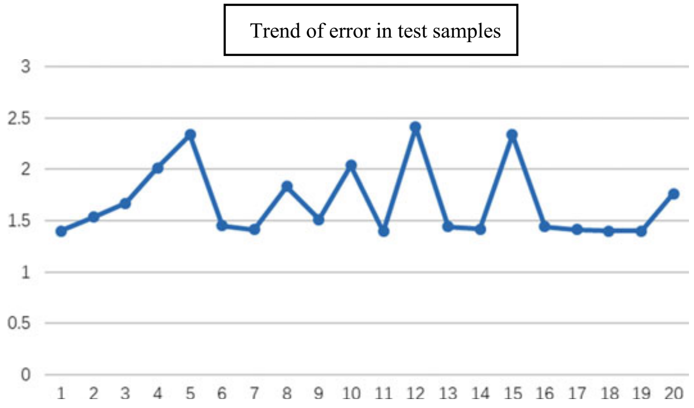

Fig. 2 Trend of error in test samples

Table 3 Prediction result of GRNN neural network

Particular year	Actual value (10,000 tons of standard coal)	Predicted value (10,000 tons of standard coal)	Relative error (%)
1997	137798	140555.62	2.00
1998	132214	141610.26	7.11
1999	133831	146542.32	9.50
2000	146964	148450.16	1.01
2001	155547	164092.67	5.49
2002	169577	168306.67	−0.75
2003	197083	179518.36	−8.91
2004	230281	237435.32	3.11
2005	261369	281716.31	7.78
2006	286467	291391.62	1.72
2007	311442	302507.19	−2.87
2008	320611	311918.82	−2.71
2009	336126	326342.49	−2.91
2010	360648	355215.77	−1.51
2011	387043	371590.98	−3.99
2012	402138	401662.61	−0.12
2013	416913	415046.65	−0.45
2014	425806	420934.50	−1.14
2015	429905.1	423467.14	−1.50
2016	436000	424551.98	−2.63

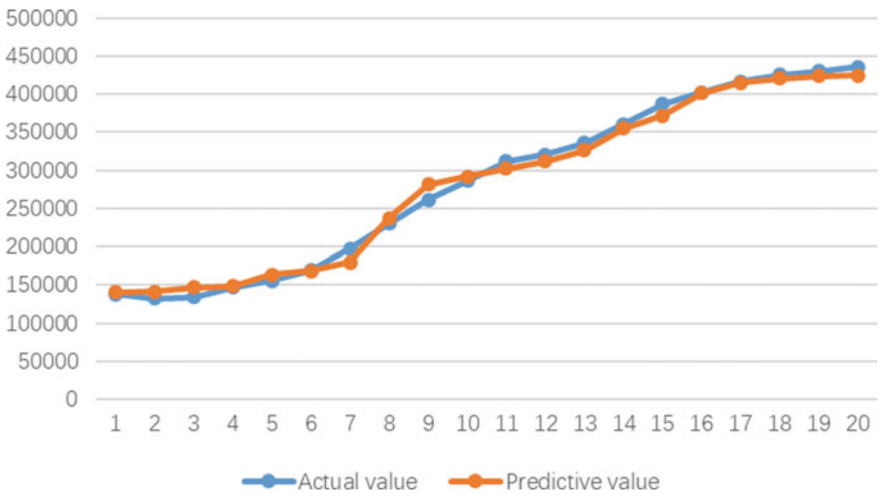

Fig. 3 Trends of predicted and actual values of GRNN neural networks

Table 4 Prediction results of fuzzy neural network

Particular year	Actual value (10,000 tons of standard coal)	Predicted value (10,000 tons of standard coal)	Relative error (%)
1997	137798	127477.56	−7.49
1998	132214	132746.34	0.40
1999	133831	138310.07	3.35
2000	146964	153347.05	4.34
2001	155547	155492.15	−0.04
2002	169577	170695.06	0.66
2003	197083	196300.23	−0.40
2004	230281	230186.28	−0.04
2005	261369	263565.74	0.84
2006	286467	284475.17	−0.70
2007	311442	305780.09	−1.82
2008	320611	320274.35	−0.11
2009	336126	337258.02	0.34
2010	360648	366309.28	1.57
2011	387043	388034.72	0.26
2012	402138	399485.23	−0.66
2013	416913	411417.15	−1.32
2014	425806	433136.40	1.72
2015	429905.1	429194.93	−0.17
2016	436000	440031	0.92

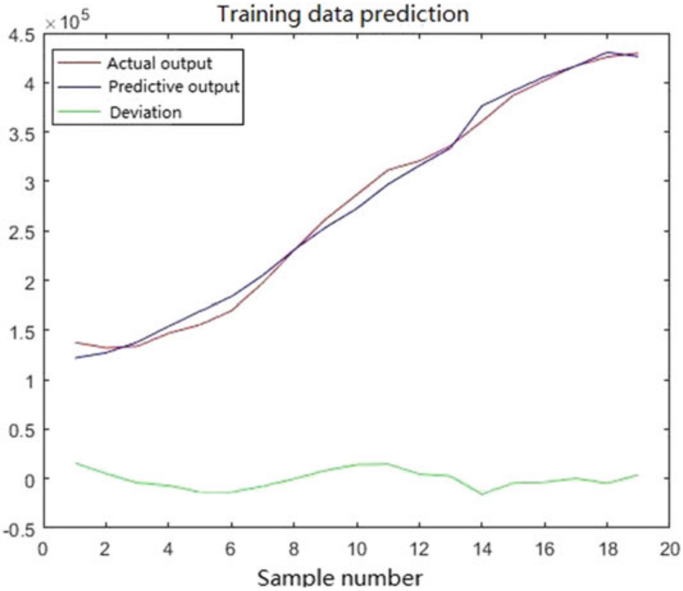

Fig. 4 Trends in the prediction and actual values of fuzzy neural networks

4.5 Combination of GRNN Neural Network and Fuzzy Neural Network Model Prediction

Comparing the prediction results of the GRNN neural network model and the fuzzy neural network model, we can see that there are certain differences between the two methods in the prediction of China's energy demand, and each has its own advantages in accuracy. In order to effectively integrate the advantages of these two methods in forecasting, this paper proposes a method to determine the dynamic weights, according to the prediction data of GRNN neural network model and the fuzzy neural network model to predict the data, starting from the weight of 0 to increase, to 0.001 steps The length is incremented to 1, and the data combination values of the two prediction models under different weights are respectively calculated, and then the actual data values are compared with the absolute values, and the difference of each weight is added to obtain the minimum value of the absolute value difference. The weights of the GRNN neural network model and the confused neural network model were determined to be 0.013 and 0.987, respectively.

According to the weights of the combined model, the predicted results of the combined model are obtained and the relative errors of the combined model are calculated. The results are shown in Table 5.

Comparing the prediction error of GRNN neural network prediction model, fuzzy neural network prediction model and combined model, we can see that the prediction results of fuzzy neural network forecasting model and combined

Table 5 Forecast results of combination forecast model

Particular year	Actual value (10,000 tons of standard coal)	Predicted value (10,000 tons of standard coal)	Relative error (%)
1997	137798	127647.58	−7.366
1998	132214	132861.57	0.490
1999	133831	138417.09	3.427
2000	146964	153283.39	4.300
2001	155547	155603.95	0.037
2002	169577	170664.02	0.641
2003	197083	196082.07	−0.508
2004	230281	230280.51	0.000
2005	261369	263801.70	0.931
2006	286467	284565.08	−0.664
2007	311442	305737.55	−1.832
2008	320611	320165.73	−0.139
2009	336126	337116.12	0.295
2010	360648	366165.06	1.530
2011	387043	387820.95	0.201
2012	402138	399513.54	−0.653
2013	416913	411464.34	−1.307
2014	425806	432977.77	1.684
2015	429905.1	429120.47	−0.183
2016	436000	439829.77	0.878

forecasting model are similar, although the predicted result of fuzzy neural network is better in some years. The combined model predicts the effect, but overall the combined model performs better on the stability of error variation. From this we can see that the forecasting result of the combined forecasting model is effective, and its forecasting accuracy is better than that of the single forecasting model in general.

5 Energy Demand Forecast Based on Combination Model

According to the Statistical Communique of the National Economic and Social Development of the National Bureau of Statistics of China in recent years, according to the "Five in One" overall layout and coordination of national policies to promote the "four comprehensive" strategic layout, combining the major institutions at home and abroad for the future of our country For the prediction of indicators, this article sets the economic growth rate for the next three years to 7%, the urbanization process in China is basically increasing at an annual rate of 1.1%, and the growth rate of the population in China is stable at about 0.5%. The contribution rate of the secondary industry is basically the same. 40.5%, urban residents

Table 6 Energy demand forecast (2017–2019)

Particular year	Combination forecast (10,000 tons of standard coal)
2017	447418.71
2018	474024.61
2019	510200.11

per capita disposable income growth rate is 6.5%, total energy production growth rate is around 3.6%, energy processing and conversion rate increases at an annual rate of 0.3%, R&D expenditure growth. The rate is about 11.5%, and the proportion of coal in energy consumption is decreasing at an annual rate of 1.5%. In summary, this article uses 2016 as a benchmark to obtain the energy demand results for 2017–2019 based on the prediction model constructed above, as shown in Table 6. According to the forecast results, China's energy demand in the next few years will continue to increase substantially. The increase in energy demand is still a severe challenge for China.

6 Conclusion

Based on generalized regression neural network algorithm and fuzzy neural network algorithm, the paper combines the advantages and disadvantages of the two to build a combined forecasting model. Due to the limitations of the conditions of the individual forecasting models, when the data series is predicted, the error degree may be too large. The combination of the individual forecasting models by dynamically determining their respective weights can make the combined forecasting model more accurate.

Because China's energy system is highly complex, non-linear, small sample, and other characteristics, energy demand forecasting is constrained by many factors, not a method or model can accurately predict. For the practical application of the combinatorial model in this paper, it can more accurately predict the energy demand, and has certain reference to the future energy research in China.

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Establishment of Distribution Center Location Problem Model

Jian Yu

Abstract Historically, the problem of site selection has been accompanied by the life of the people, with the development and progress of The Times, now the logistics industry development by leaps and bounds, in the fierce competitive environment, how to choose the site set up distribution centers, in order to better complete the task distribution, is a problem for the logistics companies, this article through to the existing classic location problems, such as P-center problems, covering problems such as model, finally combining the development of the enterprise now, maximize profit model and change model can be in a given number of distribution center construction situation, choose the optimal construction of distribution center address. It also provides a way of thinking for logistics enterprises to choose their location under the condition of sustainable development.

Keywords Site selection · Maximum profit · Demand · Sustainability

1 Introduction

The problem of site selection has been accompanied by the people's life, such as in order to survive, people will choose to compare a safe place for residence, people at the same time in order to obtain more resources, make life better, will choose to abundant supplies of live. From the historical level, many of the ancient and modern, Chinese and foreign disputes and to plunder rational region, it also shows the location is a problem along with the development of people, from the competition for resources of land, to the present location for service or the market, the location has been considered one of the problems.

Location problems involving in the presence of special widely, such as the city's location problem, merchant location of store location problem, the airport site

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selection problem, the new company set up location problem, and the establishment of branch company involved in the location selection problem, and then into the chain's location problem today, factory warehouse site selection, logistics distribution center location problem, etc. In ancient times, people used to select sites based on previous experience or superstitious ideas. With the development of the society and the deepening of scientific theory, people now research on site selection problem has built up a set of more scientific research methods, involving in operational research, topology, management and so on. At the same time due to the location of the problem involves not just address itself, also involves the location of the specific situation itself, site selection, for the sake of what, what is the location of the main body, the location after what is the purpose of the need to achieve. At the same time, the site selection is also influenced by the natural environment factors, such as the location selection within the urban circle or around the city, the topography of the site selection area, people's living habits and so on.

Enterprises, government and individuals in the location of consideration, is made up of a simple to the complex process, take the logistics distribution center location problem, the first target may be through the scientific location makes me in the process of the whole logistics cost minimum, then with the progress of the society, and the improvement of people's needs, the logistics distribution center have to take the additional goals, such as service efficiency and the aging problem, lowest cost cannot be the sole aim of most, and the need for various combination of site selection such as how to improve user satisfaction, loyalty, etc. How can we optimize our site selection so that we can adapt to the development of the society in the future, such as solving the problem of the last kilometer nowadays? It is officially based on the development of the society and the constant changes of people's demands, and under the competitive pressure of the new era, the logistics distribution center needs to continuously improve its business capability. In this paper, we will study the location of logistics distribution center in the current environment.

This article from the development of the location selection problem and now the main theoretical research of problem of site selection, analysis of the logistics distribution center's location now purpose and the method of choice, finalized now logistics distribution center location models, and provide certain algorithm to determine the final location.

2 Theoretical Research on Site Selection

Location problem of the beginning of the theory study begins with research of Weber. Weber [1] study on the plane to determine a warehouse to make its position with multiple customers the sum of the distance between the shortest problem. Contemporary [1], there are other scholars studied the location selection problem, but most studies are biased towards the actual application, such as product distribution location of sales outlets, the locations of the depot and so on. Then some scholars put forward in the P-value and P-center problems [2], after that, the location problem of the research field become more wide, such as transport hub siting, between multiple warehouse location problem, and so on. With the development of the society and the study of site selection, the problem of site selection has gradually changed from a static and fixed model to a random one [3].

At present, there are many kinds of siting problems involved in the development of siting. For example, the problem of siting can be divided into continuous siting, network siting and discrete siting according to the position allowed to be selected when siting. At the same time, it can be divided according to the number of site selection targets, such as single target selection and multiple target selection. According to the different purposes of site selection, the problem of site selection can be divided into different models, such as p-median location selection, covering location selection, p-center location selection and so on.

In the study of the location problem, comprehensive reference of other disciplines such as operations research, computer knowledge to solve the model, the current in the distribution center location, the main use of algorithm can be divided into two broad categories: accurate algorithm, heuristic algorithm [4]. Precision of the algorithm can get optimal solution algorithm, branch definition method of operational research, network flow algorithm, dynamic programming, etc., while using the results of this kind of algorithm can accurately, but as the problem size is bigger, the complexity of the algorithm into exponential growth, therefore in order to better solve the problem. People by observing the experience and laws, this paper puts forward a heuristic algorithm to solve this kind of problem, heuristic algorithm can usually get a good solution, through continuous iterative comparison, finally achieve a better solution. Because of the heuristic algorithm is likely to get the local optimal solution, and then falling into the trap of low while its complexity, solving speed, but the final result is not necessarily the global optimal solution. Now more commonly used algorithm with simulated annealing algorithm [5], neural network [6], genetic algorithm [7], ant colony algorithm [8] and so on.

In view of the above scholars research, this article from the modern technology situation faced by the logistics distribution center and multiple factors such as consumer demand to consider the distribution center location problem, not only to the cost of logistics company requirements, and the future development needs, and to meet the demand of consumers for new logistics under the new era.

3 Model Building

Starring this article studies the logistics distribution center location problem, is a typical discrete location model, depending on the logistics center of the target, can be installed in multiple models, such as in the process of site selection, making all PeiSongDian to the average distance of the distribution center is the shortest, the problem can be transformed to the value problem, here we use ReVelle and Swain the integer programming model [9].

In real life, often consumers hope logistics company able to cover all have lived, and solve the problem of last kilometer, China at that time the site selection problem can become cover problem, which is divided into full coverage and maximum coverage problems. The total coverage problem can be summarized as the minimum cost of building a distribution center to meet all the needs of consumers. We assume that the construction cost of each distribution center is the same, then it is converted to the minimum number of distribution centers.

This model does not consider the actual situation of different locations in the requirements, therefore no matter demand size need to be resolved, although solved the problem of the last mile, but may not the final result of the economy. If the demand is very small in some remote areas, the cost of building a distribution center there is high but the output is low. Therefore, in the practical application process, some scholars proposed to study the maximum coverage problem.

When the organization's resources is not enough, we need to give priority to meet can bring more revenue to organize points to the construction of distribution center, at this time due to the construction of a given the resources, therefore can only build a limited number of distribution center, the location of the problem into, under the specific scope of services, to maximize meet the needs of demand point.

As in the actual application, although limited by the service organization resources, but also needs to meet all the requirements, otherwise it will according to the loss of customers, thus to tissue damage in the interests of, so in the actual application, and problems for a class of site selection, called P-central question, this model, given the number of distribution centers, and at the same time required to solve to meet the needs of all, to ask any requirement to the smallest maximum distance of its recent distribution center.

In this paper, the model based on the contemporary enterprise not only consider the current funding problems of the construction of the distribution center (cost), should also consider the company in the future development of the situation, consumer demand, a variety of factors such as the organization's profitability a multi-objective model is set up, make enterprise long-term profit maximization.

In order to build a mathematical model, the following assumptions are made: first, the construction cost in each distribution is the same; second, when the distribution center is running, the greater the demand coverage of the distribution point is, the higher its operating income is. Third, the greater the coverage of the distribution center, the greater the cost of delivery. Fourth, the larger the distribution range, the lower the efficiency and customer satisfaction under the same distribution resources, which will lead to the loss of customers, thus reducing the operating revenue. Fifth, the distribution range of each distribution center is equal. Sixth, the delivery capacity of each distribution center is the same. Considering the actual construction process, because of the capital, land, the limitation of personnel resources, in this article, we assume that the distribution center of revenue and customer satisfaction and distribution centre distance as the inverse of the demand point, this model can be expressed as follows:

$$\mathrm{Max}\, S_j * \alpha / D - X_j c_j \tag{1}$$

$$S_j = \sum_i \left[\frac{\sum\limits_{j \in N_i} d_{ij} y_{ij} - d_{ij} y_{ij}}{\left(\sum_{j \in N_i} y_{ij} - 1\right) * \sum_{j \in N_i} d_{ij} y_{ij}} * r_i \right] \tag{2}$$

$$D \geq \sum_j d_{ij} y_{ij} \tag{3}$$

$$\sum_j X_j \leq P, \tag{4}$$

P is the total number of buildable distribution centers given

$$y_{ij} = 1, \text{ if } d_{ij} \leq \beta \tag{5}$$

Letter i is the sequence number of requirement points; Letter j is the serial number of the selected point of the facility, Ni represents the collection of the distribution center covering demand point i, and r_i represents the demand of demand point i. When the demand point i is satisfied by the distribution center j, y_{ij} is 1, otherwise it is 0. D_{ij} is the distance between demand point I and facility point j. C_j for distribution center construction costs, X_j whether to build distribution center in j point, if the j point to build distribution center, X_j is 1, otherwise 0, type (3) for any demand point I with recent facilities j (distribution), the biggest distance type (4) limit the maximum number of the construction of distribution center. Coefficient of α as profit coefficient of the distribution center, this article assumes that the same demand and service range of profit coefficient is the same, so use (α/D) said the actual profit, which is inversely proportional to the distance. β for distribution range, can be equivalent to each service radius of distribution center.

In the model r_i, d_{ij}, c_j, coefficient of α is to measure the size of the known data, can according to these data, we need objective function and ultimately determine the optimal X_j, as can be seen from the model belongs to nonlinear model, through the classic algorithm for solving nonlinear model. In practice, the difficulty of the whole model is large, so we can use the heuristic algorithm commonly used today to solve the optimal solution, and get a satisfactory solution more efficiently.

4 Conclusion and Prospect

By establishing the above model, we can use the scientific method to make logistics companies in the planning of the distribution center, choose to have the profit maximization strategy, in this model, some simplified processing parameters, such as profit coefficient, assumption is in the same conditions (demand, scale) its profitability is the same, but the actual cases, the scale of demand the same conditions, its profit level is different, because in practice there will be other competitors, when consumer is choosing have their own preference, so in the further study, we also can consider more deeply, to join in different parts of the competitors, A variety of factors, such as consumer preferences, are used to modify the model.

Due to the constant change of the social environment at the same time, the business is to pursue the maximization of profit for a long time, and is no longer a single current profit maximization, so consider in the next step of research is to set up distribution centers in relation to the operating cycle, make the whole logistics system is as the change of time and the unceasing development, finally achieve the optimal strategy of long-term development.

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Research on the Construction of Regional Intelligent Tourism Service Platform—Take Zaozhuang for Example

Xiujun Bai, Ping Li and Jinhua Duan

Abstract This paper, taking Zaozhuang as the research object, expounds the construction achievements and problems of the existing Zaozhuang intelligent tourism service platform, and puts forward a service platform for the construction of large data of intelligent tourism. Based on the large data of tourism, the model builds a data center around three aspects of the management, marketing and service of intelligent tourism, and builds the six brigades. The application service platform is used to build a large data application subsystem of different functions. Each thematic application subsystem relies heavily on big data to fulfill the great data, to realize large data collection, storage, analysis and application of intelligent tourism. At the end of the article, from the perspective of managers, some suggestions are put forward for the implementation of Zaozhuang intelligent tourism service platform. The transformation and upgrading of tourism in Zaozhuang will enable the transformation of new and old tourism momentum.

Keywords Zaozhuang city · Big data technical platform · Intelligent tourism service system

1 Introduction

In recent years, Zaozhuang tourism has entered a period of rapid development. According to statistics from the Zaozhuang City Travel Service Committee, in 2017, the number of Zaozhuang tourist trips exceeded 22.59 million, and the total consumption exceeded RMB 19.9 billion, an increase of 10.55% and 14.91% over 2016 respectively. There are 50 A-plus tourist attractions (including one 5A scenic spot), 18 star hotels, 64 travel agencies and 286 rural tourist spots in the city. Every year, the New Year’s meeting, Lufeng canal summit, Lufeng canal food festival and

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other activities are held to attract a large number of tourists to Zaozhuang, making Zaozhuang tourism develop by leaps and bounds. On this basis, Zaozhuang city focuses on building a tourism intelligent service platform to meet various new needs of tourists at different levels. In 2017, the Zaozhuang municipal party committee and municipal government took the lead in formulating “Zaozhuang City Smart City Work Essentials for 2017”, which clearly required the integration of the city’s scenic spots, transportation, catering, accommodation, business, entertainment and other related tourism resources to build a intelligent tourism big data service platform(In other words, tourism clouds), innovate tourism service methods and marketing models, further promote tourism intelligence, provide tourists with integrated tourism services, enhance the level of Zaozhuang tourism service intelligence, and promote all-round development of the tourism industry. The construction of the intelligent tourism big data service platform will provide tourists with richer tourism data services and provide more realistic tourism experience items, which is of great significance in promoting the transformation, upgrading and sustainable development of the tourism industry.

2 Format of Manuscript

2.1 Zaozhuang Intelligent Tourism Service Platform Construction Results

Zaozhuang Tourism Service Commission attaches great importance to the construction of a intelligent tourism service platform, and basically implements the “Internet+” new tourism industry development model. Taking the Internet, Internet of Things, big data and other new technologies as carriers, it aims to cultivate new business models. In order to drive the development of tourist consumption and the innovative development of tourism enterprises, the city has made every effort to promote the development of the tourism industry in the direction of informatization, intelligence, and humanization, and initially formed a intelligent tourism pattern with wisdom management, smart marketing, and wisdom services as the core. The following achievements have been achieved in the construction of tourism service platforms:

2.1.1 Zaozhuang Travel Network

Zaozhuang tourism network is the main channel for Zaozhuang tourism information release, realizing the separation of the tourism administration network and information network, and integrating and using a website www.tour.gov.cn, together known as Zaozhuang tourism network. Furthermore, the website page was redesigned to further optimize service functions. This tourism network has also developed the key corporate monitoring systems, key project construction and dispatching systems, guide information databases and other networked office platforms, and built a number of OA office automation projects featuring online direct reporting, digital storage, and intelligent management. It has realized intelligent management of online management, online scheduling, and online supervision, and improved office efficiency.

2.1.2 The Phone APP

Zaozhuang travel APP can realize the guiding and navigation functions of mobile phones, provide all-round tourism information service and location navigation service, and realize the function of "visiting Zaozhuang with one mobile phone". In order to cooperate with the construction of the tourism toilet revolution project, a travel toilet APP was developed. On the basis of perfecting the city's tourist toilet information, automatic positioning and voice navigation were automatically performed to find the closest function of the nearby toilets, providing more practical information services for visitors.

2.1.3 Industrial Monitoring and Video Monitoring and Scheduling Platform

Zaozhuang City Industrial Monitoring and Video Surveillance and Dispatching Platform has covered the city's 4A-level or more key scenic spots. It can provide 24-hour uninterrupted video surveillance for the densely populated spots of various scenic spots. It is of great positive significance for the competent authorities to keep abreast of the real-time operation of the scenic spot and prevent the occurrence of major safety accidents. Through the upgrade of software and hardware, it can connect with the provincial tourism commissions monitoring and dispatching platform, and at the same time realize the existing monitoring platform for all 4A level or above scenic spots and upload it to the Provincial Tourism Commission. Among them, the 5A-level scenic spot surveillance video has been directly connected with the National Tourism Administration through the platform, and video data sharing has been realized.

2.1.4 Zaozhuang Travel Service Official Weibo, WeChat Public Platform

The number of official Weibo fans of the Zaozhuang Travel Service Committee exceeded 630,000. The WeChat public service platform realizes service number, subscription number double number operation, and daily push service information. On the basis of the original functions of the WeChat platform, visitors' interactive games were added, further expanding the influence of the WeChat public platform.

2.2 *The Existing Problems of Zaozhuang Intelligent Tourism Service Platform*

Though the construction of Zaozhuang intelligent tourism service platform has a certain basis, it also plays an outstanding role in the tourism development process in Zaozhuang City. However, there are still some deficiencies. Some problems restrict the development of Zaozhuang intelligent tourism, mainly in the following aspect.

2.2.1 Insufficient Data Collection, Analysis and Application

The Zaozhuang intelligent tourism service platform cannot collect and store data on tourism at present. It is unable to analyze and apply data, and cannot achieve data docking and sharing. At the same time, the construction of the city's intelligent tourism service platform has not yet achieved three levels of interconnection among cities, districts and enterprises (Table 1).

2.2.2 Insufficient Capital and Manpower Input

The construction of Zaozhuang intelligent tourism service platform often requires a lot of funds and manpower investment, such as the construction of the platform, the development of the system, and the promotion and maintenance of the later stage. Upgrading requires adequate technical support and substantial capital investment. However, in the process of building and implementing a specific intelligent tourism service platform, there are problems of shortage of funds and lack of talent in implementation of a number of intelligent tourism projects in Zaozhuang City. At the same time, the lack of manpower, material resources and financial resources after the completion of the platform often results in the ordinary operation difficulties of the platform.

Table 1 Data service function statistics of intelligent tourism service platform

Intelligent travel service platform	Release data (whether or not)	Collect data (whether or not)	Analysis and application (whether or not)
Tourism administration network	Yes	Yes	No
Travel information network	Yes	Yes	No
Mobile APP platform	Yes	No	No
New media platform	Yes	No	No
Video monitoring platform	No	No	No

2.2.3 Lacking of Publicity and Promotion

The publicity and promotion of the intelligent tourism service platform is very important in the later period. The publicity and promotion of the intelligent tourism service platform is not in place. Visitors do not understand the function of the intelligent tourism service platform, and it is easy to cause the actual utilization rate of the intelligent travel service platform to be low, even idle.

2.2.4 Low Wireless WIFI Coverage

The wireless network coverage rate of Grade A or above in Zaozhuang City is still relatively low, and it has not been fully covered. Visitors get all kinds of information, using mobile phone guides, navigation, navigation and other intelligent services all need to install and download data on smart phone terminals, or access to the designated web site. And these will be constrained by the network speed. The wireless WIFI coverage is low, which will greatly affect the use and promotion of the intelligent tourism service platform (Table 2).

2.3 Zaozhuang Intelligent Tourism Big Data Service Platform Model Construction

In order to further optimize the functions of the Zaozhuang intelligent tourism service platform and solve the current problems in the Zaozhuang intelligent travel service platform, based on integrating the functions of the original intelligent travel service platform, in general, overall use the cloud computing architecture to realize the "poly", "pass" and "use" data construction ideas. Propose to construct a framework of Zaozhuang intelligent travel big data service platform with the core content of "a big data center, six service platforms, multiple application subsystems".

Table 2 Zaozhuang tourism wireless WIFI coverage statistics

District/city	A level scenic spot (%)	Characteristic rural tourism (%)	Hotel (%)	Visitor center (%)
Tengzhou	17.6	100	100	100
Xuecheng	10	100	50	100
Shanting	20	70	51	100
Shizhong	100	100	60	100
Yicheng	50	100	0	100
Taierzhuang	25	100	12.5	100

2.3.1 Tourism Big Data Center

The tourism big data center mainly realizes the convergence of tourism data and the integration of platforms. Through collecting, combing and summarizing all aspects of tourism data resources, setting data-related standards, clarifying data indicators, establishing data index system, collecting, cleaning, classifying, cataloging, and storing tourism data, realizing data management, docking, sharing, and querying to achieve unified data collection, unified management, real-time sharing, and ensure data security (Fig. 1).

The data sources are mainly divided into four major categories. First, data from internet includes search engine data such as Baidu, online travel website data, social media data, and UGC data; second, data from departments includes traffic, public security, environmental protection, and weather Such as data; The third is from the tourism industry data, including the business system data and reporting data of various levels of tourism bureaus, scenic areas, travel agencies, hotels and other tourism state data; The fourth data is from operators' data including communication operators such as mobile, China Unicom, and telecommunications, as well as data from mobile internet service providers and Tencent.

The data collection methods mainly include data capture, data purchase, data docking, data filling, and data exchange. Data crawling is the crawling of web sites such as e-commerce sites and social media through technologies such as web crawlers; The data purchase is mainly the data of the three major mobile operators; the purchase of Internet operator data, and the purchased data are also the data after desensitization; Data reporting is data that the system docks or enters into the intelligent tourism big data platform for manual reporting; valuable data involving travel companies and departments can also be shared through exchanges.

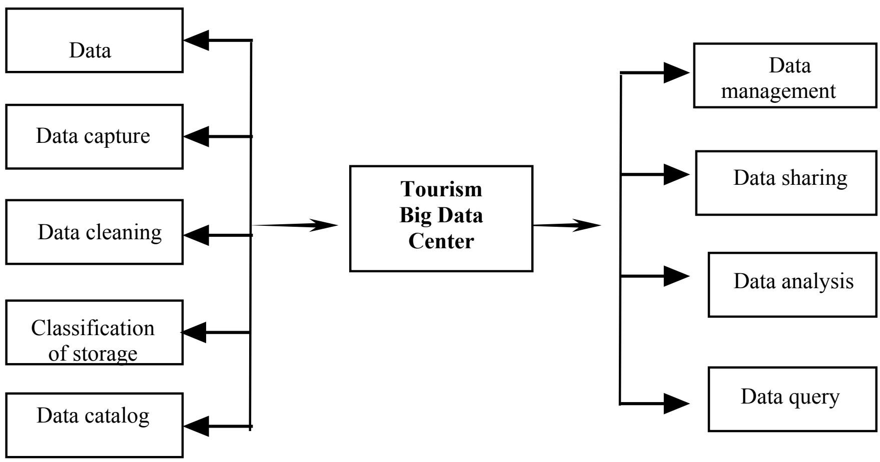

Fig. 1 Function diagram of tourism big data center

The data storage adopts the cloud storage service mode. According to the type of big data, different databases are set to classify and store data, such as structured databases, non-structured databases, and distributed file databases. The use of cloud storage can not be limited by the storage space, and the automatic expansion of storage space can be realized. At the same time, the adoption of cloud storage is also conducive to data security and unified data management [1].

2.3.2 Intelligent Tourism Big Data Service Platform

The intelligent travel big data platform is mainly an exploratory application of the data center's data around smart management, smart marketing, and smart services.

Intelligent Tourism Big Data Statistics Platform

Traditional tourism statistics are conducted in accordance with the requirements of the National Tourism Administration and the National Bureau of Statistics, and they are conducted through traditional methods such as data reporting, sample surveys, and layered reporting. The statistical project indicators are mainly based on numbers and income [2].

Through data access methods such as docking and data import, around the elements of the tourism industry chain, the intelligent travel statistics system carries out comprehensive and integrated integration and integration of the tourism industry base and operational data, and can obtain tourist location information data, thereby obtaining statistical project indicators.

For example, the number of visitors received through satellite positioning, cell phone base stations, travel APP, WeChat, vocal data boxes, OTA data, etc. Receive credits through SMS, UnionPay data and OTA online payment data. The average value of consumption allowance multiplied by the number of tourists can obtain more accurate total consumption, and its objectivity and credibility are much higher than sample surveys and questionnaires.

Intelligent Tourism Big Data Precision Marketing Platform

Traditional tourism marketing is carried out through mass media such as newspapers, television, radio, and broadcasting. At the same time, it cooperates with travel agencies at all levels to launch tourism promotion activities so as to achieve brand promotion and product sales. This kind of one-way transmission method has defects such as blindness and arbitrariness, and the marketing effect is difficult to evaluate [3].

The intelligent tourism precision marketing platform can use web crawler technology to capture various web search data, analyze the attention of tourists, and identify valuable tourism consumer groups, and use big data technology to analyze the consumer data after market segmentation, combined with the characteristics of their own business, choose the target market for the company; Through collating, summarizing and analyzing the data obtained from the Internet search, it outlines the attributes of tourist consumers, predicts the preferences of tourists, and recommends special customized travel products or services for tourists to achieve accurate marketing.

Take the accurate marketing of the Taierzhuang Ancient City Scenic Area as an example, through the web crawler technology, with "Tai'erzhuang" as the seed, conduct statistics and analysis of the network search data of the Tai'erzhuang Ancient City Scenic Spot in Zaozhuang during a certain period of time, we can get high search index in Linyi, Zaozhuang, Xuzhou, Beijing, Shanghai, Jinan and other places. During the holidays of May 1st, Spring Festival and other holidays, tourists from Linyi, Xuzhou and other places are the highest. Therefore, the scenic spot can offer some preferential policies for Linyi, Xuzhou, Jining and other tourists. This will not only achieve diversion of tourists, avoid Linfen, Xuzhou tourists get together to visit the ancient city on holiday, and can also attract a large number of tourists to visit the ancient city of Taierzhuang in order to achieve accurate marketing.

Intelligent Tourism Big Data Management Platform

(1) Tourism public opinion monitoring system

The public opinion monitoring system can collect data sources such as websites, WeChat, Weibo, blogs, forums, news websites, and post bars. Through analysis and processing of data, it is possible to implement functions such as public opinion early warning, positive and negative sentiment analysis, sound volume trend analysis, data source analysis, lyrics hot word analysis, etc. It can obtain real-time analysis of public opinion hot-spot propagation process, permeate different stages of topics such as fermentation, diffusion, peak and attenuation, and conduct in-depth observation of the event mechanism, diffusion path, and impact effects, and conduct appropriate guidance in an official or unofficial manner according to progress, avoiding the occurrence of Zaozhuang tourism network public opinion events [4].

(2) Passenger flow monitoring system of tourist attractions

The relevant data is captured by installing acoustical data boxes or mobile operator data at the entrance of the scenic area to obtain tourist flow data of tourist attractions. The tourist flow data of tourist attractions can be divided into real-time data, monthly data, and annual data. A large LED screen can be set at the entrance of the scenic spot, which can display the number of passengers in the scenic spot in real time. By analyzing the tourist flow data of tourist attractions, it is possible to effectively avoid overloading tourists in scenic spots and avoid unexpected events.

At the same time, it is also possible to predict the passenger flow and traffic flow of the scenic spot in the near future and help the scenic spot to prepare for the operation and reception in advance so as to improve the tourism service level.

(3) Travel agency team monitoring system

Collect real-time information of the city's travel team on the basis of the functions of the industry monitoring and video monitoring and dispatching platform. Monitor and control the entire operation process of the tourism team, and use the Beidou positioning data to manage the team. Realize the panoramic display of the city's team data and forecast the number of teams, and achieve the effective concatenation of travel industry chains and service providers such as travel agencies, scenic spots, hotels, and transportation. Form a complete supervision and management process for tourism services, and solve the problems of the current management team and tour guides in Zaozhuang City, and eliminate the blind spots in tourism administration.

Intelligent Tourism Big Data Service Platform

(1) Regional passenger flow trend analysis and prediction system

Use big data technology to analyze and predict passenger flow trends, formulate and implement tourist flow control plans, and use the SMS push platform and new media platform to publish passenger flow warnings and related data suggestions for tourists entering the area when necessary.SMS content is embedded in the travel big data WeChat applet, visitors can click to enter the mobile version of the Zaozhuang intelligent travel service platform, can understand information such as weather conditions, traffic conditions, scenic passenger flow, surrounding parking lots and toilets and other data, these data can provide a very important reference for tourists to make reasonable arrangements for the next travel itinerary.

(2) Passenger flow analysis and prediction system of holiday scenic spots

The system is capable of collecting and organizing holiday history and real-time data from multiple data sources, such as travel networking data, mobile operator data, and travel system own data, and predicts vacation holiday passenger flow. The Ministry of Tourism can publish the information on the analysis and prediction of tourists in holiday resorts through various channels such as SMS, WeChat, webpage, television, and radio. In addition to tourism promotion, it can provide more authoritative reference for tourists to travel, so as to promote the orderly, healthy, and stable development of the tourism industry.

(3) "Donkey" information system

The system can collect tourist demand information so that all visitors to Zaozhuang can travel together at the same time. The mutual understanding between the donkeys can enrich travel and make the journey more enjoyable. For example, after collecting tourist information, tourists from Zaozhuang can be invited to enter the group “Love Friend” at the same time. Release public service information and preferential information related to Zaozhuang Tourism in the group. Visitors can communicate with the “alien” before playing, and prepare well for travel. The play process can remind each other, help each other, make new friends, and share with each other after the game is over.

(4) Intelligent virtual tourism system

Establish a virtual tourism video database to integrate video data of the city’s tourist attractions through the collection of VR, video monitoring platform and other travel data. Visitors can directly watch the live video of the scenic spot through the “telescope” function of the Zaozhuang intelligent tourism service platform. They can also download and obtain video data, and enjoy the real-time beauty of Zaozhuang city’s major scenic spots in advance, thus creating a tourism vision [5].

Intelligent Tourism Big Data Credit Platform

Travel Credit Big Data is divided into four systems: destination credit big data, scenic credit big data, hotel credit big data, travel agency credit big data. Collect, collate and analyze collectively through the data on the Internet public opinion data, the tourism administrative department punishment notification data, 12301, the satisfaction of tourists, etc. Establish a list of “red and black” tourism integrity, and improve the data construction of the integrity of travel companies and tour guides. The entire credit chain of tourism tourism industry in Zaozhuang is displayed in a panoramic way, which facilitates the screening selection of tourism audiences. It is convenient for the government and competent authorities to conduct unified governance and comprehensive control from a higher perspective, and promote the rapid and efficient development of the entire tourism industry [6].

Intelligent Tourism Big Data Enterprise Price Monitoring Platform

The existence of price uncertainty pricing in current tourism is an infringement on the actual rights and interests of tourists, and price monitoring is conducive to the timely availability of relevant authorities. According to the analysis results, it predicts and proposes the reasonable selling price of the scenic products in the short term, monitors the price changes of the scenic spots in real time, analyzes the price change curve of the scenic spots by category and area, comprehensively predicts the change trend of the scenic ticket prices, and provides the dynamic pricing for the scenic spots. The price of online sales tickets is monitored at different prices and traced back to the source.

3 Suggestions on the Construction and Implementation of Zaozhuang Intelligent Tourism Service Platform

In order to ensure the smooth implementation of zaozhuang intelligent tourism service platform and better play the function of intelligent tourism service platform, the following Suggestions are proposed.

3.1 Improve Model Design and Enhance Service Function

Perfect intelligent tourism service platform model design of zaozhuang, platform framework should be used more than three layer architecture, has the characteristics such as easy to install, easy to use, improve the reliability of system, stability, compatibility and extensibility platform, improve the storage of database and the data processing ability, fully considering the platform after the completion of maintenance requirements, at the same time to dig deeper into big data applications in tourism, strengthen the zaozhuang intelligent travel service platform. Improve the model design of the Zaozhuang intelligent tourism service platform. The framework of the platform should adopt a three-tier or higher architecture and be easy to install and use. Improve the reliability, stability, platform compatibility and scalability of the system and improve the storage and data processing capabilities of the database. Fully consider the requirements such as ease of maintenance after the completion of the platform, and further tap into the application of big data in tourism, and strengthen the Zaozhuang intelligent tourism service platform.

3.2 Change the Data Concept and Cultivate the Awareness of Application

Big data is not only a technical change, but also more important is the transformation of thinking modes and consciousness concepts, including concepts such as cross-border, integration, opening, and sharing. It uses the concept of big data to carry out Zaozhuang tourism; attaches importance to data and respects data. The data is used in the promotion and service process of tourism, highlighting the convenience brought by big data in management applications, and continuously improving the efficiency and quality of tourism management.

3.3 Pay Attention to Personnel Training and Enhance the Ability of Application

The key to whether or not the Zaozhuang intelligent travel service platform can play a better role lies in the introduction and training of talents, mainly those who can actively collect and analyze data with strong capabilities. These talents need to have a certain computer background, and are familiar with the development of the tourism industry. They can integrate computer technology into the development of intelligent tourism. In addition, it is necessary to introduce experts who have experience in the application of tourism big data to the intelligent tourism team. In order to promote the refinement and modernization of the tourism industry, we must actively create conditions to cultivate high-end tourism complex talents.

3.4 Increase Capital Investment to Ensure Late Operation and Maintenance

The intelligent tourism service platform more embodies the tourism public welfare service. Therefore, the Zaozhuang City Travel Service Committee should strive to establish a special fund for intelligent tourism in Zaozhuang City, establish a sustainable development investment mechanism for the intelligent tourism service platform, and at the same time, through market-oriented means, mobilized tourism-related companies to raise funds in various aspects and carry out cooperation platform construction for intelligent tourism. On the one hand, it further perfects and expands the functions of the Zaozhuang intelligent travel service platform. On the other hand, it can entrust professional companies to operate and maintain the platform. For example, the collection of data, especially the analysis and application of data, requires professional personnel and corresponding capital investment. The platform is not only a construction, more importantly, the operation and maintenance of the platform in the later period.

3.5 Enhance Authority and Security and Ensure Credibility

Information security is the biggest obstacle to data sharing and full use. It is also the biggest obstacle to the application of big data in intelligent tourism. Tourism government agencies should further improve the system of data security related to the intelligent tourism service platform, and classify tourism big data. Data involving confidentiality should be well-encrypted, prevent data leakage, and avoid the occurrence of travel information security [7]. In addition, experts and professors of tourism colleges and universities may be invited to further review the data and at the same time review the information published by the intelligent tourism service platform to Guarantee the authenticity and effectiveness of information and to improve the authority and credibility of the Zaozhuang intelligent tourism service platform.

3.6 Improve Wireless Wifi Coverage and Increase Publicity

Further improve wireless WIFI coverage in high-speed railway stations, railway stations, hotels, scenic spots, bus platforms and tourist service centers. Foreign tourists entering Zaozhuang City can use the form of a push welcome message to carry out the program link of the platform and conduct targeted promotion of the intelligent travel service platform according to the tourist data. Through the tourism website, Zaozhuang Smart Travel Service website is embedded for tourists to download free of charge. Information on promotions can be embedded in public service facilities such as various signage boards, public bicycles, and gas stations so that visitors can sweep into the Zaozhuang intelligent travel service platform. In short, the platform must not only ensure fast access, but also ensure full coverage of wireless networks, and at the same time ensure that multiple channels are promoted. This will enable Zaozhuang City's intelligent travel service platform to maximize its functions and provide tourists with intelligent services for tourism.

4 Conclusion

At present, the application of tourism big data in the intelligent tourism in Zaozhuang is at the stage of exploration and program improvement. This article explores and tries to apply tourism big data to intelligent tourism based on the actual situation of tourism in Zaozhuang only for the current recognition of the tourism industry. Hope that in the follow-up study, there can be more tourism big data can be applied to Zaozhuang intelligent tourism, the construction of Zaozhuang intelligent tourism service platform for continuous improvement and improvement, and constantly improve the level of intelligence Zaozhuang tourism.

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Research on Horizontal Competition Between Dual-channel Retailer and Traditional Retailer in the Circular Market Under the Congestion Negative Effect of Physical Channel

Bing Xu, Huifang Li and Ping Wang

Abstract Combining with the Salop model, the horizontal competition between one dual-channel retailer and $N - 1$ traditional retailers is studied in a circular market where all the retailers are uniformly located. The dual-channel retailer set different pricing strategies and unified pricing strategy for products selling online and offline respectively when physical channel has congestion negative effect. This paper studies the impact of congestion negative effects on the physical channel and the effect of the number of firms on channel pricing strategies in the circular market and to illustrate the results by using numerical experiments. The results show that: (i) traditional retailers should speed up the transformation from entities to dual-channel retailers and improve their service level; (ii) the dual-channel retailer should make different pricing for products which selling online and offline; (iii) and the newly entered traditional retailers will compete for the online market share, but has no effect on offline channel.

Keywords Horizontal competition · Salop model · Dual-channel retail · Congestion negative effect

1 Introduction

According to the latest "Statistics Report of the 41st China Internet Development" conducted by China Internet Network Information Center (CNNIC), on December 2017, the number of Chinese Internet users reached 772 million, online shopping users accounted for 69.1% of the total number of Internet users. Meanwhile, online retail transactions accounted for 19.59% of retail sales of social consumer goods, which is approximately RMB 7175.1 billion. Online shopping has become a habitual shopping way. However, with the rapid development of e-commerce and

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the impact of financial crisis, more and more enterprises begin to sell products through the Internet. Such as, RAINBOW, RT-Mart, etc. On the one hand, E-Shop is easing the pressure of physical stores in a way. On the other hand, it brings challenges to the physical channel. Furthermore, a consumer's shopping experience will be affected by store size, decoration style and other factors partly. In the holidays, especially, stores are so crowded that many consumers even give up shopping. Therefore, under the congestion negative effect of physical channel, whether the traditional retailer needs to transform into a dual-channel retailer? What pricing strategy should be chosen after the transformation?

Hotelling first constructs a linear city model to study horizontal production differentiation problem, and finds that two enterprises should locate in the market center, which is "Minimum differentiation principle" [1]. Many scholars expanded this model. Krina and Nikolaos study the price competition under the network effect, while the duopoly products are different in horizontal and vertical directions. The results show when expectations are not affected by prices, the market may be equally shared. Otherwise, high-quality companies tend to occupy a larger market share [2]. Yi and Yang investigate the influence mechanism between retailer's marketing strategic and wholesale price in a market with network externality, find that the strength of network externality is inversely proportional to the wholesale price [3]. Liu et al. study the game between one retailer and one supplier when retailer sells information products with two versions in a market with network externality; the best sales channel strategy is to distribute high-quality version through direct channels and sell low-quality version through retail channels [4]. Based on Hotelling model, Suleymanova and Wey analyze the impact of consumer expectations on prices with strong, medium, and weak network externalities respectively, and find that consumer expectations are negatively correlated with market competition intensity [5]. Ahlin et al. study the Hotelling model with congestion negative effects, and proved that the "Minimum differentiation principle" of Hotelling model was right under congestion negative effects [6]. Assume that consumers are evenly distributed, and enterprises are equally distributed in the circle market, Salop constructs the two-stage game that in the first stage, potential enterprises decide whether to enter the market simultaneously; in the second stage, the enterprises compete against each other on price [7]. Wu et al. study the competition between dual-channel retailers and online retailers, and find that the relative size of the online market and the physical market determines whether the dual-channel retailer has a competitive advantage [8]. Heikkinen introduces positive and negative network externalities into the circular market competition model, and found that the negative network externalities caused the equilibrium price of market competition to decline [9]. Jiang studies the location and pricing of dual channel retailers based on the Hotelling model [10]. Xu et al. relaxed the assumption that enterprises only compete with two adjacent enterprises, analyze the location and price competition of enterprises in one circular market [11].

There are lots of studies about horizontal product differentiation, but the research of congestion negative effect in horizontal product differentiation mainly focused on the two entity retailers in linear city model. Furthermore, few of the studies are about the dual-channel retailer, most of them are only related to the dual-channel manufacturer. Therefore, this article focuses on the congestion negative effects of physical channel, and studies the price competition among one dual-channel retailer and $N - 1$ traditional retailers in one circular market.

2 Model Description and Hypothesis

There is a circular market whose length is 1, N retailers who sell same products are uniformly located at the circular market. One retailer, denoted by retailer 1, is dual-channel retailer who sells products in both offline channel and online channel, and provides free delivery service to customers who are shopping online. The others, denoted by retailer γ (γ = 2, 3, …, N), are undifferentiated entity retail enterprise. Consumers are evenly distributed in the market, and each of them only have unit need. According to the assumption of Salop [7], the entity retailers only compete with the adjacent stores on both sides, in other words, though there are various channels in the market, but one consumer will only go shopping from 3 channels that one is dual-channel retailer's online channel, and the other two channels are two entity stores adjacent to him. Since the other ($N - 1$) traditional retailers are exactly the same, so denote the total of them as: Γ. The consumer not only needs to bear the traffic cost, but also the congestion negative effect cost of physical channel, so the utility of consumer is:

$$u_i(x) = \begin{cases} u_0 - p_s - tx_s - kq_s & (i = s) \\ \theta u_0 - p_e & (i = e) \\ u_0 - p_\gamma - tx_\gamma - kq_\gamma & (i = \gamma) \end{cases} \tag{1}$$

where e, s and γ represent the dual-channel retailer's online channel, offline channel and one traditional retailer's channel, respectively; p_i and q_i are the corresponding product prices and quantities; $u_0 > 0$ is the intrinsic utility of product; $t > 0$ represents the unit traffic cost; $0 < \theta \leq 1$ denotes consumers preference for online channel; $k > 0$ is the unit congestion cost which describes the influence of unit congestion on consumers' utility; x is the distance between the consumer and the entity store. Assume that the unit cost of sales in all entity stores is the same c_s and the unit cost of sales through the online channel is c_e; denote $\Delta c = c_s - c_e > 0$. Assume that $u_0 > \max[c_e/\theta, c_s + (k + t)]$ is big enough and each consumer will buy one product. Consumers choose shopping channels based on the principle of utility maximization.

Lemma 1 *When* $p_s \leq p_e + (1 - \theta)u_0$, $p_e \leq \frac{1}{2}[(p_s + p_\gamma) + (k + t)] - (1 - \theta)u_0$ *and* $p_\gamma \leq p_e + (1 - \theta)u_0$, *all three channels will have demand.*

Proof When $p_s > p_e + (1-\theta)u_0$, we have $u_e(x) > u_s(x)$ $(\forall x \in (0,1))$, no one will visit the offline store of dual-channel retailer. When $p_e > \frac{1}{2}[(p_s + p_\gamma) + (k+t)] - (1-\theta)u_0$, we have $u_e(x) < \min[u_s(x), u_\gamma(x)](\forall x \in [0,1])$, the online channel of dual-channel retailer's will have to be closed because of no shoppers. So, the prices of dual-channel retailer's products should commit to: $p_s \le p_e + (1-\theta)u_0$ and $p_e \le \frac{1}{2}[(p_s + p_\gamma) + (k+t)] - (1-\theta)u_0$. As the same, when $p_\gamma > p_e + (1-\theta)u_0$, we have $u_e(x) > u_\gamma(x)(\forall x \in [0,1])$, traditional retailers will exit the market. So, the conclusion is hold.

According to Lemma 1, the prices of products can't be too high; otherwise the channel will be eliminated. The floor price is unit cost when there has competition. Then parameters should commit to $\Delta c \le (1-\theta)u_0 \le (k+t)/2 + \Delta c$.

There has a point where all consumers who locate at will get the same utility, which is called indifferent point. So the indifferent point between dual-channel retailer's online and offline stores is x_s, the dual-channel retailer's online store and one of the $N-1$ traditional retailers' store have an indifferent point x_γ,

$$\begin{cases} x_s = \frac{1}{t}[(p_e - p_s) + (1-\theta)u_0 - kq_s] \\ x_\gamma = \frac{1}{t}[(p_e - p_\gamma) + (1-\theta)u_0 - kq_\gamma] \end{cases} \tag{2}$$

The consumers will only choose the right or the left entity store or dual-channel retailer's online store to shopping. According to Eq. (2), the demand functions are: $q_s = 2x_s$, $q_\gamma = 2x_\gamma$, $q_e = 1 - q_s - (\mathrm{N}-1)q_\gamma$. Solve these equations, we have:

$$\begin{cases} q_s = \frac{2}{2k+t}[(p_e - p_s) + (1-\theta)u_0] \\ q_\gamma = \frac{2}{2k+t}[(p_e - p_\gamma) + (1-\theta)u_0] \\ q_e = 1 - \frac{2}{2k+t}[(N-1)(p_e - p_\gamma) + (p_e - p_s) - N(1-\theta)u_0)] \\ q_1 = q_s + q_e \\ q_\Gamma = \frac{2(N-1)}{2k+t}[(p_e - p_\gamma) + (1-\theta)u_0] \end{cases} \tag{3}$$

The profit functions of all channels and N retailers are:

$$\begin{cases} \pi_s = (p_s - c_s)q_s(p_s, p_e) \\ \pi_e = (p_e - c_e)q_e(p_s, p_e, p_\gamma) \\ \pi_1 = \pi_s(p_s, p_e) + \pi_e(p_s, p_e, p_\gamma) \\ \pi_\gamma = (p_\gamma - c_s)q_\gamma(p_\gamma, p_e) \end{cases} \tag{4}$$

2.1 Dual-channel Retailer Sets Different Channel Selling Prices

Assume that dual-channel retailer sets prices online and offline respectively, the model can be formulated as:

$$\begin{cases} \pi_1(p_s^*, p_e^*, p_\gamma^*) \geq \pi_1(p_s, p_e, p_\gamma^*), \forall p_s \geq c_s, \forall p_e \geq c_e \\ \pi_\gamma(p_\gamma^*, p_e^*) \geq \pi_\gamma(p_\gamma, p_e^*), \forall p_\gamma \geq c_s, \gamma = 2, \ldots, N \end{cases} \quad (5)$$

Since: $\frac{\partial^2 \pi_1}{\partial p_s^2} = -\frac{4}{2k+t} < 0$, $\frac{\partial^2 \pi_1}{\partial p_s^2}\frac{\partial^2 \pi_1}{\partial p_e^2} - \frac{\partial^2 \pi_1}{\partial p_s \partial p_e}\frac{\partial^2 \pi_1}{\partial p_e \partial p_s} = \frac{16(N-1)}{(2k+t)^2} > 0$, the Hessen matrix is a negative definite matrix, and the profit function is joint strictly differentiable concave function. Solve the equilibrium functions of first-order conditions, the optimal prices of each channel can be obtained. Furthermore, every consumer should get positive utility so that every consumer will buy unit product, the following conditions must be met:

$$\begin{cases} p_i \geq c_i (i = e, s, \gamma) \\ q_i \geq 0 (i = e, s, \gamma) \\ u_i(x) \geq 0 (i = e, s, \gamma) \end{cases}.$$

So the following Eq. (6) should be hold

$$(N-1)[(1-\theta)u_0 - \Delta c] \leq 2k + t \leq (N-1)[(1+2\theta)u_0 - c_s - 2c_e] \quad (6)$$

The optimal prices of three channels are respectively expressed as:

$$\begin{pmatrix} p_s^* = c_s + \frac{1}{6}[\frac{4k+2t}{N-1} + (1-\theta)u_0 - \Delta c] \\ p_e^* = c_e + \frac{1}{3}[\frac{2k+t}{N-1} - (1-\theta)u_0 + \Delta c] \\ p_\gamma^* = c_s + \frac{1}{6}[\frac{2k+t}{N-1} + 2(1-\theta)u_0 - 2\Delta c)] \end{pmatrix} \quad (7)$$

Equation (7) shows that in the circular market, when dual-channel retailer sets different channel selling prices, all the retailers determine price based on the channel cost by cost-plus method. The plus depends on the difference between channel cost and utility, the unit traffic cost, the unit congestion negative effect cost and the number of retailers in the circular market.

The optimal market share and profit of every channel and retailer can be expressed as:

$$\begin{cases} q_s^* = \frac{1}{2k+t}[(1-\theta)u_0 - \Delta c] \\ q_e^* = \frac{1}{3(2k+t)}[4k+2t-(2N+1)((1-\theta)u_0 - \Delta c)] \\ q_1 = \frac{2}{3(2k+t)}[2k+t-(N-1)((1-\theta)u_0 - \Delta c)] \\ q_\gamma^* = \frac{1}{3(2k+t)}[\frac{2k+t}{N-1} + 2((1-\theta)u_0 - \Delta c)] \\ q_\Gamma^* = \frac{1}{3(2k+t)}[2k+t+2(N-1)((1-\theta)u_0 - \Delta c)] \end{cases} \quad (8)$$

$$\begin{cases} \pi_s^* = \frac{1}{6(2k+t)}[\frac{4k+2t}{N-1} + (1-\theta)u_0 - \Delta c][(1-\theta)u_0 - \Delta c] \\ \pi_e^* = \frac{1}{9(2k+t)(N-1)}[-2k-t+(N-1)((1-\theta)u_0 - \Delta c)][-4k-2t+(2N+1)((1-\theta)u_0 - \Delta c)] \\ \pi_1^* = \pi_s^* + \pi_e^* \\ \pi_\gamma^* = \frac{1}{18(N-1)^2(2k+t)}[2(N-1)(1-\theta)u_0 - 2(N-1)\Delta c + 2k+t]^2 \\ \pi_\Gamma^* = \frac{1}{18(N-1)(2k+t)}[2(N-1)(1-\theta)u_0 - 2(N-1)\Delta c + 2k+t]^2 \end{cases} \quad (9)$$

2.2 Dual-channel Retailer Sets Unique Channel Selling Price

Assume that the dual-channel retailer takes unified pricing strategy, denote $p_s = p_e = p_1$. Now the model is as follows:

$$\begin{cases} \bar{\pi}_1(p_1^*, p_\gamma^*) \geq \bar{\pi}_1(p_1, p_\gamma^*), \quad \forall p_1 \geq \min[c_s, c_e] \\ \bar{\pi}_\gamma(p_\gamma^*, p_1^*) \geq \bar{\pi}_\gamma(p_\gamma, p_1^*), \quad \forall p_\gamma \geq c_s, \gamma = 2, \ldots, N \end{cases} \quad (10)$$

Because $\frac{d^2\bar{\pi}_1}{d\bar{p}_1^2} = -\frac{4(N-1)}{2k+4} < 0$, $\frac{d^2\bar{\pi}_\gamma}{d\bar{p}_\gamma^2} = -\frac{4}{2k+t} < 0$, $\bar{\pi}_i$ are the strictly differentiable concave function of p_i. Solve the first-order conditions functions, we have Eq. (12). And $\begin{cases} p_i \geq c_s(i = e, s, \gamma) \\ q_i \geq 0(i = e, s, \gamma) \\ u_i(x) \geq 0(i = e, s, \gamma) \end{cases}$ should be hold, we have:

$$(N-1)[(1-\theta)u_0 + 2\Delta c] \leq 2k+t \leq (N-1)[(1+2\theta)u_0 - c_s - 2c_e] \quad (11)$$

$$\begin{cases} \bar{p}_1^* = c_e + \frac{1}{3}\left[\frac{2k+t}{N-1} - (1-\theta)u_0 + \Delta c\right] \\ \bar{p}_\gamma^* = c_s + \frac{1}{6}\left[\frac{2k+t}{N-1} + 2(1-\theta)u_0 - 2\Delta c\right] \end{cases} \quad (12)$$

Equation (12) shows that in the circular market, dual-channel retailer determines price based on the online channel cost, $(N-1)$ traditional retailers decide price based on the physical channel cost by cost-plus method. The plus depends on the cost difference between online and offline channels, the unit traffic cost, the unit congestion negative effect cost and the number of retailers in the circular market.

The optimal market share and profit of each channel and retailer can be expressed as:

$$\begin{cases} \bar{q}_s^* = \frac{2}{2k+t}(1-\theta)u_0 \\ \bar{q}_e^* = \frac{2}{3(2k+t)}[2k+t-(N+2)(1-\theta)u_0+(N-1)\Delta c] \\ \bar{q}_1^* = \frac{2}{3(2k+t)}[2k+t-(N-1)((1-\theta)u_0-\Delta c)] \\ \bar{q}_\gamma^* = \frac{1}{3(2k+t)}\left[\frac{2k+t}{N-1}+2((1-\theta)u_0-\Delta c)\right] \\ \bar{q}_\Gamma^* = \frac{1}{3(2k+t)}[2k+t+2(N-1)((1-\theta)u_0-\Delta c)] \end{cases} \tag{13}$$

$$\begin{cases} \bar{\pi}_s^* = \frac{2}{3(2k+t)}\left[\frac{1}{N-1}(2k+t)-(1-\theta)u_0-2\Delta c\right](1-\theta)u_0 \\ \bar{\pi}_e^* = \frac{2[-2k-t+(N-1)((1-\theta)u_0-\Delta c)][-2k-t+(N+2)(1-\theta)u_0-(N-1)\Delta c]}{9(N-1)(2k+t)} \\ \bar{\pi}_1^* = \bar{\pi}_s^* + \bar{\pi}_e^* \\ \bar{\pi}_\gamma^* = \frac{1}{18(N-1)^2(2k+t)}[2k+t+2(N-1)(1-\theta)u_0-2(N-1)\Delta c]^2 \\ \bar{\pi}_\Gamma^* = \frac{1}{18(N-1)(2k+t)}[2k+t+2(N-1)(1-\theta)u_0-2(N-1)\Delta c]^2 \\ \pi = \bar{\pi}_1^* + \bar{\pi}_\Gamma^* \end{cases} \tag{14}$$

According to Eqs. (8), (9), (13) and (14), the market share and profit of dual-channel retailer are higher than traditional retailers.

Conclusion 1 The horizontal competition of dual-channel retailer and $(N-1)$ traditional retailers in circular market, regardless the pricing strategies, dual-channel retailer will gain higher market share and profit by opening online channel. That is, considering the negative effect of congestion, the traditional retailer will gain new competitive advantages when change to dual-channel retailer.

Conclusion 2 When N retailers compete horizontally in the circular market, the market share of dual-channel retailer's online channel decreases in the number of retailers in the market, its offline channel's market share is unchanged. The market share of one traditional retailer is decreasing, while the total market share of all traditional retailers is increasing.

According to derived function, we have:

$$\frac{\partial \bar{q}_s^*}{\partial N} = 0, \frac{\partial \bar{q}_e^*}{\partial N} = \frac{2[\Delta c - (1-\theta)u_0]}{3(2k+t)} < 0, \frac{\partial \bar{q}_1^*}{\partial N} = \frac{2[\Delta c - (1-\theta)u_0]}{3(2k+t)} < 0, \frac{\partial \bar{q}_\gamma^*}{\partial N} = -\frac{1}{3(N-1)^2} < 0,$$
$$\frac{\partial [\bar{q}_\Gamma^*]}{\partial N} = \frac{2[(1-\theta)u_0 - \triangle c]}{3(2k+t)} > 0; \frac{\partial q_s}{\partial N} = 0, \frac{\partial q_e}{\partial N} = -\frac{2(1-\theta)u_0}{3(2k+t)} < 0, \frac{\partial q_1}{\partial N} = -\frac{2N}{3(2k+t)} < 0,$$
$$\frac{\partial q_\gamma}{\partial N} = -\frac{1}{3(N-1)^2} < 0, \frac{\partial q_\Gamma}{\partial N} = \frac{2(1-\theta)u_0}{3(2k+t)} > 0.$$

So Conclusion 2 is hold.

Conclusion 3 When the dual-channel retailer and traditional retailers compete in the circular market, the price of dual-channel retailer with unified pricing strategy is equal to the price of online channel with pricing separately. Within two pricing strategies, the $(N-1)$ traditional retailers' prices are the same, the market share of dual-channel retailer and the $(N-1)$ traditional retailers have not changed, but the profit of the dual-channel retailer is lower when the dual-channel retailer chooses unified pricing strategy.

Compare Eq. (7) with Eq. (12), Eq. (8) with Eq. (13), Eq. (9) with Eq. (14), we have:

$$\bar{p}_1^* = p_e^* < p_s^*, \bar{p}_\gamma^* = p_\gamma^*; \bar{q}_s^* > q_s^*, \bar{q}_e^* < q_e^*, \bar{q}_1^* = q_1^*, \bar{q}_\gamma^* = q_\gamma^*;$$
$$\bar{\pi}_s^* > \pi_s^*, \bar{\pi}_e^* < \pi_e^*, \bar{\pi}_1^* < \pi_1^*, \bar{\pi}_\gamma^* = \pi_\gamma^*, \pi^* > \bar{\pi}^*.$$

So Conclusion 3 is hold.

Proposition 1 *In circular market, under the two pricing strategies, the congestion of physical channel will weaken the market competition, prices and profits of all channels will be higher than non-congestion.*

Proof According to derived function, we have:

$$\frac{\partial p_s^*}{\partial k} = \frac{\partial p_e^*}{\partial k} = \frac{\partial \bar{p}_1^*}{\partial k} = \frac{2}{3(N-1)} > 0, \frac{\partial p_\gamma^*}{\partial k} = \frac{\partial \bar{p}_\gamma^*}{\partial k} = \frac{1}{3(N-1)} > 0, \frac{\partial \pi_s^*}{\partial k} = -\frac{[(1-\theta)u_0 - \triangle c]^2}{6(2k+t)^2} < 0,$$
$$\frac{\partial \pi_e^*}{\partial k} = \frac{4(2k+t)^2 - 2(N^2+N-1)[(1-\theta)u_0 - \triangle c]^2}{9(2k+t)^2} > 0, \frac{\partial \pi_1^*}{\partial k} = \frac{\partial \pi_s^*}{\partial k} + \frac{\partial \pi_e^*}{\partial k} > 0,$$
$$\frac{\partial \pi_\gamma^*}{\partial k} = \frac{4(N-1)^2[(1-\theta)u_0 - \triangle c]^2 - (2k+t)^2}{3(2k+t)^2} > 0,$$

$$\frac{\partial \bar{\pi}_e^*}{\partial k} = \frac{4[[(N-1)[(1-\theta)u_0 - \triangle c]] - 2k - t][(N+2)(1-\theta)u_0 - (N+1)\triangle c - 2k - t]}{9(N-1)(2k+t)^2} > 0,$$

$$\frac{\partial \bar{\pi}_s^*}{\partial k} = \frac{4[(1-\theta)u_0 + 2\triangle c](1-\theta)u_0}{3(2k+t)^2} > 0, \quad \frac{\partial \bar{\pi}_1^*}{\partial k} = \frac{\partial \bar{\pi}_s^*}{\partial k} + \frac{\partial \bar{\pi}_e^*}{\partial k} > 0.$$

$$\frac{\partial \bar{\pi}_\gamma^*}{\partial k} = \frac{(2k+t)^2 - 4(1-N)^2[(1-\theta)u_0 - \triangle c]^2}{9(N-1)^2(2k+t)^2} > 0.$$

Proposition 2 *Congestion negative effect makes the market share of offline channels decline, while online demand increases, but the total market share of dual-channel retailer increases.*

$$\frac{\partial q_s^*}{\partial k} = -\frac{[(1-\theta)u_0 - \triangle c]}{(2k+t)^2} < 0, \frac{\partial q_e^*}{\partial k} = \frac{(2N+1)[(1-\theta)u_0 - \triangle c]}{6(2k+t)^2} > 0, \frac{\partial q_1^*}{\partial k} = \frac{2(N-1)[(1-\theta)u_0 - \triangle c]}{3(2k+t)^2} > 0,$$

$$\frac{\partial q_\gamma^*}{\partial k} = -\frac{2[(1-\theta)u_0 - \triangle c]}{3(2k+t)^2} < 0, \frac{\partial \bar{q}_s^*}{\partial k} = -\frac{2(1-\theta)u_0}{(2k+t)^2} < 0, \frac{\partial \bar{q}_e^*}{\partial k} = \frac{2(N+2)[(1-\theta)u_0 - (N-1)\triangle c]}{3(2k+t)^2} > 0,$$

$$\frac{\partial \bar{q}_\gamma^*}{\partial k} = -\frac{2(N-1)[(1-\theta)u_0 - \triangle c]}{3(2k+t)^2} < 0.$$

3 Numerical Analysis

In order to more intuitively express the above conclusions, analyze the above conclusions by numerical analysis. The parameters are as: $u_0 = 300$, $\theta = 0.85$, $c_s = 95$, $c_e = 75$, $k = 80$, $t = 75$, $N = 3$. Solve the equilibrium functions by using Matlab software, we have:

Table 1 shows that the product prices, market share and profits of the traditional retailers are the same when dual-channel retailer implement two different strategies. Meanwhile compared with implementing uniform pricing, the dual channel retailer's offline price is higher, but the market share and profit of offline channel are smaller under the differential pricing. The dual-channel retailer's online price remains unchanged, with a bigger market share and higher profits.

4 Discussion and Conclusions

Salop model is extended to investigate the pricing strategies of the dual-channel retailer under the congestion negative effect of physical channel. We build one competition model among a dual-channel retailer and $(N-1)$ traditional retailers in the circular market; analyze the impact of congestion and number of enterprises on the competition equilibrium. The results show that on the one hand, traditional retailers should switch to dual-channel retailers and improve their service level; on the other hand, the dual-channel retailers should implement differentiated pricing

Table 1 The horizontal competition between dual-channel retailer and traditional retailers in circular market

	Channels	Different pricing strategies	Unified pricing strategy
Price	s	132.083	105.833
	e	105.833	105.833
	Γ	122.917	122.917
	s	0.106	0.383
	e	0.418	0.142
Market share	1	0.525	0.525
	γ	0.238	0.238
	Γ	0.475	0.475
	s	3.945	4.149
	e	12.902	4.374
Profit	1	16.847	8.522
	γ	6.633	6.633
	Γ	13.265	13.265

strategies in their online and offline channels. At the same time, the newly entered traditional retailers will compete for the online market share, but has no effect on offline channel.

There are implications for managers based on our proposed model. We find that congestion has weakened the market competition so that the profits of all retailers are improving. However, too high intensity of congestion will lead to higher transportation costs for consumers, so that consumers' product utility is negative. There is no doubt that consumers will buy nothing at this time. Therefore, to a certain extent, retailers should focus on the shopping experience of consumers, manage congestion, and provide consumers with a more comfortable shopping environment and additional services. In addition, the traditional retailer should actively establish the sales product of the network channel to adapt to the development demand of the market. In order to realize the coexistence, retailers should consider the dual channel coexistence. Retailers should also consider factors affecting consumption such as congestion, transportation costs, and acceptance of online channels when making pricing strategy.

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Power Option Pricing Problem Based on Uncertain Mean-Reverting Stock Model with Floating Interest Rate

Can Huang and Xiangfeng Yang

Abstract Power option is a financial contract that depends its payoff on the price of the underlying assert raised to a power. In this paper, the valuation of power option is investigated under the assumption that both the stock price and interest rate follow the uncertain mean-reverting differential equations. Furthermore, a numerical algorithm is designed to calculate the price based on the pricing formulas and some examples are given.

Keywords Power option · Option pricing · Uncertain mean-reverting model · Floating interest rate

1 Introduction

Financial derivative is such a contract that derives its value from the performance of an underlying entity. As one kind of financial derivatives, option gives the buyer the right to buy or sell a certain amount of the underlying entity, but not the obligation. Power option is one kind of exotic options and depends its payoff on the underlying asset price raised to some power. This non-linear characteristic offers much more leverage, brings greater flexibility and therefore can meet the demand of investors with different risk preference.

In 1973, Black and Scholes [1] constricted the famous Black-Scholes formula for determining the European option price. Metron [2] furthered the research and derived several extensions. Heynen and Kat [3] studied the pricing and hedging of power option assuming the stock price follows a geometric Brownian motion. Macovschi and Quittard-Pinon [4] derived the closed-form pricing formula of power option. Xiang et al. [5] priced power option with stochastic interest rate under fractional jump-diffusion model. Previous studies are mainly based on the

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theory of Black-Scholes and Merton, assuming the underlying asset price process follows a stochastic differential equation.

However, some scholars argued that using stochastic differential equation to describe the stock price process may not be appropriate. Liu [6] gave some paradoxes about stochastic finance and suggested using uncertain differential equation to model stock price. Liu [7] built an uncertain stock model (called Liu's model) and derived its European option pricing formula. Afterwards, Chen investigated the American option pricing problems in 2011 [8] and proposed a model with dividends in two years later [9]. Zhang and Liu [10] investigated a pricing method for geometric average Asian option. A year later, Sun and Chen [11] derived the arithmetic average Asian option pricing formulas for uncertain financial market. Zhang et al. [12] studied the pricing problem of power option. Gao et al. [13] worked on the lookback option and derived its pricing formulas.

Considering that Liu's model describes the stock prices in the short term and that the prices fluctuate around some average value in the long-run, Peng and Yao [14] proposed an uncertain mean-reverting stock model, and Yao [15] verified the no-arbitrage determinant theorems. Zhang et al. [16] investigated the valuation of convertible bond, and Shi et al. [17] derived the pricing formulas of stock loans under uncertain mean-reverting stock model. Sun and Su [18] made an extension research and provided an uncertain mean-reverting stock model with floating interest rate. Afterwards, Sun et al. [19] studied the Asian option pricing problem of uncertain mean-reverting stock model.

In this paper, the pricing problem of power option in the uncertain financial market based on the mean-reverting stock model with floating interest rate is discussed. The rest of the paper is organized as follows. In Sect. 2, the uncertain mean-reverting stock model with floating interest rate is given. In Sects. 3 and 4, the pricing formulas of the power call option and power put option with floating interest rate are derived, respectively, along with numerical examples. Finally, a brief conclusion is made in Sect. 5

2 Uncertain Mean-Reverting Stock Model with Floating Interest Rate

The uncertain differential equations are commonly used in financial markets. In 2017, Sun and Su [18] assumed that both the interest rate r_t and the stock price X_t fluctuate around some fixed values in the long term, and presented an uncertain mean-reverting stock model with floating interest rate as below,

$$\begin{cases} dr_t = (m_1 - a_1 r_t)dt + \sigma_1 dC_{1t} \\ dX_t = (m_2 - a_2 X_t)dt + \sigma_2 dC_{2t} \end{cases}, \tag{1}$$

where m_1, m_2, a_1, a_2, σ_1, σ_2 are some positive real numbers with $a_1, a_2 \neq 0$, a_1 and σ_1 are the log-drift and log-diffusion of the interest, respectively, a_2 and σ_2 are the log-drift and log-diffusion of the stock price, respectively, and C_{1t} and C_{2t} are two independent Liu processes. By solving the uncertain differential equations, we have

$$\begin{cases} r_t = \frac{m_1}{a_1} + \exp(-a_1 t)\left(r_0 - \frac{m_1}{a_1}\right) + \sigma_1 \int_0^t \exp(a_1 s - a_1 t) dC_{1s} \\ X_t = \frac{m_2}{a_2} + \exp(-a_2 t)\left(X_0 - \frac{m_2}{a_2}\right) + \sigma_2 \int_0^t \exp(a_2 s - a_2 t) dC_{2s}. \end{cases}$$

According to Definition 7, the α-paths of r_t and X_t are

$$r_t^\alpha = r_0 \cdot \exp(-a_1 t) + \left(\frac{m_1}{a_1} + \frac{\sigma_1}{a_1} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{\alpha}{1-\alpha}\right)(1 - \exp(-a_1 t)), \tag{2}$$

$$X_t^\alpha = X_0 \cdot \exp(-a_2 t) + \left(\frac{m_2}{a_2} + \frac{\sigma_2}{a_2} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{\alpha}{1-\alpha}\right)(1 - \exp(-a_2 t)). \tag{3}$$

3 Power Call Option Pricing Formulas

As for a power option with a power of order m, a strike price K and an expiration time T, the payoff of the call power option is given by $[X_T^m - K^m]^+$. Let f_c represent the price of the power call option. Then the time-zero net return of the option holder is

$$-f_c + \exp\left(-\int_0^T r_s ds\right)\left[X_T^m - K^m\right]^+.$$

And the time-zero net return of the option issuer is

$$f_c - \exp\left(-\int_0^T r_s ds\right)\left[X_T^m - K^m\right]^+.$$

The fair price of the option should make the holder and the issuer have exactly the identical expected return, so

$$E\left[-f_c+\exp\left(-\int_0^T r_s ds\right)\left[X_T^m-K^m\right]^+\right]$$
$$=E\left[f_c-\exp\left(-\int_0^T r_s ds\right)\left[X_T^m-K^m\right]^+\right].$$

Therefore, the power call option price is

$$f_c=E\left[\exp\left(-\int_0^T r_s ds\right)\left[X_T^m-K^m\right]^+\right].$$

Theorem 1 *Assume a power option with a power of order m, a strike price K and an expiration time T. Then the price of the call option for the stock model* (1) *is*

$$f_c=\int_0^1 \exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[\left(X_T^\alpha\right)^m - K^m\right]^+ d\alpha,$$

where

$$r_s^{1-\alpha}=r_0\cdot\ \exp(-a_1 s)+\left(\frac{m_1}{a_1}+\frac{\sigma_1}{a_1}\cdot\frac{\sqrt{3}}{\pi}\ln\frac{1-\alpha}{\alpha}\right)(1-\exp(-a_1 s)),$$

$$X_T^\alpha=X_0\cdot\ \exp(-a_2 T)+\left(\frac{m_2}{a_2}+\frac{\sigma_2}{a_2}\cdot\frac{\sqrt{3}}{\pi}\ln\frac{\alpha}{1-\alpha}\right)(1-\exp(-a_2 T)).$$

Proof Since r_t and X_t are independent uncertain processes with α-paths represented by Eqs. (2) and (3), it follows from Theorem 5 that the α-paths of

$$\int_0^T r_s ds,\ X_T^m-K^m$$

are

$$\int_0^T r_s^\alpha ds,\ \left(X_T^\alpha\right)^m-K^m$$

respectively. Furthermore, the α-path of the discount rate

$$exp\left(-\int_0^T r_s ds\right)$$

is

$$\exp\left(-\int_0^T r_s^{1-\alpha} ds\right).$$

Therefore, the present value of the option

$$\exp\left(-\int_0^T r_s ds\right)\left[X_T^m - K^m\right]^+$$

has an α-path

$$\exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[\left(X_T^\alpha\right)^m - K^m\right]^+$$

according to Theorem 6. As a result, we have

$$f_c = \int_0^1 \exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[\left(X_T^\alpha\right)^m - K^m\right]^+ d\alpha$$

according to Theorems 4 and 5. The theorem is proved.

The price calculating algorithm of the power call option based on uncertain mean-reverting stock model with floating interest rate is designed as below.

Step 0: Choose two large numbers N and M according to the desired precision degree. Set $\alpha_i = i/N$ and $t_j = j \cdot T/M$, $i = 1, 2, \ldots, N-1$ $j = 1, 2, \ldots, M$.
Step 1: Set $i = 0$.
Step 2: Set $i \leftarrow i + 1$.
Step 3: Set $j = 0$.
Step 4: Set $j \leftarrow j + 1$.
Step 5: Calculate the floating interest rate

$$r_{t_j}^{1-\alpha_i} = r_0 \cdot \exp\left(-a_1 t_j\right) + \left(\frac{m_1}{a_1} + \frac{\sigma_1}{a_1} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{1-\alpha_i}{\alpha_i}\right)\left(1 - \exp\left(-a_1 t_j\right)\right).$$

If $j < M$, then return to **Step 4**.

Step 6: Calculate the discount rate

$$\exp\left(-\int_0^T r_s^{1-\alpha_i} ds\right) \leftarrow \exp\left(-\frac{T}{M}\sum_{j=1}^{M} r_{t_j}^{1-\alpha_i}\right).$$

Step 7: Calculate the stock price

$$X_T^{\alpha_i} = X_0 \cdot \exp(-a_2 T) + \left(\frac{m_2}{a_2} + \frac{\sigma_2}{a_2} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{\alpha_i}{1-\alpha_i}\right)(1 - \exp(-a_2 T)).$$

Step 8: Calculate the positive deviation between the stock price of the period T and the striking price K

$$[(X_T^{\alpha_i})^m - K^m]^+ = \max(0, (X_T^{\alpha_i})^m - K^m).$$

Step 9: Calculate

$$\exp\left(-\int_0^T r_s^{1-\alpha_i} ds\right)[(X_T^{\alpha_i})^m - K^m]^+.$$

If $i < N-1$, then return to **Step 2**.

Step 10: Calculate the price of the power call option

$$f_c \leftarrow \frac{1}{N-1}\sum_{i=1}^{N-1} \exp\left(-\int_0^T r_s^{1-\alpha_i} ds\right)[(X_T^{\alpha_i})^m - K^m]^+.$$

Example 1 Assume the parameters of the interest rate are $r_0 = 0.05$, $m_1 = 0.1$, $a_1 = 0.06$, $\sigma_1 = 0.04$ and the parameters of the stock price are $X_0 = 8$, $m_2 = 10$, $a_2 = 2$, $\sigma_2 = 4$. Then the price of a power call option with a power $m = 3$, a striking price $K = 9$ and an expiration time $T = 1$ is $f_c = 5.38$

As Fig. 1 shows, the price f_c is an increasing function with respect to the expiration time T when the other parameters remain unchanged. That is, the power call option will appreciate in value if the expiration time T is extended; and the power call option will devaluate if the expiration time T is shortened.

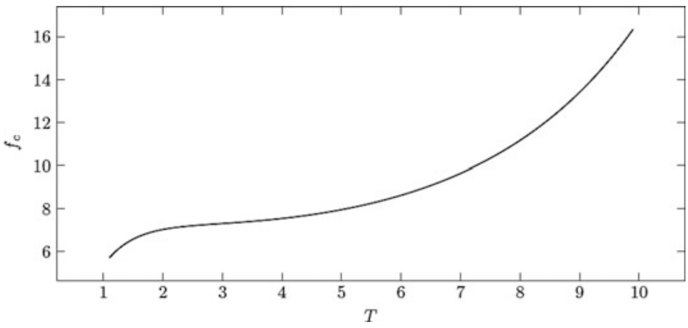

Fig. 1 Power call option price f_c with respect to expiration time T in Example 1

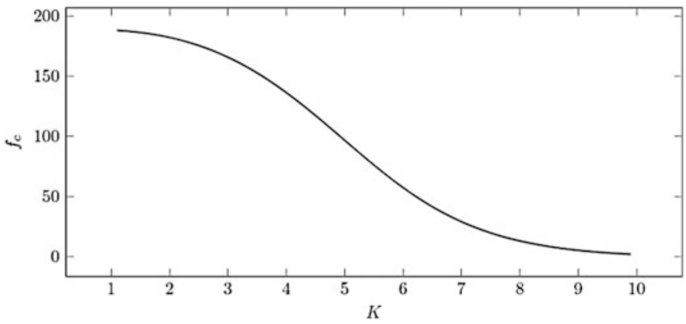

Fig. 2 Power call option price f_c with respect to striking price K in Example 1

As Fig. 2 shows, the price f_c is a decreasing function with respect to the striking price K when the other parameters remain unchanged. That is, the power call option will devaluate if the striking price K is raised; and the power call option will appreciate in value if the striking price K is reduced.

Note that when the power $m = 1$, a power call option is simply a European call option. With other parameters remain the same in Example 1, the price of such a power call option is $f_c = 0.02$.

4 Power Put Option Pricing Formulas

As for a power option with a power of order m, a strike price K and an expiration time T, the payoff of the put power option is given by $\left[K^m - X_T^m\right]^+$. Let f_p represent the price of the power put option. Then the time-zero net return of the option holder is

$$-f_p + \exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+.$$

And the time-zero net return of the option issuer is

$$f_p - \exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+.$$

The fair price of the option should make the holder and the issuer have exactly the identical expected return, so

$$E\left[-f_p + \exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+\right]$$
$$= E\left[f_p - \exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+\right].$$

Therefore, the power put option price is

$$f_p = E\left[\exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+\right].$$

Theorem 2 *Assume a power option with a power of order m, a strike price K and an expiration time T. Then the price of the put option for the stock model* (1) *is*

$$f_p = \int_0^1 \exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[K^m - (X_T^{1-\alpha})^m\right]^+ d\alpha,$$

where

$$r_s^{1-\alpha} = r_0 \cdot \exp(-a_1 s) + \left(\frac{m_1}{a_1} + \frac{\sigma_1}{a_1} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{1-\alpha}{\alpha}\right)(1 - \exp(-a_1 s)),$$

$$X_T^{1-\alpha} = X_0 \cdot \exp(-a_2 T) + \left(\frac{m_2}{a_2} + \frac{\sigma_2}{a_2} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{1-\alpha}{\alpha}\right)(1 - \exp(-a_2 T)).$$

Proof Since r_t and X_t are independent uncertain processes with α-paths represented by Eqs. (2) and (3), it follows from Theorem 5 that the α-paths of

$$\int_0^T r_s ds,\ K^m - X_T^m$$

are

$$\int_0^T r_s^\alpha ds,\ K^m - (X_T^{1-\alpha})^m$$

respectively. Furthermore, the α-path of the discount rate

$$\exp\left(-\int_0^T r_s ds\right)$$

is

$$\exp\left(-\int_0^T r_s^{1-\alpha} ds\right).$$

Therefore, the present value of the option

$$\exp\left(-\int_0^T r_s ds\right)\left[K^m - X_T^m\right]^+$$

has an α-path

$$\exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[K^m - \left(X_T^{1-\alpha}\right)^m\right]^+$$

according to Theorem 6. As a result, we have

$$f_p = \int_0^1 \exp\left(-\int_0^T r_s^{1-\alpha} ds\right)\left[K^m - \left(X_T^{1-\alpha}\right)^m\right]^+ d\alpha$$

according to Theorems 4 and 5. The theorem is proved.

As for the calculating algorithm of the power put option based on uncertain mean-reverting stock model with floating interest rate, the first six steps are the same with that of power call option, and the rest steps are below.

Step 7': Calculate the stock price

$$X_T^{1-\alpha_i} = X_0 \cdot \exp(-a_2 T) + \left(\frac{m_2}{a_2} + \frac{\sigma_2}{a_2} \cdot \frac{\sqrt{3}}{\pi} \ln \frac{1-\alpha_i}{\alpha_i}\right)(1 - \exp(-a_2 T)).$$

Step 8': Calculate the positive deviation between the stock price of the period T and the striking price K

$$\left[K^m - (X_T^{1-\alpha_i})^m\right]^+ = \max\left(0,\ K^m - (X_T^{1-\alpha_i})^m\right).$$

Step 9': Calculate

$$\exp\left(-\int_0^T r_s^{1-\alpha_i} ds\right)\left[K^m - \left(X_T^{1-\alpha_i}\right)^m\right]^+.$$

If $i < N-1$, then return to **Step 2**.

Step 10': Calculate the price of the power put option

$$f_p \leftarrow \frac{1}{N-1}\sum_{i=1}^{N-1} \exp\left(-\int_0^T r_s^{1-\alpha_i} ds\right)\left[K^m - \left(X_T^{1-\alpha_i}\right)^m\right]^+.$$

Example 2 Assume the parameters of the interest rate are $r_0 = 0.05$, $m_1 = 0.1$, $a_1 = 0.06$, $\sigma_1 = 0.04$ and the parameters of the stock price are $X_0 = 8$, $m_2 = 10$, $a_2 = 2$, $\sigma_2 = 4$. Then the price of a power call option with a power $m = 3$, a striking price $K = 9$ and an expiration time $T = 1$ is $f_p = 482.73$.

As Fig. 3 shows, the price f_p is a decreasing function with respect to the expiration time T when the other parameters remain unchanged. That is, the power put option will devaluate in value if the expiration time T is extended; and the power put option will appreciate if the expiration time T is shortened.

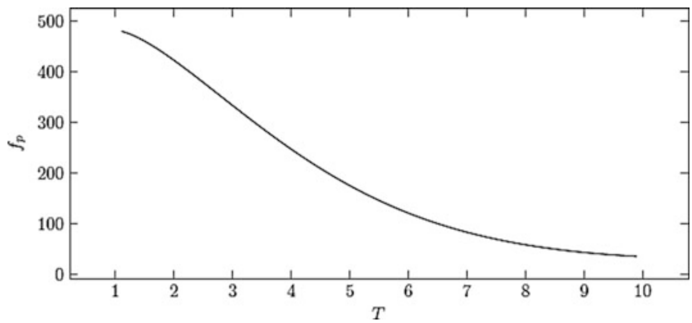

Fig. 3 Power put option price f_p with respect to expiration time T in Example 2

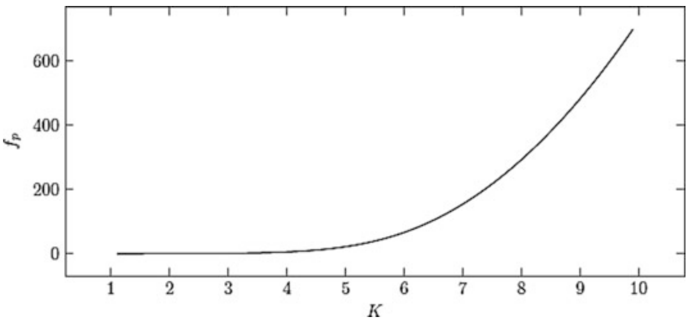

Fig. 4 Power put option price f_p with respect to striking price K in Example 2

As Fig. 4 shows, the price f_p is an increasing function with respect to the striking price K when the other parameters remain unchanged. That is, the power put option will appreciate if the striking price K is raised; and the power put option will devaluate in value if the striking price K is reduced.

Note that when the power $m = 1$, a power put option is simply a European put option. With other parameters remain the same in Example 2, the price of such a power put option is $f_p = 3.31$.

5 Conclusions

This paper investigated the power option pricing problems within the framework of uncertainty theory. We first introduced the uncertain mean-reverting model with floating interest rate, and then derived the power option pricing formulas based on the assumption that both the interest rate and the stock price follow uncertain mean-reverting differential equations. Afterwards, some numerical examples were given to illustrate the pricing formulas, after which we discussed the relationship between the prices and some key parameters.

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Appendix

In this section, some basic knowledge in uncertainty theory is introduced as follows. These definitions and theorems will help to understand this paper better.

Uncertain Variable

Definition 1 (Liu [20]) Let $\mathcal{L}$ be a σ-algebra on a non-empty set Γ. A set function $\mathcal{M}:\mathcal{L}\to[0,1]$ is called an uncertain measure if it satisfies the following axioms,

Axiom 1: (Normality Axiom) $\mathcal{M}\{\Gamma\}=1$ for the universal set Γ.
Axiom 2: (Duality Axiom) $\mathcal{M}\{\Lambda\}+\mathcal{M}\{\Lambda^c\}=1$ for any event Λ.
Axiom 3: (Subadditivity Axiom) For every countable sequence of events $\Lambda_1,\Lambda_2,\ldots$, we have

$$\mathcal{M}\left\{\bigcup_{i=1}^{\infty}\Lambda_i\right\}\le\sum_{i=1}^{\infty}\mathcal{M}\{\Lambda_i\}.$$

The triplet $(\Gamma,\mathcal{L},\mathcal{M})$ is called an uncertainty space. In addition, Liu [7] defined a product uncertain measure as the following axiom in order to describe the set function $\mathcal{M}$ on the product σ-algebra $\mathcal{L}$.

Axiom 4: (Product Axiom) Let $(\Gamma_k,\mathcal{L}_k,\mathcal{M}_k)$ be uncertainty spaces for $k=1,2,\ldots$ The product uncertain measure $\mathcal{M}$ is an uncertain measure satisfying

$$\mathcal{M}\left\{\prod_{k=1}^{\infty}\Lambda_k\right\}=\bigwedge_{k=1}^{\infty}\mathcal{M}_k\{\Lambda_k\}$$

where Λ_k are arbitrarily chosen events from $\mathcal{L}_k$ for $k=1,2,\ldots$, respectively.

Liu [20] defined the uncertain variable ξ as a measurable function from an uncertainty space $(\Gamma,\mathcal{L},\mathcal{M})$ to the set of real numbers such that $\{\xi\in B\}$ is an event for any Borel set B of real numbers. The uncertainty distribution Φ of an uncertain variable ξ follows as

$$\Phi(x)=\mathcal{M}\{\xi\le x\}$$

for any real number x.

For an uncertain variable, if its uncertainty distribution $\Phi(x)$ is a continuous and strictly increasing function with respect to x at which $0<\Phi(x)<1$, and

$$\lim_{x\to-\infty}\Phi(x)=0,\quad\lim_{x\to+\infty}\Phi(x)=1,$$

then $\Phi(x)$ is said to be a regular distribution, and the inverse function $\Phi^{-1}(\alpha)$ is called the inverse uncertainty distribution of ξ.

Definition 2 (Liu [21]) Let ξ be an uncertain variable. Then the expected value of ξ is defined by

$$E[\xi] = \int_{0}^{+\infty} \mathcal{M}\{\xi \geq r\}dr - \int_{-\infty}^{0} \mathcal{M}\{\xi \leq r\}dr$$

provided that at least one of the two integrals is finite.

Theorem 3 (Liu [20]) *Let ξ be an uncertain variable with uncertainty distribution Φ. If the expected value exists, then*

$$E[\xi] = \int_{0}^{+\infty} (1 - \Phi(x))dx - \int_{-\infty}^{0} \Phi(x)dx.$$

Theorem 4 (Liu [21]) *Let ξ be an uncertain variable with regular uncertainty distribution Φ. Then*

$$E[\xi] = \int_{0}^{1} \Phi^{-1}(\alpha)d\alpha.$$

Definition 3 (Liu [7]) The uncertain variables $\xi_1, \xi_2, \ldots, \xi_n$ are said to be independent if

$$\mathcal{M}\left\{\bigcap_{i=1}^{n} \xi_i \in B_i\right\} = \bigwedge_{i=1}^{n} \mathcal{M}\{\xi_i \in B_i\}$$

for any Borel sets $B_1, B_2, \ldots, B_n$ of real numbers.

Uncertain Differential Equation

An uncertain process is a sequence of uncertain variables indexed by a totally ordered set T. A formal definition is given below.

Definition 4 (Liu [22]) Let $(\Gamma, \mathcal{L}, \mathcal{M})$ be an uncertainty space and let T be a totally ordered set (e.g., time). An uncertain process is a function $X_t(\gamma)$ from $T \times (\Gamma, \mathcal{L}, \mathcal{M})$ to the set of real numbers such that $\{X_t \in B\}$ is an event for any Borel set B at each time t.

Definition 5 (Liu [7]) An uncertain process C_t is said to be a Liu process if

(i) $C_0 = 0$ and almost all sample paths are Lipschitz continuous;
(ii) C_t has stationary and independent increments;
(iii) every increment $C_{s+t} - C_t$ is a normal uncertain $\mathcal{N}(0, t)$ variable with inverse uncertainty distribution

$$\Phi_t^{-1}(\alpha) = \frac{t\sqrt{3}}{\pi} \ln \frac{\alpha}{1 - \alpha}.$$

Definition 6 (Liu [22]) Suppose C_t is a Liu process, and f and g are two functions. Then

$$dX_t = f(t, X_t)dt + g(t, X_t)dC_t$$

is called an uncertain differential equation.

Definition 7 (Yao and Chen [23]) Let α be a number with $0 < \alpha < 1$. An uncertain differential equation

$$dX_t = f(t, X_t)dt + g(t, X_t)dC_t$$

is said to have an *α-paths* X_t^α if it solves the corresponding ordinary differential equation

$$dX_t^\alpha = f\left(t, X_t^\alpha\right)dt + \left|g\left(t, X_t^\alpha\right)\right|\Phi^{-1}(\alpha)dt$$

where $\Phi^{-1}(\alpha)$ is the inverse standard normal uncertainty distribution, i.e.,

$$\Phi^{-1}(\alpha) = \frac{\sqrt{3}}{\pi}\ln\frac{\alpha}{1-\alpha}.$$

Theorem 5 (Yao and Chen [23]) *Let X_t and X_t^α be the solution and α-path of the uncertain differential equation*

$$dX_t = f(t, X_t)dt + g(t, X_t)dC_t,$$

respectively. Then, the solution X_t has an inverse uncertainty distribution

$$\Psi^{-1}(\alpha) = X_t^\alpha.$$

And for any time $s > 0$ and strictly increasing function $J(x)$, the time integral

$$\int_0^s J(X_t)dt$$

has an inverse uncertainty distribution

$$\Psi^{-1}(\alpha) = \int_0^s J\left(X_t^\alpha\right)dt.$$

Liu [24] proposed that the uncertain processes $X_{1t}, X_{2t}, \ldots, X_{nt}$ are independent if for any positive integer k and any times $t_1, t_2, \ldots, t_k$, the uncertain vectors

$$\xi_i = (X_{it_1}, X_{it_2}, \ldots, X_{it_k}), i = 1, 2, \ldots, n$$

are independent, that is, for any Borel sets $B_1, B_2, \ldots, B_n$ of k-dimensional real vectors, we have

$$\mathcal{M}\left\{\bigcap_{i=1}^{n} \xi_i \in B_i\right\} = \bigwedge_{i=1}^{n} \mathcal{M}\{\xi_i \in B_i\}.$$

Theorem 6 (Yao [25]) *Assume that $X_{1t}, X_{2t}, \ldots, X_{nt}$ are some independent uncertain processes derived from the solutions of some uncertain differential equations. If the function $f(x_1, x_2, \ldots, x_n)$ is strictly increasing with respect to $x_1, x_2, \ldots, x_m$ and strictly decreasing with respect to $x_{m+1}, x_{m+2}, \ldots, x_n$, then the uncertain process*

$$X_t = f(X_{1t}, X_{2t}, \ldots, X_{nt})$$

has an α-path

$$X_t^{\alpha} = f\left(X_{1t}^{\alpha}, \ldots, X_{mt}^{\alpha}, X_{m+1,t}^{1-\alpha}, \ldots, X_{nt}^{1-\alpha}\right).$$

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Uncertain UAV Mission Planning Problem Considering Value and Survivability

Jian Wang, Jiansheng Guo, Jicheng Cheng and Tengjiao Wang

Abstract Unmanned aerial vehicle (UAV) mission planning generally suffers from the influence of the uncertainty in the battlefield environment. This paper considers two practical objectives for mission planning, mission value and survivability. Firstly, the effects of Information loss, enemy weapon deployment and environment factor are regarded as independent uncertain variables. Secondly, an uncertain multiobjective UAV mission planning model is established based on uncertainty theory. Then, it becomes tractable by combining the weighted sum method with expected value principle. Finally, the bat algorithm is modified for discrete optimization situation in the paper. The results indicate that the proposed model and algorithm have excellent efficiency in solving the uncertain UAV mission planning problem.

Keywords Uncertainty theory · Mission planning · Multiobjective programming · Bat algorithm

1 Introduction

Unmanned aerial vehicle (UAV) has been widely used for intelligence, surveillance, and investigation in battlefield, because of its advantages in boring and dangerous military missions [1]. Mission planning is an important process that tasks are assigned according to certain principles. Until now the studies almost focus on establishing the UAV mission planning model with certain parameters. As a matter of fact, parameter uncertainty is worthy of serious treatment, because a tiny perturbation of a parameter may result in a large violation [2]. During the execution of the mission, the mission planning faces the challenges of some factors, such as

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Information loss, enemy weapon deployment and environment. Existing of uncertainty may lead to the results unfeasible or suboptimal.

For the past few years, mission planning considering indeterminacy has become the focus researches. Some scholars model this kind of indeterminacy as a serial of random variables with known independent distributions. Evers et al. supposed that travel and recording times are uncertain, and established an online stochastic UAV mission planning model [3]. Shang et al. considered a situation that surveillance benefits are uncertain, which are modeled as random variables in some special intervals, and proposed an algorithm based on multiple scenario approach [4]. Most of researches are based on probability theory.

How, it is worth noting that the premise of applying probability theory is based on a fact that the cumulative frequency is close enough to the true probability. When making mission planning for UAV, decision makers are scarce of data required. Therefore, some experts have to be invited to evaluate the unknown factors. Liu [5] indicated that dealing with expert belief degree by probability theory may cause something counterintuitive. In other words, belief degree is essentially different from probability. Liu [6, 7] proposed a mathematic axiomatic foundation called uncertainty theory for belief degree. Due to the advantages in analyzing and evaluating the uncertainty, Wang and Guo et al. first researched the UAV ISR mission planning problems based on uncertainty theory [8, 9]. Wang et al. focused on the uncertain multiobjective orienteering problem and applied it to UAV reconnaissance mission planning [10, 11]. This paper aims to investigate UAV mission planning problem with correlated uncertain objective functions, which include the mission value and the UAV survivability.

This paper is organized as follows. Section 2 presents a brief introduction to uncertainty theory. An uncertain UAV mission planning model is established based on uncertainty theory in Sect. 3. A classical bat algorithm is modified to solve the discrete mixed integer optimization problem. In the Sect. 4, a case study validates the model and algorithm proposed in this paper.

2 Preliminaries

In this paper, we aim to research the uncertain UAV mission plan based on uncertainty theory, therefore, some definitions and theorems such as uncertain measure, uncertainty space, uncertain variable, and uncertainty distribution are presented in the section.

Definition 1 Let Γ be a nonempty set, and $\mathcal{L}$ a σ-algebra over Γ. Each element Λ in $\mathcal{L}$ is called an event. The set function $\mathcal{M}$ from $\mathcal{L}$ to [0, 1] is uncertain measure if it satisfies the following axioms [6]:

Axiom 1 $\mathcal{M}\{\Gamma\} = 1$ for the universal set Γ.

Axiom 2 $\mathcal{M}\{\Lambda\} + \mathcal{M}\{\Lambda^c\} = 1$ for any event Λ.

Axiom 3 For every countable sequence of events $\Lambda_1, \Lambda_2, \ldots$, we have

$$\mathcal{M}\left\{\bigcup_{i=1}^{\infty}\Lambda_i\right\} \le \sum_{i=1}^{\infty}\mathcal{M}\{\Lambda_i\}.$$

The triplet $(\Gamma, \mathcal{L}, \mathcal{M})$ is called an uncertainty space. Furthermore, defined a product uncertain measure by the fourth axiom [7].

Axiom 4 Let $(\Gamma_k, \mathcal{L}_k, \mathcal{M}_k)$ be uncertainty space for $k = 1, 2, \ldots$. The product following uncertain measure is an uncertain measure satisfying

$$\mathcal{M}\left\{\prod_{k=1}^{\infty}\Lambda_k\right\} = \wedge_{k=1}^{\infty}\mathcal{M}\{\Lambda_k\}.$$

where Λ_k are arbitrarily chosen events from $(\Gamma_k, \mathcal{L}_k, \mathcal{M}_k)$ for $k = 1, 2, \ldots$, respectively.

Definition 2 (Liu [6]) An uncertain variable is a function ξ from an uncertainty space $(\Gamma, \mathcal{L}, \mathcal{M})$ to the set of real numbers such that $\{\xi \in B\}$ is an event for any Borel set B of real numbers.

Definition 3 (Liu [6]) The uncertainty distribution Φ of an uncertain variable ξ is defined by $\Phi(x) = \mathcal{M}(\xi < x)$ for any real number x.

Definition 4 (Liu [12]) The uncertain variables $\xi_1, \xi_2, \ldots, \xi_n$ are said to be independent if

$$\mathcal{M}\left\{\bigcap_{i=1}^{n}(\xi_i \in B_i)\right\} = \wedge_{i=1}^{n}\mathcal{M}\{\xi_i \in B_i\}$$

for any Borel sets $B_1, B_2, \ldots, B_n$ of real numbers.

Theorem 1 (Liu [7]) *Let ξ be an uncertain variable with regular uncertainty distribution Φ. Then*

$$E[\xi] = \int_0^1 \Phi^{-1}(\alpha)d\alpha$$

3 Model of Uncertain UAV Mission Planning

In this section, we introduce uncertainty in the objective functions of the UAV mission planning problem. A model is established for researching the correlated effect of information loss, enemy weapon deployment and environment factor during mission. Then, transformation is preformed based on the expected value principle.

3.1 Problem Description

UAV mission planning aims to gather as much information as possible within the flight constraints. Traditional mission planning does usually not provide the appropriate solutions due to the existing of uncertainty. A way to analysis and model this uncertainty is required. Consider a generic situation of the uncertain UAV mission planning. There is a tactical UAV available for reconnaissance mission on a recovery base. A certain number of targets are to be visited during the mission. Since the UAV has a capacity limit, not all the targets can be visited in the path, and each target must be visited no more than once. Besides, the targets own their mission values and survivability, which are affected by the uncertainty, such as information loss, enemy weapon deployment and environment factor. The problem is to maximize the total value and survivability of the mission.

3.2 Mathematical Formulation

In order to convenient for notation, we denote set of targets by N. Then, $|N|$ is number of targets, and $0(\notin N)$ denotes base location. The point set can be denoted by $N^+ = N \cup \{0\}$. For any target $i \in N$, we denote p_i for target value. Probability p_i is that the UAV is intercepted at target i. The problem is defined on a complete graph $G = (N^+, A)$ with arc $(i,j) \in A$. The c_{ij} represents the cost between target i and j. Here, uncertain vector $\boldsymbol{\xi} = (\xi_1, \xi_2, \xi_3)$ is used to model the uncertainty, including information loss ξ_1, enemy weapon deployment ξ_2, and environment factor ξ_3.

The normalized uncertain mission value and survivability can be denoted as follows,

$$V(\boldsymbol{x}, \boldsymbol{\xi}) = \frac{\xi_1}{\xi_1 + \ln \xi_2} \frac{\sum_{i \in N} p_i \sum_{j \in N^+ \setminus \{i\}} x_{ij}}{\sum_{i \in N} p_i}, \quad \textit{and}$$
$$S(\boldsymbol{x}, \boldsymbol{\xi}) = \frac{\xi_1 + \xi_2}{\xi_1 + \xi_2 + \xi_3} \prod_{(i,j) \in A} \left(1 - m_{ij}\right)^{x_{ij}}.$$

Then, the uncertain mission planning problem can be model as

$$\begin{cases} \max\limits_{\mathbf{x}}(V(\boldsymbol{x},\boldsymbol{\xi}),S(\boldsymbol{x},\boldsymbol{\xi})) \\ s.t. \\ \quad \sum\limits_{(i,j)\in A} d_{ij}x_{ij} \le R; \quad \sum\limits_{i\in N} x_{0i} = \sum\limits_{i\in N} x_{i0} = 1; \\ \quad \sum\limits_{i\in N^+\setminus\{j\}} x_{ij} = \sum\limits_{i\in N^+\setminus\{j\}} x_{ji} \le 1, \quad \forall j\in N; \\ \quad u_i - u_j + 1 \le \left(1 - x_{ij}\right)|N|, \quad \forall i,j\in N; \\ \quad 1 \le u_i \le |N|, \quad \forall i\in N; \\ \quad x_{ij}\in\{0,1\}, \quad \forall (i,j)\in A; \quad u_i\in N^*, \quad \forall i\in N \end{cases} \tag{1}$$

In model (1), the feasible solution satisfying all the constraints can by denoted by $\boldsymbol{x}\in\mathcal{D}$. Therefore, the model is simplified to the model $\max_{\boldsymbol{x}\in\mathcal{D}}(V(\boldsymbol{x},\boldsymbol{\xi}),S(\boldsymbol{x},\boldsymbol{\xi}))$. Since the objective functions contain uncertain vector, it is intractable to deal with. We try to transform it into a certain form.

3.3 Transformation of the Uncertain Multiobjective Model

In order to deal with uncertain multiobjective optimization problem, Liu and Chen [13] proposed a compromise model. According the first compromise model, we can transform model as follows,

$$\max_{\boldsymbol{x}\in\mathcal{D}} \lambda_1 E[V(\boldsymbol{x},\boldsymbol{\xi})] + \lambda_2 E[S(\boldsymbol{x},\boldsymbol{\xi})] \tag{2}$$

where the weights λ_1,λ_2 are all nonnegative numbers with $\lambda_1+\lambda_2=1$. The expected values of the objective functions can be obtained by the following equations,

$$E[V(\boldsymbol{x},\boldsymbol{\xi})] = \frac{\int_0^1 \Phi_1^{-1}(\alpha)d\alpha}{\int_0^1 \Phi_1^{-1}(\alpha)d\alpha + \ln\int_0^1 \Phi_2^{-1}(1-\alpha)d\alpha}\frac{\sum_{i\in N} p_i \sum_{j\in N^+\setminus\{i\}} x_{ij}}{\sum_{i\in N} p_i} \tag{3}$$

and

$$E[S(\boldsymbol{x},\boldsymbol{\xi})] = \frac{\int_0^1 \Phi_1^{-1}(\alpha)d\alpha + \int_0^1 \Phi_2^{-1}(\alpha)d\alpha}{\int_0^1 \Phi_1^{-1}(\alpha)d\alpha + \int_0^1 \Phi_2^{-1}(\alpha)d\alpha + \int_0^1 \Phi_3^{-1}(1-\alpha)d\alpha}\prod_{(i,j)\in A}\left(1-m_{ij}\right)^{x_{ij}}. \tag{4}$$

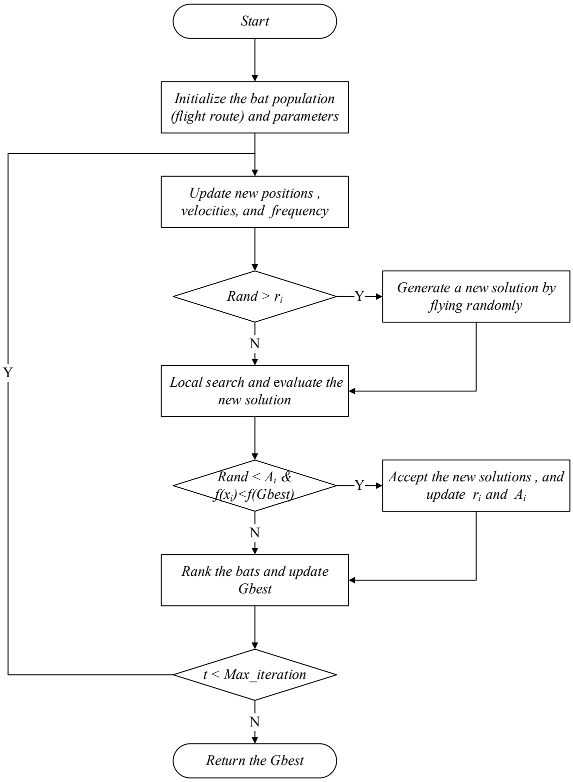
Through the above deduction, the model (1) can be transformed into a single objective integral programming problem.

4 A Modified Bat Algorithm for UAV Mission Planning

In Sect. 3, an integral programming with a single objective is obtained. Since it is proved to be NP-hard, a discrete heuristic algorithm is necessary. In this section, a newly-developed bio-inspired algorithm, proposed by Yang [14], will be improved propitious to the above problem. Some general steps of the modified bat algorithm are presented in Fig. 1.

The modified bat algorithm is a single objective version of the algorithm proposed in [10]. The process of coding, initialization, and updating are similar, however, a general reduce variable neighborhood search serves as the process of local search, which aims to improve the quality of the solution.

Fig. 1 General steps of the modified bat algorithm



5 Case Study

In this section, we will introduce a case to illustrate the use of the uncertain UAV mission planning model and the proposed algorithm. A tactical UAV is available for the reconnaissance mission, and its maximal range is 300 km. The coordinates and Parameters of the base and targets are presented in the Table 1. The value and survivability of the mission planning are considered, which are influenced by information loss, enemy weapon deployment, and environment factor. These influences are assumed to be uncertain variables on uncertainty space $(\Gamma, \mathcal{L}, \mathcal{M})$. The uncertainty distributions are assumed as follows, $\xi_1 \sim \mathcal{L}(0.8, 1.2)$, $\xi_1 \sim \mathcal{Z}(0.8, 0.9, 1.0)$, and $\xi_3 \sim \mathcal{N}(0.95, 0.2)$ respectively. The modified bat algorithm is used to solve the integral programming problem. The number of artificial bats is 20, and maximal iterative times is 50.

We choose three scenarios for the weighting coefficients, $(0.2, 0.8)$, $(0.4, 0.6)$, and $(0.7, 0.3)$ respectively. Then the computational results are summarized in Table 2.

By the above table, we can find that decision maker can choose the weighting coefficients according to their preference. Different weighting coefficients lead to diverse decision schemes. No absolute optimal routes exist. The results indicate that the model and algorithm can provide a Pareto efficient plan for a UAV, and the works provide a new way for decision-makers in UAV mission, especially for a multiple attribute and uncertain situation.

Table 1 The coordinates and parameters of targets in the mission

Targets	X (km)	Y (km)	Value	Probability (%)	Targets	X (km)	Y (km)	Value	Probability (%)
0 (Base)	74.51	8.92	0	0	7	90.31	57.99	20	6
1	79.79	72.91	20	7	8	60.00	30.00	20	1
2	36.22	32.16	20	10	9	46.82	23.00	20	2
3	88.82	29.39	30	1	10	15.75	66.8	15	10
4	20.68	18.10	15	3	11	45.00	58.00	10	8
5	5.74	34.11	15	9	12	82.00	55.00	10	6
6	59.75	47.57	10	5	13	25.00	45.00	10	6

Table 2 The computational results of three scenarios

Scenarios	Mission routes	Value	Survivability (%)
$\lambda = (0.2, 0.8)$	$0 \rightarrow 3 \rightarrow 1 \rightarrow 13 \rightarrow 9 \rightarrow 8 \rightarrow 0$	110	87.58
$\lambda = (0.4, 0.6)$	$0 \rightarrow 8 \rightarrow 9 \rightarrow 4 \rightarrow 13 \rightarrow 1 \rightarrow 7 \rightarrow 3 \rightarrow 0$	150	76.56
$\lambda = (0.7, 0.3)$	$0 \rightarrow 8 \rightarrow 9 \rightarrow 2 \rightarrow 4 \rightarrow 5 \rightarrow 13 \rightarrow 10 \rightarrow 11 \rightarrow 6 \rightarrow 1 \rightarrow 7 \rightarrow 3 \rightarrow 0$	220	49.32

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Study on Location Selection and Pricing Competition of Two Supply Chains Under Consumption Incentives

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Abstract Based on the Hotelling model with quadratic transport cost in “linear market”, this paper studies the location and pricing competition of two supply chains under the assumption that the consumers purchase the same product with discount-price for the second time. The competitive equilibrium models are established respectively when two SCs are decentralized SCs (DD mode), one decentralized SC and one centralized SC (DI mode), or two centralized SCs (II mode). The existence conditions of equilibrium and the equilibrium solution are obtained. It shows that the price discount strategy can affect the pricing of product, but can’t affect location of SCs and the profit of SCs.

Keywords Consumer incentives · Hotelling model · Supply chain competition · Multi-level programming

1 Introduction

In the real scene, some shopping malls, such as Outlets, Sam’s Clubs and so on, tend to locate at the edge of the city rather than in commercial centers, and offer discount-price to attract consumers. Taking into account the geographical location of shopping malls and price discounting strategies, consumers will make smaller-batch and multi-batch purchases in order to increase their utilities. Since Amazon came up with “Amazon Go”, some famous domestic enterprises are also working hard on retailing, even taking the lead in commercialization around the world. The application of new retail mode, such as Tmall unmanned supermarket and Suning store, makes the concept of “retail” wisdom arise at the historic moment. Nevertheless, intelligent retailers face some problems, for example, responding quickly to consumer needs, choosing the right number of SKU in limited space, reducing the impact of bullwhip effect. To solve these problems,

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manufacturers and retailers form a supply chain to meet the changing market demand and strengthen the competitiveness of supply chain enterprises. Enterprises need to not only consider product pricing, but also decide the spatial location or product orientation. The existing literature mainly studies the competition in inventory, price and quality of two supply chains. The location decisions and horizontal competition of two SCs are not involved.

Hotelling model is an important theoretical model to study horizontal competition. Therefore, this paper will study the location and pricing competition of two SCs. Each SC has one manufacturer and one retailer. The remainder of this paper is organized as follows. In Sect. 2, the relevant literature is reviewed. Section 3 makes some assumptions about the model. Section 4 formulates a location and price competition of two supply chains model under consumption incentives. We analyze static equilibrium analysis in Sect. 5. Finally, conclusions are presented in Sect. 6.

2 Literature Review

The research literature about this paper could be divided into two streams as supply chain competition and Hotelling model.

2.1 Supply Chain Competition

Boyaci and Gallego [1] study the inventory satisfaction rate competition between two SCs under the condition of same product price [1]. After that, the competition between supply chains has attracted the attention of many scholars. For one is a vertically integrated supply chain and another is a manufacturer's main subordinate supply chain, Wu [2] assumes that the demand is similar to the general distribution of the newsboy model, and analyzes the influence of repurchase policy on retail price, wholesale price and order quantity [2]. Khan et al. [3] assume that there are defects in the products and the buyer has established inspection procedures to separate the defective products, subsequently, they analyze the optimal batch size and the supplier's shipment quantity per batch in the supply chain of single supplier and single buyer [3]. Esmaeili et al. [4] show that information sharing is more beneficial to the warehouse rather than the retailer under a two-echelon supply chain that includes one warehouse and one retailer with stochastic demand and an up-to-level policy [4].

Anderson and Bao [5] solve the price competition equilibrium problem under the both supply chains are centralized or decentralized and linear demand function, meanwhile, they analyze the influence of price competition on the profit of supply chain [5]. Amin-Naseri and Khojasteh [6] adopt Stackelberg model to analyze the price competition of two SCs composed of risk-neutral manufacturers and risk-averse retailers in the case of uncertain demand [6]. Jena and Jog [7] prove that most of the tourism supply chain market demand is only affected by tourism price in competition environment [7]. Ali et al. [8] consider both a centralized and a decentralized supply chain structure to examine the effect of potential market demand disruptions on price and service level for competing retailers [8].

Xu and Zhou [9] assume that the two competing supply chains provide substitute products and the market demand is flexible, and construct EPEC, MPEC and Nash equilibrium models to analyze the quality and price competitive equilibrium of the supply chain [9]. Li and Chen [10] develop game-theoretic models to study a supply chain in which two manufacturers supply a product in quality-differentiated brands to a common retailer [10]. These literatures focused on the inventory, price and quality competition of supply chain. The location is one important factor in supply chain competition. Further study is needed in this problem.

2.2 Hotelling Model

Since Harold Hotelling published a famous spatial competition model on Economic Journal in 1929, many scholars have expanded and enriched the model [11]. D'Aspremont et al. [12] find that the price reduction will occur and no pure strategy Nash equilibrium exists, when two retailers locate at the center of linear market with linear transport cost function; two retailers will locate at two ends of market to maximize the differentiation under quadratic transport cost function [12]. Gabszewicz and Thisse [13] find that there was no pure strategy equilibrium after discussing the linear-quadratic transport cost [13]. Cao [14] assumes that the duopoly enterprises has selected the positions at both ends of the market and introduced the consumer demand density function, then, he analyzes the equilibrium of the price competition of the duopoly [14]. Xu and Sun [15, 16] study the competition balance between order quantity and shelf display quantity of two supply chains under random demand in DD, II, and DI modes, and the demand depends on shelf display quantity [15, 16]. Gao et al. [17] assume that there exists a remanufacturing supply chain consisting of OEM and IR, and analyze the impact of quality decision on competitive remanufacturing supply chain under the price and quantity game model [17]. Pinto et al. [18] develop a theoretical framework to study the location-price competition in a Hotelling-type network game [18]. These literatures enrich the theory of location and pricing competition between two retailers in linear market.

This paper will further study the location and pricing competition of two SCs under the price discount strategy, and try to explore the internal factors influencing the decision-making of location and pricing.

3 Model Assumption

Assume that consumers obedience to the uniform distribution of (0, 1) on the "linear market" with a length of 1, and there exist two supply chains each consisting of one manufacturer M_i and one retailer $R_i (i = 1, 2)$ respectively, two retailers offer price discount to repeated purchasers. The products are homogenous, and two SCs play one three-phase game with full information. Firstly, two retailers make location decisions at the same time. Secondly, both manufacturers decide wholesale prices. Thirdly, both retailers make pricing decisions. Assume that the distance from R_1 to the left side of the market is a, and the distance from R_2 to the right side of the market is b, satisfying $0 \leq a \leq 1 - b \leq 1$. Assume $p_i \geq w_i + c_{R_i}$, $w_i \geq c_{M_i}$, where c_{M_i} is the unit production cost of the manufacturer M_i, c_{R_i} is the unit sales cost of retailer R_i, p_i is the sell price. The supply chain $i (i = 1, 2)$ implements the discount price with a discount factor of $\lambda_i (0 \leq \lambda_i \leq 1)$, i.e., $\lambda_i p_i$ to the consumers who buy products in second time. Assuming that the product's utility U_0 is large enough that all consumers will buy products, but each only buy unit good in one time. Let U_{mn} denote the utility of consumers who buy products two times, where m, n represent the retailers from whom the consumers buy good in the first and second time. With the secondary transportation cost, the utility of the consumer at position x is:

$$U_{mn} = \begin{cases} 2U_0 - (1 + \lambda_1)p_1 - 2t(x - a)^2 & m = 1, n = 1 \\ 2U_0 - p_1 - p_2 - t\left[(x - a)^2 + (1 - b - x)^2\right] & m = 1, n = 2 \\ 2U_0 - p_1 - p_2 - t\left[(x - a)^2 + (1 - b - x)^2\right] & m = 2, n = 1 \\ 2U_0 - (1 + \lambda_2)p_2 - 2t(1 - b - x)^2 & m = 2, n = 2 \end{cases}$$

where t is the unit cost of transportation.

Assume that $U_{ii} > U_{i(3-i)}$ (i = 1, 2), solve $U_{11} = U_{22}$, we have

$$x* = \frac{1 + a - b}{2} + \frac{(1 + \lambda_2)p_2 - (1 + \lambda_1)p_1}{4t(1 - a - b)}$$

The market share of retailer R_i is: $q_1 = x*$, $\quad q_2 = 1 - q_1$. Considering that consumers have secondary purchase behavior, the total demand is the double of q_i.

Denote $c_i = c_{M_i} + c_{R_i}$, $\bar{c}_i = w_i + c_{R_i}$, $\Delta w = w_2 - w_1$, $\Delta c_M = c_{M_2} - c_{M_1}$, $\Delta c_R = c_{R_2} - c_{R_1}$, $\Delta \bar{c} = \Delta w + \Delta c_R$, $\Delta c = \Delta c_M + \Delta c_R$. With full information, the retailer's order quantity to the manufacturer is equal to total demand including the repeated purchases by consumers, the profit functions of manufacturer M_i, retailers R_i and supply chains are as follows.

$$\pi_{M_i}(w_i) = 2(w_i - c_{M_i})q_i \tag{1}$$

$$\pi_{R_i}(p_i, x_i) = [(1+\lambda_i)p_i - 2\bar{c}_i]q_i(p_1, p_2, a, b) \tag{2}$$

$$\pi_i(p_1, p_2, a, b) = [(1+\lambda_i)p_i - 2c_i]q_i(p_1, p_2, a, b) \tag{3}$$

4 Location and Pricing Competition Equilibrium of Two SCs

4.1 Competition Equilibrium Model in DD Mode

Assume that both supply chains are decentralized SCs, so retailer R_i and manufacturer M_i aim to maximize their own profits. In DD mode, the competition equilibrium is one three-level programming model. The first-level is two retailers' competition equilibrium of location, the second-level is two manufacturers' competition equilibrium of wholesale price, and the third-level is two retailers' competition equilibrium of pricing. The model is as follows.

$$\begin{aligned}
&\begin{cases} \pi_{R_1}(a^{DD}, b^{DD}) \geq \pi_{R_1}(a, b^{DD}) & \forall\ 0 \leq a \leq 1-b \\ \pi_{R_2}(a^{DD}, b^{DD}) \geq \pi_{R_2}(a^{DD}, b) & \forall\ 0 \leq b \leq 1-a \end{cases} \\
s.t. &\begin{cases} \pi_{M_1}\left(w_1^{DD}, w_2^{DD}\right) \geq \pi_{M_1}\left(w_1, w_2^{DD}\right) & \forall\ w_1 \geq c_{M_1} \\ \pi_{M_2}\left(w_1^{DD}, w_2^{DD}\right) \geq \pi_{M_2}\left(w_1^{DD}, w_2\right) & \forall\ w_2 \geq c_{M_2} \end{cases} \\
s.t. &\begin{cases} \pi_{R_1}\left(p_1^{DD}, p_2^{DD}\right) \geq \pi_{R_1}\left(p_1, p_2^{DD}\right) & \forall\ p_1 \geq w_1 + c_{R_1} \\ \pi_{R_2}\left(p_1^{DD}, p_2^{DD}\right) \geq \pi_{R_2}\left(p_1^{DD}, p_2\right) & \forall\ p_2 \geq w_2 + c_{R_2} \end{cases}
\end{aligned} \tag{4}$$

The back induction method is used to solve the three-level programming model.

Proposition 1 *Under the condition that the secondary purchase has a price discount coefficient, the equilibrium price* $\left(p_1^{DD}, p_2^{DD}\right)$ *of the two supply chains in DD mode satisfies:*

$$\begin{cases} p_1^{DD} = \frac{2\bar{c}_1}{1+\lambda_1} + \frac{2}{3(1+\lambda_1)}[(1-a-b)(3+a-b)t + \Delta\bar{c}] \\ p_2^{DD} = \frac{2\bar{c}_2}{1+\lambda_2} + \frac{2}{3(1+\lambda_2)}[(1-a-b)(3-a+b)t - \Delta\bar{c}] \end{cases} \tag{5}$$

Conclusion 1 The retailer's product pricing is negatively correlated with the product price discount coefficient in DD model. Based on the retailer's total cost (including the purchase cost and the sales cost), the price plus markup depend not only on the retailer's location and the difference in cost also depends on the discount factor.

In real-life scenarios, some malls usually take promotion measures during holidays, such as buy one then get one free. The price of the product is higher than usual in promotion case, which also confirms the conclusion.

Proposition 2 *The manufacturer's equilibrium wholesale price* $\left(w_1^{DD}, w_2^{DD}\right)$ *and the retailer's product equilibrium price* $\left(p_1^{DD}, p_2^{DD}\right)$ *are as follows.*

$$\begin{cases} w_1^{DD} = c_{M_1} + \frac{1}{3}[(1-a-b)(9+a-b)t + \Delta c] \\ w_2^{DD} = c_{M_2} + \frac{1}{3}[(1-a-b)(9-a+b)t - \Delta c] \end{cases} \tag{6}$$

$$\begin{cases} p_1^{DD} = \frac{2c_1}{1+\lambda_1} + \frac{8}{9(1+\lambda_1)}[(1-a-b)(9+a-b)t + \Delta c] \\ p_2^{DD} = \frac{2c_2}{1+\lambda_2} + \frac{8}{9(1+\lambda_2)}[(1-a-b)(9-a+b)t - \Delta c] \end{cases} \tag{7}$$

Proof Substituting Eq. (5) into the profit function of manufacturer M_i, we have

$$\begin{cases} \pi_{M_1} = \frac{w_1 - c_{M_1}}{3t(1-a-b)}[(1-a-b)(3+a-b)t + \Delta\bar{c}] \\ \pi_{M_2} = \frac{w_2 - c_{M_2}}{3t(1-a-b)}[(1-a-b)(3-a+b)t - \Delta\bar{c}] \end{cases} \tag{8}$$

π_{M_i} is a second-order differentiable concave function for w_i since $\frac{\partial^2 \pi_{M_i}}{\partial w_i^2} = \frac{-2}{3t(1-a-b)} < 0$, a first-order set of conditional equations is solved:

$$\begin{cases} \frac{\partial \pi_{M_1}}{\partial w_1} = (1-a-b)(3+a-b)t + w_2 - 2w_1 + c_{M_1} + \Delta c_R = 0 \\ \frac{\partial \pi_{M_2}}{\partial w_2} = (1-a-b)(3-a+b)t - 2w_2 + w_1 + c_{M_2} - \Delta c_R = 0 \end{cases}$$

The formula (6) can be obtained and substituted into the formula (5) to obtain the formula (7).

At this time, the profit function of the retailer R_i is:

$$\begin{cases} \pi_{R_1} = \frac{[(1-a-b)(9+a-b)t + \Delta c]^2}{81t(1-a-b)} \\ \pi_{R_2} = \frac{[(1-a-b)(9-a+b)t - \Delta c]^2}{81t(1-a-b)} \end{cases} \tag{9}$$

Now, we have:

$$\frac{\partial \pi_{R_1}}{\partial a} = \frac{-1}{81t(1-a-b)^2}[(1-a-b)(7+3a+b)t + \Delta c][(1-a-b)(9+a-b)t + \Delta c] < 0$$

$$\frac{\partial \pi_{R_2}}{\partial b} = \frac{-1}{81t(1-a-b)^2}[(1-a-b)(7+a+3b)t + \Delta c][(1-a-b)(9-a+b)t - \Delta c] < 0$$

It shows that the two retailers will move towards the ends of the market in order to obtain the maximum profits, which is inconsistent with the D'Aspremont's conclusion.

Conclusion 2 The wholesale price decision of producer M_i and the profit of supply chain are independent of the discount coefficient of secondary purchase stage. Retailer R_i will locate at the end of market, that is, $a^{DD} = b^{DD} = 0$ and we have

$$\begin{cases} w_1^{DD} = c_{M_1} + \frac{(9t+\Delta c)}{3} \\ w_2^{DD} = c_{M_2} + \frac{1}{3}(9t - \Delta c) \end{cases}, \begin{cases} p_1^{DD} = \frac{2c_1}{1+\lambda_1} + \frac{8}{9(1+\lambda_1)}(9t+\Delta c) \\ p_2^{DD} = \frac{2c_2}{1+\lambda_2} + \frac{8}{9(1+\lambda_2)}(9t-\Delta c) \end{cases}, \begin{cases} \pi_{R_1}^{DD} = \frac{(9t+\Delta c)^2}{81t} \\ \pi_{R_2}^{DD} = \frac{(9t-\Delta c)^2}{81t} \end{cases}.$$

4.2 Competition Equilibrium Model in DI Mode

Assume that supply chain 1 is decentralized SC and supply chain 2 is centralized SC, both retailer R_1 and manufacturer M_1 aim to maximum their own profits, supply chain 2 aims to maximize the profit of SC. Two supply chains' competition equilibrium in DI mode can be characterized as the following three-level programming model:

$$\begin{cases} \pi_{R_1}\left(a^D, b^I\right) \geq \pi_{R_1}\left(a, b^I\right), & \forall\ 0 \leq a \leq 1-b \\ \pi_2\left(a^D, b^I\right) \geq \pi_2\left(a^D, b\right), & \forall\ 0 \leq b \leq 1-a \end{cases}$$
$$s.t \max_{w_1 \geq c_{M_1}} \pi_{M_1}\left(w_1, p_1^D, p_2^I\right) \tag{10}$$
$$s.t. \begin{cases} \pi_{R_1}\left(p_1^D, p_2^I\right) \geq \pi_{R_1}\left(p_1, p_2^I\right), & \forall\ p_1 \geq w_1 + c_{R_1} \\ \pi_2\left(p_1^D, p_2^I\right) \geq \pi_2\left(p_1^D, p_2\right), & \forall\ p_2 \geq c_{M_2} + c_{R_2} \end{cases}$$

The first-level is the competition of location between retailer R_1 and supply chain 2, the second-level is the maximizing-profit of manufacturer M_1, and the third-level is the competition equilibrium of price between retailer R_1 and supply chain 2.

Proposition 2 *The consumer's second purchase has a discount, and the manufacturer's optimal wholesale price and equilibrium price* $\left(p_1^D, p_2^I\right)$ *in DI mode are as following.*

$$w_1^D = c_{M_1} + \frac{1}{2}[(1-a-b)(3+a-b)t + \Delta c] \tag{11}$$

$$\begin{cases} p_1^D = \dfrac{2c_1}{1+\lambda_1} + \dfrac{4}{3(1+\lambda_1)}[(1-a-b)(3+a-b)t + \Delta c] \\ p_2^I = \dfrac{2c_2}{1+\lambda_2} + \dfrac{1}{3(1+\lambda_2)}[(1-a-b)(9-a+b)t - \Delta c] \end{cases} \tag{12}$$

Proof Since $\frac{\partial^2 \pi_{r1}}{\partial p_1^2} = \frac{-(1+\lambda_1)^2}{2t(1-a-b)} < 0, \frac{\partial^2 \pi_2}{\partial p_2^2} = \frac{-(1+\lambda_2)^2}{2t(1-a-b)} < 0$, the profit functions of retailer R_1 and SC 2 are differentiable concave functions of price, solves the first-order system of equations:

$$\begin{cases} \dfrac{\partial \pi_{r1}}{\partial p_1} = \dfrac{1+a-b}{2} + \dfrac{(1+\lambda_2)p_2 - 2(1+\lambda_1)p_1 + 2\bar{c}_1}{4t(1-a-b)} = 0 \\ \dfrac{\partial \pi_2}{\partial p_2} = \dfrac{1-a+b}{2} - \dfrac{2(1+\lambda_2)p_2 - (1+\lambda_1)p_1 - 2c_2}{4t(1-a-b)} = 0 \end{cases}$$

We have:

$$\begin{cases} p_1^D = \dfrac{2}{3(1+\lambda_1)}[(1-a-b)(3+a-b)t + 4\bar{c}_1 + 2c_2] \\ p_2^I = \dfrac{2}{3(1+\lambda_2)}[(1-a-b)(3-a+b)t + 2\bar{c}_1 + 4c_2] \end{cases} \tag{13}$$

Substituting Eq. (13) into the profit function of manufacturer M_1, we have $\frac{\partial^2 \pi_{m1}}{\partial w_1^2} = -\frac{2}{3t(1-a-b)} < 0$, so the maximum profit of manufacturer M_1 is obtained by solving its first-order equation $\frac{\partial \pi_{m1}}{\partial w_1} = 0$, i.e., Eq. (11). Substitutes Eq. (11) into Eq. (13), we have Eq. (12).

At this time, the profit functions of retailer R_1 and supply chain 2 are:

$$\begin{cases} \pi_{R_1} = \dfrac{[(1-a-b)(3+a-b)t + \Delta c]^2}{36t(1-a-b)} \\ \pi_2 = \dfrac{[(1-a-b)(9-a+b)t - \Delta c]^2}{36t(1-a-b)} \end{cases} \tag{14}$$

Now, we have: $\frac{\partial \pi_{r1}}{\partial a} < 0, \frac{\partial \pi_2}{\partial b} < 0$, indicating that retailer R_1 and supply chain 2 will move to the ends of "linear market" in order to obtain the maximum profits.

Conclusion 3 Considering that consumers have secondary purchase behavior, the equilibrium prices of the two supply chains in DI model are negatively correlated with their respective discount coefficients, the product pricing p_i decreases as $\lambda_i (0 \le \lambda_i \le 1)$ increases, and two supply chains will use the price strategy of cost-plus based on the total cost of SC. The size of cost-plus depends on the difference between the cost of two SCs and the discount coefficient; the equilibrium of location is: $a^D = b^I = 0$, and we have:

$$w_1^D = c_{M_1} + \tfrac{1}{2}(3t + \Delta c),\ p_1^D = \tfrac{2c_1}{1+\lambda_1} + \tfrac{4(3t+\Delta c)}{3(1+\lambda_1)},\ p_2^I = \tfrac{2c_2}{1+\lambda_2} + \tfrac{1}{3(1+\lambda_2)}(9t - \Delta c),$$
$$\pi_{R_1}^D = \tfrac{(3t+\Delta c)^2}{36t},\ \pi_2^I = \tfrac{(9t-\Delta c)^2}{36t}.$$

4.3 Competition Equilibrium Model in II Mode

Assume that both supply chains are centralized SCs, so both SCs aim to maximize the profits of their own SC. The competition equilibrium of t two SCs in II mode is the following two-level programming model.

$$\begin{cases} \pi_1(a^{II}, b^{II}) \geq \pi_1(a^{II}, b), & \forall\ 0 \leq a \leq 1-b \\ \pi_2(a^{II}, b^{II}) \geq \pi_2(a^{II}, b), & \forall\ 0 \leq b \leq 1-a \end{cases}$$
$$s.t. \begin{cases} \pi_1\left(p_1^{II}, p_2^{II}\right) \geq \pi_1\left(p_1, p_2^{II}\right), & \forall\ p_1 \geq c_1 \\ \pi_2\left(p_1^{II}, p_2^{II}\right) \geq \pi_2\left(p_1^{II}, p_2\right), & \forall\ p_2 \geq c_1 \end{cases} \quad (15)$$

The upper layer is two SCs' competition equilibrium of location, and the lower layer is two SCs' equilibrium of price.

Proposition 3 *Under the discount of the consumer's secondary purchase, the equilibrium price* $\left(p_1^{II}, p_2^{II}\right)$ *in II mode is:*

$$\begin{cases} p_1^{II} = \dfrac{2c_1}{1+\lambda_1} + \dfrac{2}{3(1+\lambda_1)}[(1-a-b)(3+a-b)t + \Delta c] \\ p_2^{II} = \dfrac{2c_2}{1+\lambda_2} + \dfrac{2}{3(1+\lambda_2)}[(1-a-b)(3-a+b)t - \Delta c] \end{cases} \quad (16)$$

Proof Since $\frac{\partial^2 \pi_i}{\partial p_i^2} = \frac{-(1+\lambda_i)^2}{2t(1-a-b)} < 0$, π_i is the diffractive function of p_i, solving first-order conditional equations:

$$\begin{cases} \dfrac{\partial \pi_1}{\partial p_1} = \dfrac{1+a-b}{2} + \dfrac{(1+\lambda_2)p_2 - 2(1+\lambda_1)p_1 + 2c_1}{4t(1-a-b)} = 0 \\ \dfrac{\partial \pi_2}{\partial p_2} = \dfrac{1-a+b}{2} - \dfrac{2(1+\lambda_2)p_2 - (1+\lambda_1)p_1 - 2c_2}{4t(1-a-b)} = 0 \end{cases}$$

We have Eq. (16). Substituted it into formula (3) to obtain the profit function of the two supply chains:

$$\begin{cases} \pi_1 = \dfrac{[(1-a-b)(3+a-b)t + \Delta c]^2}{9t(1-a-b)} \\ \pi_2 = \dfrac{[(1-a-b)(3-a+b)t - \Delta c]^2}{9t(1-a-b)} \end{cases} \quad (17)$$

Now, we have: $\frac{\partial \pi_1}{\partial a} < 0, \frac{\partial \pi_2}{\partial b} < 0$, so two SCs will move to the end of the market to maximize the profit of SC, i.e., $a^{II} = b^{II} = 0$.

Conclusion 4 Considering that consumers have secondary purchase behavior and have the same product with a price discount for the second time, the product pricing

p_i in II model decreases with the increase of its own $\lambda_i (0 \le \lambda_i \le 1)$. The equilibrium of location is: $a^{II} = b^{II} = 0$, and we have:

$$p_1^{II} = \frac{2c_1}{1+\lambda_1} + \frac{2(3t+\Delta c)}{3(1+\lambda_1)}, p_2^{II} = \frac{2c_2}{1+\lambda_2} + \frac{2(3t-\Delta c)}{3(1+\lambda_2)},$$
$$\pi_1^{II} = \frac{(3t+\Delta c)^2}{9t}, \pi_2^{II} = \frac{(3t-\Delta c)^2}{9t}.$$

5 Static Equilibrium Analysis and Managerial Implications

Analyze the equilibrium price in three modes (DD, DI, II), we have:

$$p_1^{DD} - p_1^{D} = \frac{4(9t-\Delta c)}{9(1+\lambda_1)} > 0,\ p_1^{D} - p_1^{II} = \frac{2(3t+\Delta c)}{3(1+\lambda_1)} > 0;$$
$$p_2^{DD} - p_2^{I} = \frac{5(9t-\Delta c)}{9(1+\lambda_2)} > 0,\ p_2^{I} - p_2^{II} = \frac{3t+\Delta c}{3(1+\lambda_2)} > 0.$$

And the profit functions of SC are as following.

$$\begin{cases} \pi_1^{DD} = \dfrac{4(9t+\Delta c)^2}{81t}, \\ \pi_2^{DD} = \dfrac{4(9t-\Delta c)^2}{81t}, \end{cases} \begin{cases} \pi_1^{D} = \dfrac{(3t+\Delta c)^2}{9t}, \\ \pi_2^{I} = \dfrac{(9t-\Delta c)^2}{36t}, \end{cases} \begin{cases} \pi_1^{II} = \dfrac{(3t+\Delta c)^2}{9t}, \\ \pi_2^{II} = \dfrac{(3t-\Delta c)^2}{9t}; \end{cases}$$
$$\pi_1^{DD} - \pi_1^{D} = \frac{(9t-\Delta c)(27t+5\Delta c)}{81t} > 0, \quad \pi_1^{D} = \pi_1^{II}$$
$$\pi_2^{DD} - \pi_2^{I} = \frac{7(9t-\Delta c)^2}{324t} > 0,\ \pi_2^{I} - \pi_2^{II} = \frac{(5t-\Delta c)(3t-\Delta c)}{12t} > 0$$

Conclusion 5 Considering consumers' secondary purchase behavior and retailer R_i offer the discount for secondary purchase behavior. Two SCs' competition equilibrium price is relevant with the discount coefficient in the mode of DD, DI, II, but the profits of two supply chains are not connected with discount λ_i. At the point, both the price and profit in mode DD are higher than those in modes of DI and II, since

$$p_1^{DD} > p_1^{D} > p_1^{II},\ p_2^{DD} > p_2^{I} > p_2^{II};\ \pi_1^{DD} > \pi_1^{D} = \pi_1^{II},\ \pi_2^{DD} > \pi_2^{I} > \pi_2^{II}.$$

It means that centralized decision-making is not the dominant strategy of SC under the competition of location and pricing of two SCs. Then, by the derivative analysis method, we have:

$$\frac{dp_i}{d\lambda_i} < 0, \frac{d\pi_i}{dt} > 0, \frac{d\pi_1}{d\Delta c} > 0, \frac{d\pi_2}{d\Delta c} < 0.$$

Conclusion 6 The price will reduce with the increase of discount coefficient λ_i. The profit of supply chain will increase with the increase of products' horizontal differentiation t. The cost difference between two SCs increases, the profit of SC with higher cost will decline, and the profit of SC with lower cost will increase.

According to conclusions 2–4, the market share of supply chain i in modes of DD, DI, II are as following.

$$\begin{cases} q_1^{DD} = \frac{9t + \Delta c}{18t}, \\ q_2^{DD} = \frac{9t - \Delta c}{18t}, \end{cases} \begin{cases} q_1^{D} = \frac{3t + \Delta c}{12t}, \\ q_2^{I} = \frac{9t - \Delta c}{12t}, \end{cases} \begin{cases} q_1^{II} = \frac{3t + \Delta c}{6t}, \\ q_2^{II} = \frac{3t - \Delta c}{6t}; \end{cases}$$

$$q_1^{DD} - q_1^{D} = \frac{9t - \Delta c}{36t} > 0, \; q_1^{II} - q_1^{D} = \frac{3t + \Delta c}{12t} > 0, \; q_1^{II} - q_1^{DD} = \frac{\Delta c}{9t}$$

$$q_2^{DD} - q_2^{I} = -\frac{9t - \Delta c}{36t} < 0, \; q_2^{II} - q_2^{I} = -\frac{3t + \Delta c}{12t} < 0, \; q_2^{II} - q_2^{DD} = -\frac{\Delta c}{9t}$$

Conclusion 7 Market share is not influenced by price discount λ_i in modes of DD, DI, and II. Considering consumers' secondary purchasing behavior and retailer' price discount to consumers who purchase second time. The market share of decentralized SC in DD mode will increase if he turns to centralized SC, but the market share of another one will decrease since $q_2^I > q_2^{DD}$, $q_1^D < q_1^{DD}$. The market share of decentralized SC in DI mode will increase if he turns to centralized SC, but the market share of another SC will decrease, that is $q_1^{II} > q_1^D$, $q_2^{II} < q_2^I$.

Conclusion 7 shows that centralized control would be the dominant strategy for SC to maximize market share. However, according to conclusion 5, centralized control is not dominant strategy for SC to maximize SC profit.

Several managerial implications are generated from the analysis of static equilibrium analysis. First, centralized control strategy is SC's dominant strategy for market share maximization. When profit maximization as the goal, decentralized control would be better. Second, in order to increase profit by increasing demand, supply chain managers should offer price discount to consumers which would encourage consumers' repeat purchasing behavior. Third, supply chain managers could expand horizontal differentiation to make consumers pay higher price, and to obtain more profits. Fourth, lower operation cost is one advantageous factor for SC to compete against each other. Reasonable consumers' transport cost would expand market share when supply chain enterprises locate on the market endpoint.

6 Summary

Considering the repeated purchase behavior of consumers and the price discount strategy of the retailers, we analyze the location and pricing of two competitive supply chains. We find that the price p_i of the product decreases with the increase of $\lambda_i (0 \leq \lambda_i \leq 1)$, that is the larger the discount coefficient, the corresponding product price will be lower. It also explains the phenomenon why the price of the product is higher than the usual after the discount. However, the two supply chain profits have nothing to do with the price discount λ_i, and two retailers will be located at the end of the market, indicating that the location of SC is not related to the price discount.

This paper assumes that consumer distribution is the same as Hotelling model. However, consumer distribution is affected by many factors in reality such as geographical environment, economy and politics, and so on. Future research could combine with consumers' non-uniform, non-linear transportation costs, consumers' brand preference, which will be more theoretical and practical significance.

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Game Analysis on Urban Traffic Congestion Charging

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Abstract The paper constructs the game model of the main stakeholders of urban traffic congestion charging by using the related theories and methods about relevant stakeholders and game theory. Through the equilibrium analysis of the game model, several possible pure strategy Nash equilibrium results and their realization conditions are obtained. An analysis of the mixed strategy Nash equilibrium shows that the government can use part of the cost of traffic congestion to subsidize the traveler through direct or indirect methods, thus inducing the traveler to choose public transport. The government makes a reasonable traffic congestion rate and the fees are used for public transport subsidies and urban road construction. It can induce travelers to choose public transport. Especially in the early period of traffic congestion charging, providing certain compensation for the public transports will be conducive to development and sustainable development.

Keywords Traffic congestion charging · Stakeholders · Game analysis · Nash equilibrium · Mixed strategy

1 Introduction

According to statistics from the National Bureau of Statistics, from the 5 years of 2016, the number of private cars in China rose rapidly from 88.838 million vehicles to 163.3022 million vehicles, an increase of 84.76% points; In the same period, the urban population density rose from 2307 to 2408 persons/km^2, and the per capita urban road area only increased from 14.39 m^2 to 15.8 m^2, an increase of 4.38 and 9.8% points respectively. The scale of urban population and the size of private cars in China are continuously expanding, and the traffic demand is also increasing rapidly. Although China's cities continue to increase the investment in transportation facilities, their growth rate seems to never keep up with the growth of

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transportation demand. In most cities, the traffic demand has exceeded the capacity of transport supply. No matter whether in time or in space, the transportation supply has lost its balance, and the congestion situation has become increasingly severe, which seriously restricts the development of urban social economy. According to foreign practical experience, it is not feasible to simply rely on increasing the supply of traffic to resolve traffic congestion. It is easy to fall into a vicious cycle of "traffic congestion—road expansion—increased demand for private transport—declining demand for public transport—further demand for private transport—traffic congestion again [1]". China has a large population. Due to the limited area of the city, we should seek a traffic congestion solution that meets the actual situation in China. Traffic congestion charges are considered to be one of the most direct and effective measures to alleviate traffic congestion. From the perspective of game theory, this paper builds a traffic congestion game model drawing on existing research results, analyzes the conditions and results of the game equilibrium, and provides theoretical basis and decision support for government decision-making. The game process discussed is very meaningful. It has important theoretical and practical significance.

2 Basic Principle of Congestion Charging

Road congestion charges come from the fact that the roads are crowded: The road construction and its capacity are limited, while the traffic demand growth is expanding. Congestion charges refer to the implementation of charges for vehicles of peers in specific time periods and road sections to adjust the traffic demand of congested road sections, thereby reducing the traffic load during busy hours and busy road sections and improving the road capacity. At the same time, travelers are encouraged to turn to public transport to achieve traffic control measures to ease traffic congestion [2].

The root cause of traffic congestion is the externality of "quasi-public goods" on urban roads. Urban roads belong to "quasi-public products" and have the dual features of exclusivity and non-competition. When the traffic volume of a particular section is small, the use of a bicycle on a road does not affect the use of the same road by other vehicles. However, once the traffic density exceeds the blocking density, traffic congestion will occur, and the performance of the exclusion will be quite prominent.

Traffic traveler costs include private costs and external costs. Private costs include personal costs such as vehicle maintenance fees, fuel costs, and time value. External costs refer to the extra costs incurred by others due to traffic jams caused by private transport traffic, as well as the cost of the loss of time, shared by the entire society. The social cost of congested roads is much greater than the private costs of the traffic travelers. When the congested roads are not charged, the travelers only pay attention to private costs, which leads to excessive use of roads and road congestion. By charging users who drive vehicles on congested roads, they rely on economic means-price mechanisms to guide and regulate real-time traffic flow. The real-time traffic flow is guided and adjusted by charging a user who drives a vehicle on a congested road-depending on economic means, a price mechanism. As a result, external effects due to road congestion are internalized in the form of traffic congestion fees, and congestion problems caused by excessive use of traffic roads are corrected. Congestion charges can also effectively encourage travelers whose time value is lower than the congestion rate to travel to the public transport, so as to alleviate the traffic congestion in the city and improve the operational efficiency of the entire urban transport system [3].

The concept of traffic congestion charging is actually that the traveler with a higher time value has the right to pass through a certain amount of expenses, occupying the scarce resources such as peak hours and peak sections. Make travel time and route available to travelers who can use no specific road section, thus reducing traffic demand and alleviating road congestion. The traffic congestion charge is the use of the price principle in economics to limit the traffic demand and make the urban traffic system in an optimal state. Make full use of urban road space resources, internalize external costs of road use, and maximize social benefits.

3 Game Analysis of Congestion Charging

As a rational traveler, while maximizing its own utility, it loses the maximization of collective welfare and ultimately leads to the loss of its own utility. To solve this problem, it is difficult to solve the problem simply by relying on market measures. It is necessary to run government administrative measures to solve this problem. This article selects the traffic traveler and the government (actually the traffic manager to represent the government) as the decision-making body involved in the congestion charging game. The user selects the transportation mode on the basis of the game, and the government analyzes the congestion charging decision based on the game.

The public habitually believes that the urban road network is a public facility built using taxation, and the public's support for the congestion charge is related to the orientation of government policies [4]. Therefore, in order to facilitate the analysis, it is assumed that the model which builds referencing existing research includes two main stakeholders: government and traffic traveler. The government also includes relevant transportation organizations and associations; at the same time, it is assumed that governments and traffic travelers participating in the game are all rational economic people, that is, they aim at maximizing their own economic interests. In addition, it is assumed that both sides of the game know each other's strategic space and corresponding benefits. In the short-term equilibrium, a complete information static game can be dealt with and a Nash equilibrium solution can be obtained.

For the government, it is the representative of the overall interests of the society. Therefore, the basis for its decision should be the maximization of social benefits and utilities. The government supports and guides travelers to choose public transport by providing subsidies for public transport, policy advocacy, and ecological monitoring to achieve the purpose of relieving traffic congestion. The government has two strategies: The first is to "charging" and to use directly or indirectly the traffic congestion fees that it receives to subsidize public transport and investment road resource construction, publicity, and environmental monitoring. The second is "free", that is, the government does not take any charging measures to influence and interfere with the current traffic situation.

For travelers, the choice of whether to continue to choose private or public transport depends on the relative time value of the traveler when congestion charges are collected. People with high relative value in time will choose to continue driving and people with low relative value will choose to travel by public transport. Therefore, there are two strategies for traffic travelers to choose from: to accept traffic congestion charges and not to accept traffic congestion charges. When a traveler receives traffic congestion charges, he or she can enjoy certain direct or indirect subsidies from the government.

Based on this, this paper makes the following assumptions for traffic managers and traffic travelers' income and costs under different strategies.

Assumption 1: For the government, unit income is I_1, unit cost is C_1 when choosing congestion pricing (investment of previous equipment and normal operating expenses, etc.); when no fee is selected, both its revenue and cost are 0; Represents the public interest, so we must bear the environmental and social negative impact caused by the traffic congestion, and use L to represent the social welfare loss paid for the unit. When the government chooses free, the fees and costs are zero. Because the government representatives represent the public interest, they must bear the environmental and social negative impacts caused by the traffic congestion and use L to indicate the unit's social welfare losses paid for.

Assumption 2: For traffic travelers, utility is achieved by satisfying the need to enjoy private or public transport traveling. Set the unit utility of the travelers when they choose public transport as I_{21}, and the unit cost is C_{21}. Set the unit utility obtained by the travelers when they select a private transport for travel to I_{22}, and the unit cost is C_{22}; The unit subsidy provided is when the government charges for congestion; when the government conducts a congestion charge, the traveler chooses a private transport to travel and needs to pay the congestion charge he receives each time.

Obviously, the result is $C_{21} < C_{22}$ and $I_1 = T$.

4 Model Construction

Based on the above assumptions, this paper establishes a game model for both traffic managers and traffic travelers. The payoff matrix is shown in Table 1.

Table 1 Payoff matrix

Government	Traffic traveler	
	The travel by private transport	The travel by public transport
Charging	$I_1 - C_1 - L$	$-C_1 - S$
	$I_{22} - C_{22} - T$	$S + I_{21} - C_{21}$
Free	$-L$	0
	$I_{22} - C_{22}$	$I_{21} - C_{21}$

5 The Analysis of Game Equilibrium

5.1 The Analysis of Pure Strategy Nash Equilibrium

Through the equilibrium analysis of the game model shown in Table 1, we can know that there are three pure Nash equilibrium results when certain conditions are met, as shown in Table 2.

The combination of strategies (Free, The travel by public transport) should be the best combination of strategies. The conditions for its establishment are: $I_{21} - C_{21} > I_{22} - C_{22}$. This shows that the government does not charge for congested traffic and therefore does not need to pay the corresponding costs and social welfare losses. Travelers who enjoy the benefits of using public transport to meet their own needs and get the benefits they need are not less than the utility of private transports and make the choice of public transport more effective than private transports. Travelers are fully aware of the root causes of traffic congestion and are willing to take social responsibility for solving traffic congestion. At the time, the private costs and the external costs (social costs) of traffic travelers tend to be the same. In the long run, this should be the result of the game between the two sides. However, this condition is too ideal and harsh. It should be difficult to achieve in the early stages of urban traffic congestion management. In the early days, most of the public believed that urban roads were public facilities built by taxpayers for taxpayers' investments. They would ignore or be unwilling to bear external costs (social costs).

In addition, we can conclude that if we consider from the perspective of pure economic interests, the government will tend to choose free, so as not to have to pay for propaganda and other costs. Therefore, the combination of strategy (Charging, The travel by private transport), (Charging, The travel by public transport) will not naturally become a purely strategic equilibrium.

Table 2 The results and conditions of pure strategy Nash equilibrium

No.	Condition	Pure strategy combination
1	$I_1 - C_1 - L > -C_1 - S$	(Charging, The travel by private transport)
2	$I_1 - C_1 - L < -C_1 - S$	(Charging, The travel by public transport)
3	$I_{22} - C_{22} < I_{21} - C_{21}$	(Free, The travel by public transport)

When all the conditions in Table 1 are not established, there is no unique stable Nash equilibrium solution. The government, tourism companies, and tourists will choose a mixed strategy.

5.2 The Analysis of Mixed Strategy Nash Equilibrium

Under the condition that there is no pure strategy Nash equilibrium, the government and traffic travelers will adopt a hybrid strategy and adopt their pure strategy with a certain probability. Assuming that the government selects the strategy G_1 (Charging) with the probability of x and the strategy G_2 (Free) with the probability of $(1 - x)$; the traveler selects the strategy Y_1 (The travel by private transport) with the probability of y, taking $(1 - y)$ Probability selection strategy Y_2 (The travel by public transport), among them, $x, y \epsilon [0, 1]$.

The revenue function of the government's selection strategy G_1 (Charging) is:

$$E_{G_1}(x, y) = y(I_1 - C_1 - \mathrm{L}) + (1 - y)(-\mathrm{C}_1 - S) \tag{1}$$

The revenue function of the government's selection strategy G_2 (Free) is:

$$E_{G_2}(x, y) = y(-\mathrm{L}) + (1 - y)(0) \tag{2}$$

The income function of traveler selection strategy Y_1 (The travel by private transport) is:

$$E_{Y_1}(y) = x(I_{22} - C_{22} - T) + (1 - x)(I_{22} - C_{22}) \tag{3}$$

The income function of traveler selection strategy Y_2 (The travel by public transport) is:

$$E_{Y_2}(y) = x(S + I_{21} - C_{21}) + (1 - x)(I_{21} - C_{21}) \tag{4}$$

For the government and the traveler, when the expected returns from different strategies are equal, the game will reach a stable equilibrium, from which x and y can be determined.

$$\text{Let } E_{\mathrm{G}_1} = E_{\mathrm{G}_2}, \text{then } y = \frac{C_1 + S}{I_1 + S} = \frac{C_1 + S}{T + S} \tag{5}$$

$$\text{Let } E_{Y_1} = E_{\mathrm{Y}_2}, \text{ then } x = \frac{I_{22} - C_{22} - (I_{21} - C_{21})}{S + T} \tag{6}$$

If the probability of charging is less than $\frac{I_{22} - C_{22} - (I_{21} - C_{21})}{S + T}$, the best choice for the traveler is the travel by private transport; if the probability of government charges is greater than $\frac{I_{22}-C_{22}-(I_{21}-C_{21})}{S+T}$, the best choice for travelers is the travel by transport travel.

Therefore, the hybrid strategy Nash equilibrium is: $x^* = \frac{I_{22}-C_{22}-(I_{21}-C_{21})}{S+T}, y^* = \frac{C_1+S}{T+S}$.

(1) The analysis of influencing factors x

According to formula (6), it can be concluded that x^* is a decreasing function of S, T and $I_{21} - C_{21}$, and $I_{22} - C_{22}$ is an increasing function.

When S increases, the government's willingness to choose charging will be less because it will reduce the expenditure on transportation subsidies.

When T increases, the total cost of traffic congestion will increase first and then decrease. When T increases to a certain extent, the total traffic congestion will gradually decrease, and the government's willingness to select fees will be smaller.

When $I_{22} - C_{22}$ increases, that is, the income of the traveler who chooses a private transport to travel increases, it indicates that the congestion density increases and the traffic congestion level increases. At this time, the willingness of government charges will be even greater.

When $I_{21} - C_{21}$ increases, the net income of the traveler who chooses private transport travel increases, it indicates that the congestion density decreases and the degree of traffic congestion decreases. At this time, the government's willingness to charge will decrease.

Therefore, the possibility of government traffic charges x will increase with the increase in traffic congestion in any of the above cases. In fact, it can be seen from the previous game profit matrix that the government is more inclined to not support from the perspective of rational economic man. Considering that the government can't completely choose the strategy from the perspective of a rational economic man in the process of congested traffic, it can take some measures and measures to relieve traffic congestion.

(2) The analysis of influencing factors y

According to formula (5) it can be concluded that y^* is a decreasing function of the congestion charging rate T.

When T increases, that is, the higher the government charges for traffic congestion, the probability that the traffic traveler chooses a private transport to travel will decrease. This means that the probability that the traveler will choose public transport to travel will be greater, and the degree of traffic congestion will gradually decrease as the congestion charging rate increases.

When S increases and $T > C_1$, the probability that the traveler chooses to travel by private transport will increase, and the probability of choosing public transport to travel will decrease.

When S increases and $T < C_1$, the probability that the traveler selects a private transport to travel will decrease, and the probability of choosing a public transport to travel will increase.

6 Conclusion

By using game theory and method, this paper deeply analyzes the game relationship between the government and the traveler involved in traffic congestion charging. The research shows that: (1) In the complete information static game model, there may be three pure strategy Nash equilibriums, and only the equilibrium results (Free, Travel by public transport) can achieve the goal of healthy development of urban traffic order. The requirements for sustainable development, due to the initial practice of urban traffic congestion, implementation condition $I_{21} - C_{21} > I_{22} - C_{22}$ is difficult to achieve. (2) The analysis of mixed strategy Nash equilibrium shows that by charging the government can effectively reduce the number of traveler by private transports, increase the number of traveler by public transports, effectively alleviate the traffic congestion, and improve social welfare. The government can control the ratio of private travel to public travel by affecting y^*. If the rate (or price) of congestion charging imposed on private transports are higher, the smaller the y^*, the smaller the proportion of private transport traveling. The government can give public transport more subsidies to improve public transport services and increase the attractiveness of public transport so as to increase the efficiency of road-use. The government does not simply decide whether to charge or not, the rate will determine the blocking density of the road network. If the rate is reasonable, the traffic congestion status will be greatly improved, and the rate will be set too high, resulting in y^* being too small, and the traffic volume will not be optimal. In a saturated state, road resources are wasted, and if the rate is too low, it will be difficult to ease traffic congestion. The Nash equilibrium solution of the mixed strategy is a fixed point. Both private utility and social utility reach the optimal level. No party will actively change its behavior. Therefore, we can use this Nash equilibrium solution to guide our decision-making.

This paper has also gained some useful inspiration: (1) From the perspective of long-term development, the solution to the urban traffic congestion in China is to firstly play the role of the government in macro-economic regulation. The government can actively guide and publicize the traffic congestion charging decree and the social responsibility and obligations of traffic-transporters, create external conditions for the congestion charging, reduce the income (or utility) of private travelers, and increase the cost; increase the public transport traveler's income (or utility), reduce the cost, and gradually induce the traveler to consciously turn to public transport to increase social welfare. (2) The rate of traffic congestion charging should be reasonable, and if it is too low, it will be difficult to achieve the expected aims. Too high will cause waste of road resources.

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Study on the Mechanism of Energy Structure Optimization to Low-Carbon Economy

Jing Cao and Mei Huan

Abstract This paper starts with a low-carbon economy and energy structure, and uses qualitative and quantitative research methods to analyze the mechanism of energy structure optimization for low-carbon economy, and screens and measures the influence factors of energy structure from the perspective of 3E, using Cointegration Test and Granger causality analysis to determine the impact of various indicators on the energy structure and degree of impact.

Keywords Low-carbon economy · Energy · Structural optimization · Influencing factors

1 Introduction

Energy is an important material basis for human survival and development, and also an important strategic resource for the country's economic lifeline and national security. The realization of a low-carbon economy cannot be separated from the adjustment of the energy system [1, 2]. Optimizing energy structure is an important way to reduce carbon emissions [3, 4]. China's economy is in the stage of "shifting," the concept of the new normal and the Fifth Plenary Session of the 18th CPC Central Committee proposed that "green development" be considered as one of the five major concepts that have a bearing on the overall development of China, which requires China to enter the green low-carbon cycle mode as soon as possible. Low-carbon economy has gradually been accepted by people. Low-carbon life and building a low-carbon society have gradually become a global consensus.

Scholars at home and abroad have made many studies on the interaction between energy structure and low-carbon economy. Schipper et al. conducted a LMDI model decomposition of the factors affecting the CO_2 emissions of a number of

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International Energy Coalition member states, suggesting that the change in CO_2 emission levels in most countries is due to changes in energy output and total energy demand [5, 6]. Su et al. analysis urban energy structure optimization at the sector scale, it concludes that the multi-objective optimization model integrating environmental impact is useful for reasonable allocation of energy resources across the urban sectors [7]. Feng Xu study the optimization of energy structure under the background of energy conservation and emission reduction in Guangdong province through the Computable General Equilibrium (CGE) Model. The result shows that, under the premise of maintaining steady growth, Guangdong can effectively improve the energy structure, reduce the consumption of fossil fuels and improve the proportion of low carbon energy [8]. Wang Shaohua and Yu Weiyang discussed the mechanism models of the two, and used carbon path analysis to measure the interaction between the two [9]. Zhang Yunhe and others qualitatively analyzed the adjustment direction of China's energy structure optimization in the light of the low-carbon background. Research shows that China's future adjustment direction should be replayed to promote the diversified development of energy composition [10]. Fan Chendi used qualitative methods to analyze the relationship between the two, and believed that the low-carbon model has a significant effect in promoting diversification of energy structure and improving energy efficiency [11]. Fan Decheng and Wang Shaohua have made clear that the energy bottleneck in China is the structural contradiction of energy, and divides the three economic benefits dimensions of social economy, energy planning, and environment, and uses rough set theory to establish a rationalized evaluation system for the degree of energy allocation [12, 13].

In summary, this paper analyzes the correlation mechanism between energy structure optimization and low-carbon economy based on a low-carbon economy; it analyzes various factors affecting energy structure optimization through quantitative methods, it can provide reference for the formulation of energy development plans and fulfillment of emission reduction commitments, and is of great significance for optimizing the energy structure.

2 The Concept and Relationship Analysis of Low-Carbon Economy and Energy Structure

2.1 The Concept of Low-Carbon Economy and Energy Structure

(1) The concept of low-carbon economy. Low-carbon economy has increasingly become a political and economic problem. Therefore, the connotation of a low-carbon economy is also continuously expanding, and it is difficult to form an accurate definition [14, 15]. Considering that this article focuses on the optimization of energy structure under low-carbon economy, the concept of

low-carbon economy proposed by the CCICED report is more comprehensive, that is, "low-carbon economy is not only a basic economic model for promoting energy conservation and emission reduction, maintaining energy development, but also It is an economic form that adapts to the gradual deepening of the industrialization process [16]."

(2) The concept of energy structure. The energy structure refers to the composition and ratio of various primary energy sources and secondary energy sources in total energy [17]. Energy structure is usually composed of two parts: supply structure and consumption structure. The energy supply structure represents the share of all types of energy production in total energy supply. The energy consumption structure can be divided again according to the consumption category or the industrial part that consumes energy. According to its different consumption entities, it can be divided into a primary energy consumption structure and a terminal energy consumption structure.

2.2 Impact of Energy Structure Optimization on Economic Development

The effective optimization of energy structure is the inevitable choice to achieve the goal of low-carbon economy. The analysis of China's current energy structure shows that the current contradiction between China's energy structure and economic development has intensified. On the one hand, with the demand for economic development as a guide, large-scale development of infrastructure requires a large amount of fossil energy as a support. However, high-energy-consuming industries cannot avoid the thorny issue of high-carbon emission status. The low consumption efficiency and high environmental pollution are facing the dual constraints of energy and the environment. Therefore, it is necessary to optimize the existing energy structure to form a relatively stable, low-carbon and economical energy development system to deal with the bottleneck of economic development due to the high carbonization of energy.

Optimizing the energy structure is the main prerequisite for the smooth progress of the low-carbon economy. In China's existing energy structure, coal is still the dominant factor. Compared with the supply structure of oil and gas as an important energy source, the energy efficiency of the former is about 8–9% lower. On the one hand, when coal is used as a fuel to provide energy, the energy conversion efficiency of its intermediate conversion device is lower than that of liquid or gaseous fuel and it is difficult to increase. On the other hand, because 40% of China's coal consumption has been burned as a terminal energy supply, a large amount of soot and waste, mainly CO_2 and SO_2, has been generated. Therefore, the existing energy structure needs to be optimized to reduce its carbon intensity in response to climate change.

Optimizing the energy structure is the main path for promoting low-carbon economy. Extensive mining of various types of resources has caused problems such as the collapse of the goaf, land subsidence and other geological disasters, destruction of biological resources, and atmospheric pollution, which have greatly damaged the sustainable development of the economy. If all kinds of energy minerals are unsustainable, the main industries will rapidly decline, resulting in economic sluggishness and social unrest. Therefore, only by optimizing the energy structure can we develop a peaceful and stable low-carbon economy and promote the stable development of the regional economy.

2.3 Impact of Energy Structure Optimization on Carbon Emissions

According to the preparation method of IPCC's GHG inventory and related experts' research, carbon emissions are mainly generated in the five major areas such as energy activities and industrial development. Due to differences in oxygen supply rate, combustion efficiency, combustion conditions, and calorific value, the carbon emission factors of various energy sources are different, and the unit of coal has the largest amount of carbon emissions, followed by oil and natural gas.

As shown in Table 1, for the sake of comparison, assuming 100 million tons of standard energy consumption, if the proportion of primary energy consumption reaches the world average, the ratio is about 3:3:3, and the world will produce 89 million tons of carbon. And if the proportion of consumption reaches the average level of China, the ratio is about 7:2:1, CO_2 emissions will increase by 54 million tons of carbon; this shows that the energy allocation of multiple coals and less gas will inevitably lead to the same consumption. The production of more CO_2 and pollutants has a negative effect on the development of a low-carbon economy.

Table 1 A comparison of total carbon emissions in 2015

Area	The proportion of primary energy consumption structure (%)			Total carbon emissions (Billion tons)
	Coal	Oil	Natural gas	
Global	32.6	23.7	30	0.89
China	68.1	19.6	6.2	1.43

3 Empirical Analysis

3.1 Variable Selection

In 2005, an energy index system was defined by the IAEA, focusing on the impact of low-carbon economy on energy and published in the "Guidelines and Methodology for Energy Indicators for Sustainable Development" report [17]. Measured indicators come from three major areas: social, economic, and environmental, with top-down structures. The 3E system is a multi-element and multi-level complex system that contains these three major areas. Various factors in the system influence each other to achieve the purpose of energy structure optimization in a low-carbon economy environment (Fig. 1).

(1) Economic system

GDP represents the overall level of development of a region within a fixed period of time. In general, the higher the level of GDP, the overall energy consumption will show the same trend, the structural configuration will also be more biased toward clean and efficient; energy intensity, that is, energy consumption per unit of GDP, intuitively reflects the economic value of energy consumption. Specifically expressed as the energy required for the growth of the gross value of production per unit of time within the time node. The per capita GDP represents the relationship between the total population of the region and the total GDP. The increase in per capita GDP represents the input of more energy while maintaining the existing energy structure, and will increase the total amount of carbon emissions. Therefore, GDP, per capita GDP, energy intensity, and energy consumption are closely related. It is a very important factor affecting the energy structure that is economic growth.

(2) Energy system

The energy system is mainly composed of depleted energy and renewable energy. The production and consumption of energy forms the tidal effect of the energy system, making the energy system from disorder to order [18]. Coal, oil, and natural gas are exhaustible energy sources and they are the main body of the current energy

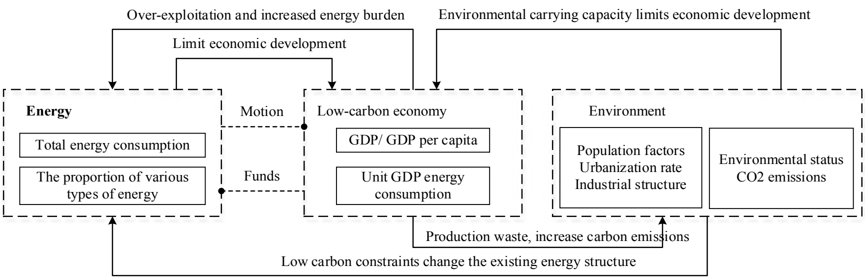

Fig. 1 Low carbon 3E system mechanism of action

system. Total energy consumption directly expresses future demand, and its structure reflects the proportion of various fossil fuels. Due to the large differences in different calorific values and carbon emissions, changes in energy consumption configuration directly affect the development of low-carbon economies. Based on previous studies, this paper selected the total energy consumption and the proportion of fossil energy consumption as indicators for optimizing the energy structure.

(3) Environmental system

The environmental system includes various factors in the environment and their interactions with each other. It is not limited to the natural environment, but it also needs to consider the influence factors in the social environment. The total population is the fundamental element of the environmental system, and the total population and total consumption will show the same trend growth. Therefore, the total population needs to be used as an indicator of energy demand; the urbanization rate represents the rate of urban development, the rapid development of the city and the expansion will inevitably increase regional carbon emissions and lead to a shift in the energy structure toward higher carbon. Therefore, the role of urbanization rate in the energy structure is taken into consideration, and the energy structure is negatively related to the urbanization rate; many scholars have studied it. It is found that the industrial structure has different resource utilization characteristics. Adjustment of the industrial structure will directly affect the total demand and configuration. Therefore, we must use the industrial structure as an index of influence.

3.2 Measurement of Energy Structure by Influencing Factors

According to the effects of various system representative factors on the energy structure in the 3E system, the corresponding influencing factors are selected. At the same time, as a key link in the realization of a low-carbon economy, the theoretical support for the selection of energy structure optimization system indicators mainly includes systematic, hierarchical, and feasibility principles; method selection combines qualitative methods and quantitative methods, and fully combines dynamic and static methods. Finally, an energy structure optimization index system is formed, as shown in Table 2. Existing indicators can be divided into profit-oriented indicators, cost-based indicators, and moderate indicators based on their influence on variables.

Entropy weight method as a complex objective weighting method, the principle is based on the actual sample data observation index information size to determine

Table 2 Energy structure optimization index system

Affiliation system	Index name	Index	Indicator properties
Economic system	GDP	x_1	Benefit index
	Energy intensity	x_2	Cost index
	Per capita GDP	x_3	Benefit index
Energy system	Total energy demand	x_4	Moderation index
	The proportion of coal consumption	x_5	Moderation index
	The proportion of oil consumption	x_6	Moderation index
	The proportion of natural gas consumption	x_7	Moderation index
	The proportion of one power consumption	x_8	Moderation index
Environmental system	Total population	x_9	Moderation index
	Urbanization rate	x_{10}	Moderation index
	Industrial structure	x_{11}	Moderation index

the index weight, the impact of the measure. It can to a certain extent avoid subjective errors such as the Delphi method. In this paper, the entropy method is used to calculate the impact of factors on the energy structure measurement. The specific steps are as follows:

(1) Establish the decision matrix of the original data: X_{ij} denotes the original sample data value of the object set relative to the indicator set, that is, the actual measured value of the i indicator in the j year, where $i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$. The decision matrix is:

$$X = \begin{bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,n} \\ X_{2,1} & X_{2,2} & & X_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ X_{m,1} & X_{m,2} & \cdots & X_{m,n} \end{bmatrix} \quad (1)$$

(2) Standardization decision matrix: First, the evaluation values are preprocessed, and each index value is non-dimensionalized, so as to eliminate the difference between attribute dimensions.

$$\text{Benefit index: } Y_{ij}^{+} = \frac{(X_{ij} - X_j^{\min})}{(X_j^{\max} - X_j^{\min})},\ i = I_1 \tag{2}$$

$$\text{Cost index: } Y_{ij}^{-} = \frac{(X_j^{\max} - X_{ij})}{(X_j^{\max} - X_j^{\min})},\ i = I_2 \tag{3}$$

$$\text{Moderate index: } Y_{ij} = 1 - \frac{\left|X_j^{\max} - X_{ij}\right|}{X_j^{\max}},\ i = I_3 \tag{4}$$

(3) Calculate the weighting value under the i index item, and set the proportion under the i index as:

$$\rho_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}} \tag{5}$$

(4) Calculate the entropy of index i:

$$E_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} \rho_{ij} \ln(\rho_{ij}) \tag{6}$$

In the formula, when $\rho_{ij} = 1$ or $\rho_{ij} = 0$, $\rho_{ij} \ln(\rho_{ij}) = 0$, and the size of the entropy is inversely related to the magnitude of the information.

(5) Calculate the difference coefficient θ_j of the j index, $\theta_j = 1 - E_j$, The difference between the size of indicators and the meaning of entropy is the opposite. Therefore, this paper calculates the data of entropy weights as the coefficient of difference between indexes.
(6) Let w_i denote the weight of indicator i in the indicator system:

$$w_i = \frac{\theta_i}{\sum_{i=1}^{m} \theta_i}, i = 1, 2, \ldots, m \tag{7}$$

According to the calculation procedure of the entropy method, the initial indicator impact measurement system was established using the data of each index for the decade from 2006 to 2015 as the initial data, and the initial indicator impact measurement result was calculated as shown in Table 3.

This paper is based on the study of energy structure optimization under the low-carbon economic environment. It selects the representatives of GDP, coal consumption and urbanization as influencing factors.

Table 3 Energy structure impact index measurement system

Influencing factors	Index name	Index	Impact measure
Economic system	GDP	x_1	0.3396
	Energy intensity	x_2	0.2897
	GDP per capita	x_3	0.3396
Energy system	Total energy demand	x_4	0.0085
	The proportion of coal consumption	x_5	0.0040
	The proportion of oil consumption	x_6	0.0036
	The proportion of natural gas consumption	x_7	0.0036
	The proportion of one power consumption	x_8	0.0035
Environmental system	Total population	x_9	0.0001
	Urbanization rate	x_{10}	0.0005
	Industrial structure	x_{11}	0.0004

3.3 Stationarity Test

This article selects the comprehensive evaluation index of urbanization rate, coal energy ratio, economic growth and total energy demand for statistical analysis, and obtains the trend chart as shown in the Figs. 2, 3 and 4.

As shown in Figs. 2, 3 and 4, the total demand, GDP, urbanization rate, and coal consumption share almost simultaneous increases and decreases, i.e., the same trend. This article will use cointegration analysis to prove the long-term stable relationship between the four. According to the four dimensions of the non-dimensionalized values in the entropy weight calculation, Eviews8 can be used for cointegration analysis.

First, the stability test of the sequence is performed: according to the evaluation index of the total energy demand (enr), GDP (gdp), coal consumption, and urbanization rate (city), the line graph can be drawn. It can be seen that the above four Item indicators are not stable. Therefore, this paper successively takes its first-order and second-order differentials to do ADF test to verify the stability of each indicator time series. Eviews8.0 yields the Table 4.

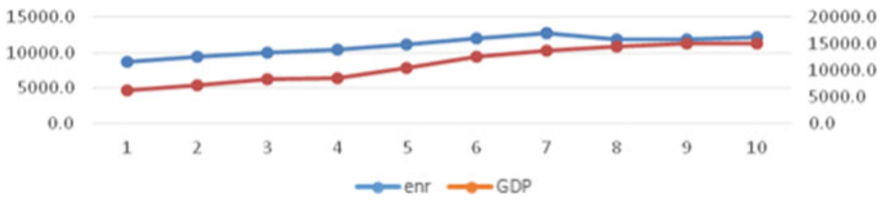

Fig. 2 The trend of total energy demand and GDP

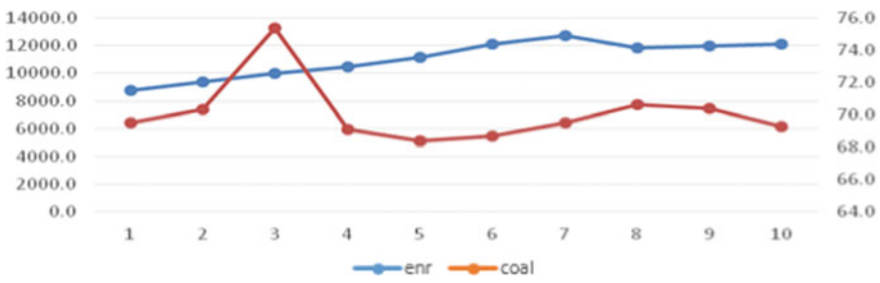

Fig. 3 The trend of total energy demand and coal consumption

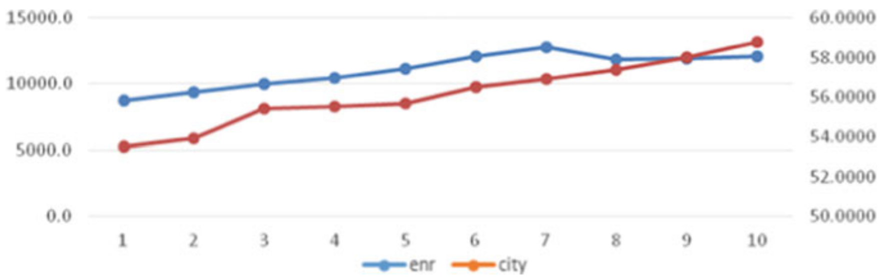

Fig. 4 The trend of total energy demand and urbanization rate

Table 4 Enr, gdp, coal, city ADF analysis test results

Sequence	ADF value	1% critical value	5% critical value	10% critical value	Conclusion
enr	−0.876866	−5.521860	−4.107833	−3.515047	Unstable
△	−2.320302	−6.292057	−4.450425	−3.701534	Unstable
$△^2$	−3.263838	−2.937216	−2.006292	−1.598068	Stable
gdp	3.141875	−2.847250	−1.988198	−1.600140	Unstable
△	−1.629789	−5.835286	−4.246503	−3.590496	Unstable
$△^2$	−6.237074	−6.006336	−4.773194	−3.877714	Stable
coal	−0.081889	−2.847250	−1.988198	−1.600140	Unstable
△	−4.654019	−6.292057	−4.450425	−3.701534	Unstable
$△^2$	−12.27721	−7.006336	−4.773194	−3.877714	Stable
city	4.124592	−2.847250	−1.988198	−1.600140	Unstable
△	−7.455488	−6.292057	−4.450425	−3.701537	Stable

According to the Eviews calculation results, the ADF values of the second-order differences of the above indicators are less than their 1% critical values, so the second-order differentials are all stationary sequences and can be tested in the next step.

3.4 Cointegration Test and Granger Causal Analysis

Next, a data cointegration test is performed: There is a smooth sequence of the same order among the above indexes. According to the cointegration theory, there is a certain probability of cointegration between them. According to the OLS method in Eviews, the regression equations between each sequence are obtained respectively. In order to prevent the pseudo regression phenomenon of each regression equation, ADF test is performed on the residuals of this equation. The regression equations and residual ADF test results are as follows (Tables 5, 6 and 7).

$$(1)\ \text{enr} = -2.2228 + 3.2344\ \text{city}$$

$$(3)\ \text{enr} = 1.9302 - 1.1443\ \text{coal}$$

$$(4)\ \text{enr} = 0.5449 + 0.4348\ \text{gdp}$$

The above results indicate that there is a long-term stable co-integration relationship between the total energy demand (enr), GDP (gdp), coal consumption, and urbanization indicators.

Granger (1969) described the causality as a connotation of time: "To determine the causal effect of Y on X, examine the extent to which the past value of Y explains the current value, and then examine whether the lag value of adding X can improve. Interpretation degree. If the lag value of X changes the interpretation of Y, then X is considered to be the Granger cause of Y [19]." It was determined that co-integration tests were used among various elements, and Granger causality was

Table 5 Residual unit root test

Residual unit root test results	−4.243015
1% critical value	−2.937216
5% critical value	−2.006292
10% critical value	−1.598068

Table 6 Residual unit root test

Residual unit root test results	−3.760289
1% critical value	−3.007406
5% critical value	−2.021193
10% critical value	−1.597291

Table 7 Residual unit root test

Residual unit root test results	−3.095807
1% critical value	−3.007406
5% critical value	−2.021193
10% critical value	−1.597291

Table 8 Granger causality test

Granger causality	Lag order	F statistics	P value	Causal relationship
city is not a causality of enr	2	0.16418	0.08557	Refuse
enr is not a causality of city		0.05476	0.9476	Accept
gdp is not a causality of enr		0.60656	0.6009	Refuse
enr is not a causality of gdp		0.67259	0.5737	Refuse
coal is not a causality of enr		0.30339	0.7586	Refuse
enr is not a causality of coal		1.35933	0.3800	Accept

used to test whether there was a causal relationship between total energy demand, GDP, coal consumption, and urbanization rate. The results are shown in Table 8.

The practical results show that the urbanization rate is the one-way causal relationship between the total energy demand; GDP is the two-way causal relationship between the total energy demand; total energy demand is a one-way causal relationship between coal consumption.

4 Conclusion

Based on the current status of energy and the development of low-carbon economy, this paper studies the mechanism of energy structure optimization and low-carbon economy. Based on the low-carbon 3E system, the index that determines the energy structure is determined, and the entropy weight method is used to measure the influencing factors. These factors are cointegrated and Granger causal analysis. The conclusions obtained in this paper are as follows:

(1) This paper studies the relationship between energy structure and low-carbon economy based on the 3E system, and uses the entropy method to measure the impact factor. According to the measurement result, GDP can be used as the core indicator of national economic accounting. The impact measure is 0.3396 and can represent Low-carbon economic systems; total energy demand and coal consumption as a proxy for energy systems, and urban systems are represented by urbanization rates.

(2) This article analyzes the trends of indicators that represent the energy system, economic system, and environmental system. Based on the trend of line charts, it is found that they have synergistic trends. Firstly, the degree of smoothness of each index was determined by ADF method, and then cointegration analysis was performed to confirm that there was a cointegration relationship between the three. Granger causality analysis of various indicators found that urbanization rate is a one-way causal relationship between total energy demand; GDP is a two-way causal relationship between total energy demand; total energy demand is a one-way causal relationship between coal consumption. This is also more in line with the actual situation, that is, the higher

urbanization rate, the greater the gap in energy demand, so it needs a reasonable energy structure; the higher the GDP, the greater the energy demand, but only the increase in energy demand, but the energy structure is not further Optimization has made the rate of GDP growth constrained; energy demand has a direct causal relationship to the proportion of coal consumption. Reducing the coal share ratio can make energy demand move toward a more low-carbon and economic structure.

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Construction of Interdisciplinary Logistics Education System for Intelligent Logistics

Fei Liang

Abstract The logistics industry has undergone a range of significant changes over the past decade, and emerging technologies such as the Internet of Things and big data mining are changing the focus of logistics education and increasing the importance of interdisciplinary education with computer science. An interdisciplinary logistics education system bridges the gap between current intelligent logistics practice and higher education. The interdisciplinary logistics education focuses on integrated course design and laboratory setup by making full utilization of various resources from industry, research centers and educational institutions.

Keywords Intelligent logistics · Interdisciplinary logistics education · Course design · Laboratory construction

1 Introduction

Logistics plays an important role in various fields of economic activities and events. With the development of information technology and social economic, emerging technologies and innovations such as cloud computing, the Internet of Things (IoT), Beidou satellite navigation system and big data have brought great challenges to logistics industry and logistics education. Competence job or position requirements for university graduates have significantly risen along with the emergence of new logistics business models and types. Therefore it is necessary to focus sufficient attention on the reform of the ideas and models of logistics education regarding interdisciplinary talent training and reconstruct a systematic logistics "Science-Production-Education" model in order to meet the new professional ability requirements.

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Regarding logistics technology, Hou makes a comprehensive introduction on the evolution of logistics and supply chain management and demonstrates that information technologies including GPS, GIS, crowd computing, big data analysis and perceptive technology have profound influences on logistics industry [1]. Kaina and Verma completed an overview on current logistics issues emphasizing the technology integration and function combination promote the efficiency and effectiveness of logistics [2]. As for higher education of logistics, Uckelmann indicates that the logistics labs should play a vital role in logistics education because it connects the current needs and future needs by applying new developed information technology [3]. Klumpp discusses the competence requirements of logistics in a dynamic environment, while university graduates and traditional blue-collar occupations in logistics are facing challenging brought by the emerging logistics information technology [4]. Hofmann concludes that logistics education should include IT emulation and virtual commissioning [5]. Angolia and Pagliari introduces using the live commercial-software application SAP ERP in the simulation of logistics and supply chain management for higher education has become an advantage for students during collegiate recruiting [6].

2 IoT Technology of Intelligent Logistics in China

IOT technology is currently applied in four main areas: intelligent traceability system, visual intelligent logistics management system, intelligent distribution and delivery system, and intelligent supply chain management system. The perceptive technologies such as barcode, RFID and Beidou satellite navigation system are used in positioning, process tracing, data collecting and sorting. The network and communication technologies such as the Internet, LAN technology, and WLAN technology support the communication among logistics links and networks. Meanwhile, the intelligent management technologies such as data mining, automatic dispatching, information sharing and optimization facilitate fully automated and intelligent logistics operations. Therefore, logistics includes not only basic logistics skills but also the information systems application, logistics network design, supply chain design, etc.

3 Construction of an Interdisciplinary Logistics Education System

3.1 Talent Training Goal of Logistics Education

The cross-boundary development of multi-industry integration has become a new trend and an important approach of innovation. It is critical to align the goals of logistics education with the updated requirements from industry in this changing world. The goal of logistic education and training for individual student is not only obtaining the knowledge of logistics, but also raising competency levels by improving their professional skills such as analytical skills, communication skills and computer skills. For instance, the government personnel in charge of industrial planning and regional infrastructure planning use logistics information technology to assist in logistics channel planning, node design and information platform construction; employees involved in the development of strategic planning, business system planning and design, and supply chain project management also need to be prepared with relevant computer decision skills. With the cross-boundary diversification of logistics industry and the massive use of IoT technology, students should be equipped with the knowledge of information technology, modern communication technology, information processing, computing technology and systems engineering closely related to intelligent logistics.

3.2 Interdisciplinary Logistics Course Design

A comprehensive series of logistics courses must consist of the integration of various courses from logistics management, logistics engineering, computer science and technology, marketing, e-commerce, international trade, etc. Therefore a concept of "Big Logistics" should be established during the interdisciplinary course design process to facilitate and students' cross-border learning. Under the concept of "Big Logistics", educational institutions should provide a platform for the exchange and sharing of the course resources of different subjects, such as instructors from variant background, training equipment and laboratory devices.

With the aim of improving students' knowledge structure, most of the computer science-related courses, for instance, data analysis, information management and system design should be arranged after the basic courses set in the early stage of learning. In order to advance students' competency level in the era of intelligent logistics, educational institutions should evaluate the current logistics course design and ensure the selected computer science-related courses to be added. As shown in Fig. 1, logistics management and logistics engineering should also involve courses such as information management, information service, data analysis, and logistics system design.

Giving the higher standard and requirement brought by intelligent logistics, educational institutions should modify the course program targeting at improving the understanding of basic theory and fundamental knowledge, logistics system analysis and design skills, logistics operation skills. First, as for logistics management skills, courses should focus on helping students understand the basic management principles and appropriately apply them in logistics activities, including coordinating and optimizing the links of logistics chain. Second, regarding the logistics system analysis and design, courses should help students obtain a systematic view to support them to analyze and solve logistics problems

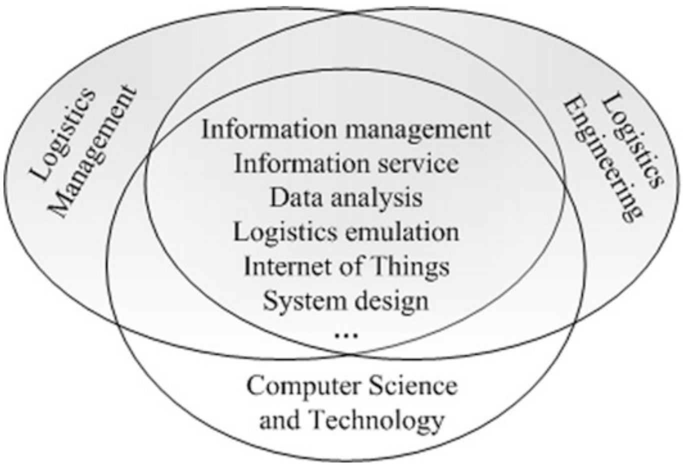

Fig. 1 Intersection of logistics management, logistics engineering and computer science

independently. Third, professional skills such as the operation of logistics equipment and facilities and on-site operation should be addressed as well.

To students majoring in logistics, some professional computer courses like software programming, network framework construction would not be a necessary for logistics course design. However, modern sensor theory, the IoT-related high-frequency microwave technology, wired and wireless network communication, information processing, system engineering should be taken into account.

3.3 Design and Establishment of Interdisciplinary Logistics Laboratory

Interdisciplinary logistics laboratory can display the interconnection between IoT technology and intelligent logistics, as shown in Fig. 2. It provides practical training for students during the teaching session of logistics information technology, IoT technology and distribution center operation, etc. From the perspective of professional skill building, the laboratory focuses on logistics activities and covers the fields of smart e-commerce, marketing, strategic planning, supply chain resources planning. Students can have an in-depth learning on the real-time information acquisition in all links of intelligent logistics by adopting IoT technology, as well as the real-time information sharing and tracking to eliminate the information asymmetry in transmission links and improve the efficiency and accuracy of intelligent logistics.

Combining the current popular IoT technology and applications urgently needed by logistics supply chain management, providing a simulated environment that is

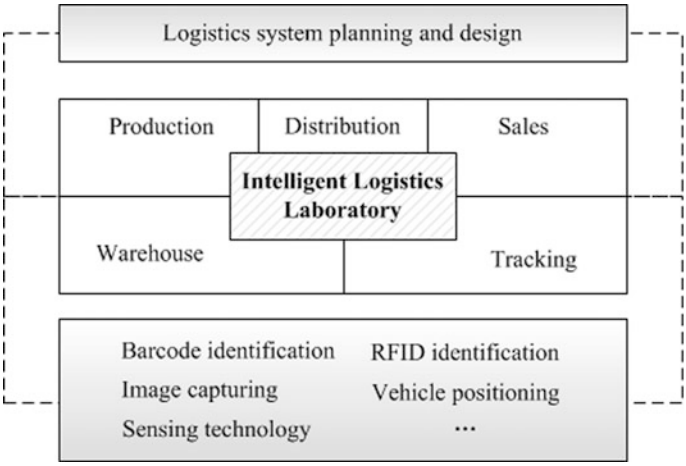

Fig. 2 Functions of intelligent logistics laboratory

close to reality, the laboratory can not only be used in experimental teaching of basic theory of IoT technology, but also in practical teaching of integrated logistics system wiring and software secondary development. Students can experience actual logistics procedure during the laboratory practice: order processing, product labeling, commodity sales and outgoing, commodity distribution, inventory management, vehicle positioning, in-transit commodity monitoring, smart shelf management and automatic settlement design, etc.

4 Application of Interdisciplinary Logistics Education

4.1 The Application of Teaching Scenarios and Cases

Comprehensive teaching scenarios and cases should be designed according to the teaching objective and students' cognitive level. Unlike the traditional case method in a simple application level, intelligent logistics courses need massive amount of dynamic case study as a teaching support. The case design should focus attention on the features of interdisciplinary logistics education, and a good case demonstrates the interconnection of relevant subjects such as logistics, marketing, financial, e-commerce and computer science. A well-designed case can be applied in different subjects. Hence, it is important to build a dynamic case method database to collect valuable cases from enterprises' practice and logistics projects. Through the dynamic case method, students should not only understand the theoretical part but also be problem-solvers by delivering specific solutions for real-time issues occurred in separate scenarios.

4.2 The Adoption of Various Teaching Methods

Compared with traditional teaching method, teachers and students have more flexible and diversified methods to choose, for example, flipped classroom, micro-teaching, Massive Open Online Courses (MOOC). Take flipped classroom as an example, teaching video, case material, project information, handout and test paper can be uploaded onto a computerized and internet connected platform. During the learning session, students can log on the platform and download the material, conduct an online group discussion, and ask question. The intelligent laboratory is equipped with devices enabling functions as speech recognition, gesture input, visual tracking, and sensory feedback. Therefore, students' performance can be tracked and recorded for evaluation. Besides, analyzing tool with data visualization function also help teacher adjust teaching method by presenting an accurate learning result.

4.3 The Integration of Teaching Resources

To build an integrated "Science-Production-Education" model, resources across industries and subjects should be re-allocated for intelligent logistics education. Educational institution should work with enterprises from various fields and research institutions in order to conduct the interdisciplinary course design, case design, learning project design, etc. Employing enterprises' experts of e-commerce, logistics management, IoT application design to train teachers would also be a solution for teaching resources integration.

5 Conclusion

The paper presents the impact of intelligent logistics on current logistics education, and the necessity of establishing an interdisciplinary logistics education system. The key issues are interdisciplinary logistics course design and laboratory design. With the application of IoT equipment and devices, teachers and students can achieve an up-to-date logistics learning experience.

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Non-radial Fuzzy Network DEA Model Based on Directional Distance Function and Application in Supply Chain Efficiency Evaluation

Liqin Wang and Chuntao Yao

Abstract In this paper, we combine the non-radial directional distance function with the network DEA model to analyze the effect of the efficiency of the internal links of the supply chain on system efficiency with taking into account the economic and environmental factors. In addition, we introduce the triangular fuzzy numbers into this paper because the qualitative evaluation language was not precise to measure the production efficiency of supply chain. Finally, the model is used to evaluate the efficiency of the 10 supply chains and compared with the efficiency of the traditional DEA model to reflect the advantages of the non-radial directional distance function. Then we provide managers with suggestions on the optimization of the efficiency of the supply chain.

Keywords Directional distance function · Network DEA · Fuzzy DEA

1 Introduction

With the increasingly fierce market competition, competition among companies has gradually developed into competition among supply chains. The increasing of the efficiency of supply chains can reduce business costs and increase the economic efficiency of companions. In the past, the supply chain efficiency research mainly analyzed from the economic aspect. Although the operation efficiency of the supply chain has been improved and the company has achieved rapid development, environmental indicators have not been considered that the harm caused to the environment has been neglected. For example, in the production of a company, harmful pollutants such as sewage, waste, etc., as well as carbon dioxide emitted by the company during transportation, which cause great harm to the environment. In particular, as the "greenhouse effect" has become more and more serious in the environment, the climate gradually becomes bad. Protecting the environment has

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become the responsibility of the company's economic development. Therefore, the impact of environmental factors must be considered in the supply chain efficiency evaluation process.

Because the traditional DEA model does not make assumptions about the internal structure of the DMU. In contrast, the DEA model treats each DMU as a "black box", considering only the initial inputs and final outputs of the DMU. This view applies only to simple production processes. For the complex structure of the supply chain, this method ignores the links between the internal bodies of the supply chain. Therefore, it cannot accurately measure the efficiency of the supply chain. In order to effectively measure the efficiency of a complex network system, some scholars began to consider the internal structure of the DEA model. These models are called "Network DEA" in the DEA literature. They treat undesired output as input processing in the next stage, but in the supply chain, the supplier produces undesired output which are bound to affect the efficiency of the manufacturer stage. Therefore, this paper adopts a three-stage supply chain structure, and the undesired output in the adjacent stage is not considered as the input in the next stage.

The existing directional distance function only considers the exact data, but there may be some qualitative indicators in the input and output of the decision unit, which cannot be represented by specific data, such as the retailer's service level and customer satisfaction. The common treatment method in the literature is to introduce the concept of fuzzy mathematics, treat the qualitative indicators as fuzzy numbers and process them into interval numbers for analysis. Therefore, this paper will use non-radial directional distance function combined with fuzzy network DEA model to deal with the problem of supply chain efficiency evaluation with undesired output.

2 Literature Review

Supply chain management refers to the planning, implementation and control of all relevant business processes related to the transportation of goods and information transfer from the raw material stage to the end user [1, 2]. Stock and Boyer defined SCM as the management of a network of relationships between internal and interdependent organizations and business units [3]. These organizations and business units consist of raw material suppliers, manufacturing manufacturers, logistics providers, and related systems. The main objective of supply chain management is to maximize overall output while minimizing total costs, while producing and distributing goods at the right time and at the right place, bringing value to customers and other stakeholders [4, 5]. Performance measurement can be defined as the process of quantitatively or qualitatively evaluating the effectiveness and efficiency of a business process. Assessing performance can assess and control business progress, highlight achievements, improve understanding of key processes, identify potential issues, and provide insights about possible future improvement actions [6, 7].

Research methods for the supply chain efficiency evaluation, including the measurement conceptual framework [7], investigations to determine the main evaluation indicators [8], case study methods [9] and support quantitative model of the performance evaluation process [10]. For the efficiency evaluation of the supply chain considering environmental factors, scholars study the evaluation indicators and evaluation methods. Linton et al. assess the sustainability of the supply chain through a combination of environmental [11] and social factors. Genovese and others used the principal component analysis method to analyze the index system of environmental performance from the viewpoint of supply chain sustainability and removed redundant indicators [12].

The directional distance function is often used in energy efficiency and environmental performance evaluation. The directional distance function was originally proposed by Chambers et al. [13] and has been widely used for efficiency and productivity analysis in the presence of undesired outputs. Fare and Chung et al. used the directional distance function to consider the situation of undesired output and constructed new production techniques [14]. However, when there is a non-zero slack variable, the directional distance function with input and output using the same proportional change is no longer applicable because the efficiency of the decision unit may be higher [15]. In order to solve this problem, Fare and Grosskopf have developed a generalized form of inefficient directional distance function [16], which was further extended by Fukuyama et al. [17] and Barros et al. [18]. There are few research literatures that apply the non-radial directional distance function to the supply chain efficiency evaluation of the network structure. The theoretical research in this area has yet to be extended.

While the traditional DEA model has no assumptions about the internal structure of the DMU, only major inputs and final outputs are considered in the analysis. At the time of assessment, the internal activities of many decision-making units such as hospitals, factories, or production lines are also important. Then, Fare and Grosskopf developed a network DEA model with intermediate connection variables [19], linking via intermediate variables and performing product exchange within subunits. Toneab further extended the network DEA model that introduced a network DEA model based on weighted slack variables to evaluate the efficiency of the division [20].

Traditional DEA models require accurate measurements of inputs and outputs. However, the input and output data observed in real-world problems are sometimes inaccurate. Inaccurate values may result in inaccurate evaluation results. Bellman and Zadeh first proposed how to use fuzzy sets to model objective functions and constraints to process fuzzy data [21]. Kao and Liu convert uncertain data to interval values based on alpha cuts [22]. Similarly, Liu and Chuang introduce guaranteed areas by extending the α set in a fuzzy DEA environment [23], while Wang et al. rely on fuzzy algorithms to handle fuzzy inputs and outputs [24].

3 Proposed Model

3.1 Production Technology Possible Set

First, we introduce some necessary variables in the model, as shown in Table 1.

Considering that there are n supply chains, and each supply chain is divided into three stages: supplier, manufacturer, and retailer, as shown in Fig. 1. Each stage has an input vector $x \in R_m^+$, an output vector $y \in R_s^+$, and an intermediate connection

Table 1 Definition of variables

Variables	Definition
$j = 1, 2, \ldots, n$	The number of supply chains
$i = 1, 2, \ldots, m$	Type of input
$r = 1, 2, \ldots, s$	The type of desired output
$f = 1, 2, \ldots, F$	Types of undesirable outputs
$f = 1, 2, \ldots, F$	Intermediate connection variable Link type set
$k = 1, 2, 3$	The number of internal stages of the supply chain
A, B, C	Supplier stage, manufacturer stage, retailer stage
x_{ij}^k	The *j*th input of the *j*th supply chain in the *k* stage
y_{rj}^k	The *r*th desired output of the *j*th supply chain in the *k* stage
b_{fj}^k	The *j*th supply chain in the k-stage of the *f*th undesirable output
Z_{lj}^k	The *j*th supply chain generates the first intermediate connection product in *k* stage and consumed by adjacent *k* + 1 stages
$\vec{D}^{(A)}(x, y, Z, b; \vec{g})$	Directional distance function value
$\vec{D}^{(A)}_{non-radial}(x, y, Z, b; \vec{g})$	Non-radial directional distance function value
β	Proportion of change in each input and output in the directional distance function
$\beta_{x_{ij}}, \beta_{y_{rj}}, \beta_{Z_{lj}}, \beta_{b_{fj}}$	The coefficient of elasticity of each input, expected output, intermediate product, and unintended output in supply chain *j*, i.e. the largest proportion of each expansion or contraction
$\vec{g} = \left(g_x, g_y, g_Z, g_b\right)$	Input, expected output, intermediate product, and direction of undesired output
$g = \left(-x_{i0}, y_{r0}, Z_{l0}, -b_{f0}\right)$	Current evaluation of supply chain input, expected output, intermediate products, and direction of unintended output
$w_{x_j}, w_{y_j}, w_{Z_j}, w_{b_j}$	The weight of each input, expected output, intermediate product, and undesired output in supply chain *j*
$\lambda_{1j}, \lambda_{2j}, \lambda_{3j}$	Decision unit parameters for suppliers, manufacturers, and retailers
$\tilde{y}_{rj}^k$	The *r*th fuzzy expected output of the *j*th supply chain in the *k* stage (without intermediate products)
$E^{(A)}, E^{(B)}, E^{(C)}, E, CCR-E$	Supply chain *j* efficiency at the supplier, manufacturer, retailer stage, overall efficiency, and efficiency of the CCR model

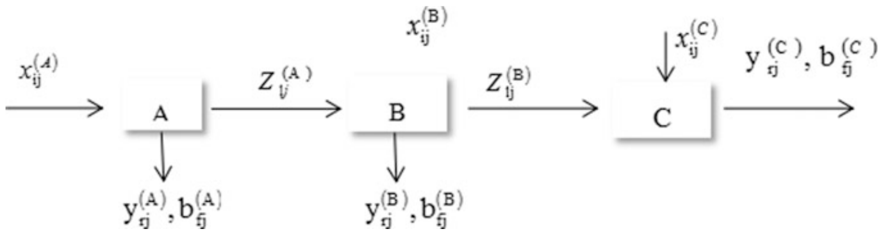

Fig. 1 Three-stage supply chain structure

product vector $Z \in R_L^+$. In actual production, in addition to good output, bad output will also be obtained.

Refer to Fare and Grosskopf [25] for dealing with "environmental technology" that contain undesired outputs. Since no loss function is defined, the loss function of the undesired output to the environment is not considered. The possible production set of supply chain j may be defined as:

$$T(x) = \begin{cases} (x, y, b) : \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{i0} \\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0} \\ \sum_{j=1}^{n} \lambda_j Z_{lj} \ge Z_{l0} \\ \sum_{j=1}^{n} \lambda_j b_{fj} = b_{f0} \\ \lambda_j \ge 0, \mathrm{j} = 1, \ldots, n, \\ \mathrm{i} = 1, \ldots, m, \mathrm{r} = 1, \ldots, s, \\ \mathrm{f} = 1, \ldots, F, l = 1, \ldots, L \end{cases} \tag{1}$$

3.2 Model Construction

In the directional distance function, the value of the distance function represents the distance from input or output to the optimal production frontier or the level of production inefficiency. In the supplier stage, the desired output does not include intermediate connection variables. The direction distance function is expressed as follows:

$$\vec{D}^{(A)}\left(x^{(A)}, y^{(A)}, b^{(A)}; \vec{g}^{(A)}\right) = \sup\left\{\left(\beta_{\mathrm{j}}^{(A)} : \left(x^{(A)}, y^{(A)}, b^{(A)}\right) + \beta_{\mathrm{j}}^{(A)} \cdot \vec{\mathrm{g}}^{(A)}\right) \in T(x)\right\} \tag{2}$$

In order to maximize corporate efficiency, we hope that the supply chain has as little investment as possible, as much output as possible, and undesired output will reduce the effective returns of the company. Therefore, we hope that the non-expected output will also be as small as possible. The direction vector is shown as follow:

$$\vec{g}^{(A)} = \left(g_{x^{(A)}}, g_{y^{(A)}}, g_{b^{(A)}}\right) = \left(-x^{(A)}, y^{(A)}, -b^{(A)}\right)$$

which defines the direction of input, expected output, and undesired output to the optimal production frontier, can be transformed into the following DEA type model solution:

$$\vec{D}^{(A)}\left(x^{(A)}, y^{(A)}, Z^{(A)}, b^{(A)}; \vec{g}^{(A)}\right) = \max \beta_j^{(A)}$$
$$s.t. \begin{cases} \sum_{j=1}^{n} \lambda_{1j} x_{ij}^{(A)} \le x_{i0}^{(A)}\left(1 - \beta_j^{(A)}\right) \\ \sum_{j=1}^{n} \lambda_{1j} y_{rj}^{(A)} \ge y_{r0}^{(A)}\left(1 + \beta_j^{(A)}\right) \\ \sum_{j=1}^{n} \lambda_{1j} Z_{lj}^{(A)} \ge Z_{l0}^{(A)} \\ \sum_{j=1}^{n} \lambda_{1j} b_{fj}^{(A)} = b_{j0}^{(A)}\left(1 - \beta_j^{(A)}\right) \\ \lambda_{1j} \ge 0, \beta_j^{(A)} \ge 0, \mathrm{j} = 1, \ldots, n \\ \mathrm{i} = 1, \ldots, m, \mathrm{r} = 1, \ldots, s, \\ \mathrm{f} = 1, \ldots, F, l = 1, \ldots, L \end{cases} \tag{3}$$

λ_{1j} is the decision variable, $\lambda_{1j} \ge 0$ means that the scale of production can be changed.

The definition of variables in the model is shown in Table 1. In the model (3), the lower 0 indicates the decision making unit being evaluated. The model (3) can still be regarded as radial because of the same adjustment rate of β. Since the non-radial direction distance function (non-radial DDF) can identify all the relaxation variables in the input and output, and flexibly satisfy the efficiency of different production situations, we will use it to evaluate the efficiency of the supply chain j. In the supplier stage, the non-radial direction distance function is expressed as:

$$\vec{D}^{(A)}\left(x^{(A)}, y^{(A)}, \mathrm{Z}^{(A)}, \mathrm{b}^{(A)}; \vec{g}^{(A)}\right) = \max\left[\left(w'\beta^{(A)} : \left(x^{(A)}, y^{(A)}, Z^{(A)}, b^{(A)}\right) + \vec{g}^{(A)} \cdot diag(\beta)\right) \in T(x)\right] \tag{4}$$

Then we have the following model:

$$\vec{D}^{(A)}_{non\text{-}radial}\left(x^{(A)}, y^{(A)}, \mathrm{Z}^{(A)}, \mathrm{b}^{(A)}; \vec{\mathrm{g}}^{(\mathrm{A})}\right) = \max\left(\sum_{i=1}^{m} \mathrm{w}_{x_{\mathrm{j}}^{(A)}} \beta_{x_{\mathrm{ij}}^{(A)}} + \sum_{r=1}^{s} \mathrm{w}_{y_{\mathrm{j}}^{(A)}} \beta_{y_{\mathrm{rj}}^{(A)}} + \sum_{f=1}^{F} \mathrm{w}_{b_{\mathrm{j}}^{(A)}} \beta_{b_{\mathrm{fj}}^{(A)}}\right)$$
$$s.t.\begin{cases} \sum_{j=1}^{\mathrm{n}} \lambda_{1j} x_{\mathrm{ij}}^{(A)} \le x_{\mathrm{i0}}^{(A)} + \beta_{x_{\mathrm{i0}}^{(A)}} \cdot g_{x_{\mathrm{i0}}^{(A)}} \\ \sum_{j=1}^{n} \lambda_{1j} y_{rj}^{(A)} \ge y_{r0}^{(A)} + \beta_{y_{r0}^{(A)}} \cdot g_{y_{r0}^{(A)}} \\ \sum_{j=1}^{n} \lambda_{1j} Z_{lj}^{(A)} \ge Z_{l0}^{(A)} \\ \sum_{j=1}^{n} \lambda_{1j} b_{fj}^{(A)} = b_{j0}^{(A)} + \beta_{b_{j0}^{(A)}} \cdot g_{b_{j0}^{(A)}} \\ \lambda_{1j} \ge 0, \mathrm{j} = 1, \ldots, n \\ \beta_{x_{\mathrm{ij}}^{(A)}}, \beta_{y_{\mathrm{rj}}^{(A)}}, \beta_{b_{f\mathrm{j}}^{(A)}} \ge 0 \\ \mathrm{i} = 1, \ldots, m, \mathrm{r} = 1, \ldots, s, \\ \mathrm{f} = 1, \ldots, F, l = 1, \ldots, L \end{cases} \tag{5}$$

In model (5), $\mathrm{w}^{\mathrm{T}} = \left(w_{x_{\mathrm{j}}}, w_{y_j}, w_{b_j}\right)^T$ represents the weights of inputs, expected outputs and undesirable outputs are expressed. The model (5) is a non-radial DEA model and a directional vector. If the direction vector is set as $\vec{\mathrm{g}}^{(\mathrm{A})} = \left(-x_{\mathrm{i0}}^{(\mathrm{A})}, y_{\mathrm{r0}}^{(\mathrm{A})}, -b_{\mathrm{f0}}^{(\mathrm{A})}\right)$, the model (5) is consistent with the model (3), but the model (3) allows the input and output to be adjusted at different proportions.

Therefore, in the supplier stage, the DEA model based on the non-radial directional distance function is:

$$\vec{D}^{(A)}_{non\text{-}radial}\left(x^{(A)}, y^{(A)}, \mathrm{Z}^{(A)}, \mathrm{b}^{(A)}; \vec{\mathrm{g}}^{(\mathrm{A})}\right)$$
$$= \max\left(\sum_{i=1}^{m} \mathrm{w}_{x_{\mathrm{j}}^{(A)}} \beta_{x_{\mathrm{ij}}^{(A)}} + \sum_{r=1}^{s} \mathrm{w}_{y_{\mathrm{j}}^{(A)}} \beta_{y_{\mathrm{rj}}^{(A)}} + \sum_{f=1}^{F} \mathrm{w}_{b_{\mathrm{j}}^{(A)}} \beta_{b_{\mathrm{fj}}^{(A)}}\right)$$
$$s.t.\begin{cases} \sum_{j=1}^{\mathrm{n}} \lambda_{1j} x_{\mathrm{ij}}^{(A)} \le x_{\mathrm{i0}}^{(A)}\left(1 - \beta_{x_{\mathrm{i0}}^{(A)}}\right) \\ \sum_{j=1}^{n} \lambda_{1j} y_{rj}^{(A)} \ge y_{r0}^{(A)}\left(1 + \beta_{y_{r0}^{(A)}}\right) \\ \sum_{j=1}^{n} \lambda_{1j} Z_{lj}^{(A)} \ge Z_{l0}^{(A)} \\ \sum_{j=1}^{n} \lambda_{1j} b_{fj}^{(A)} = b_{f0}^{(A)}\left(1 - \beta_{b_{f0}^{(A)}}\right) \\ \lambda_{1j} \ge 0, \mathrm{j} = 1, \ldots, n \\ \beta_{x_{i0}^{(A)}}, \beta_{\mathrm{y}_{r0}^{(A)}}, \beta_{b_{j0}^{(A)}} \ge 0 \\ \mathrm{i} = 1, \ldots, m, \mathrm{r} = 1, \ldots, s, \\ \mathrm{f} = 1, \ldots, F, l = 1, \ldots, L \end{cases} \quad (6)$$

In the definition of the technical efficiency of the directional distance function, the efficiency E is expressed as an exponent between 0 and 1, so the efficiency of the supply chain j at the supplier stage is:

$$\mathrm{E}^{(A)} = \left(1 + \overrightarrow{D}^{(A)}\left(x^{(A)}, y^{(A)}, \mathrm{b}^{(A)}; \overrightarrow{g^{(A)}}\right)\right)^{-1} \quad (7)$$

In the manufacturer stage, the intermediate connection products at the supplier stage also serve as inputs for the manufacturer stage. As input, we hope that the fewer the better. Similarly, the non-radial DEA model at the manufacturer stage can be obtained:

$$\vec{D}^{(B)}_{non\text{-}radial}\left(x^{(B)}, Z^{(A)}, y^{(B)}, \mathrm{b}^{(B)}; \vec{\mathrm{g}}^{(\mathrm{B})}\right)$$
$$= \max\left(\sum_{i=1}^{m} \mathrm{w}_{x_{\mathrm{j}}^{(B)}} \beta_{x_{\mathrm{ij}}^{(B)}} + \sum_{r=1}^{s} \mathrm{w}_{y_{\mathrm{j}}^{(B)}} \beta_{y_{\mathrm{rj}}^{(B)}} + \sum_{l=1}^{L} \mathrm{w}_{Z_{\mathrm{j}}^{(A)}} \beta_{Z_{\mathrm{lj}}^{(A)}} + \sum_{f=1}^{F} \mathrm{w}_{b_{\mathrm{j}}^{(B)}} \beta_{b_{\mathrm{fj}}^{(B)}}\right)$$
$$s.t.\begin{cases} \sum_{j=1}^{\mathrm{n}} \lambda_{2j} x_{\mathrm{ij}}^{(B)} \leq x_{\mathrm{i0}}^{(B)}\left(1-\beta_{x_{\mathrm{i0}}^{(B)}}\right) \\ \sum_{j=1}^{n} \lambda_{2j} Z_{lj}^{(A)} \leq Z_{l0}^{(A)}\left(1-\beta_{Z_{l0}^{(A)}}\right) \\ \sum_{j=1}^{n} \lambda_{1j} y_{rj}^{(B)} \geq y_{r0}^{(B)}\left(1+\beta_{y_{r0}^{(B)}}\right) \\ \sum_{j=1}^{n} \lambda_{2j} Z_{lj}^{(B)} \geq Z_{l0}^{(B)} \\ \sum_{j=1}^{n} \lambda_{2j} b_{fj}^{(B)} = b_{f0}^{(B)}\left(1-\beta_{b_{f0}^{(B)}}\right) \\ \lambda_{2j} \geq 0, \mathrm{j}=1,\ldots,n \\ \beta_{x_{i0}^{(B)}}, \beta_{Z_{l0}^{(A)}}, \beta_{\mathrm{y}_{r0}^{(B)}}, \beta_{b_{j0}^{(B)}} \geq 0 \\ \mathrm{i}=1,\ldots,m, \mathrm{r}=1,\ldots,s, \\ \mathrm{f}=1,\ldots,F, l=1,\ldots,L \end{cases} \tag{8}$$

The efficiency at the manufacturer stage is:

$$\mathrm{E}^{(B)} = \frac{1}{1+\vec{D}^{(B)}\left(x^{(B)}, Z^{(A)}, y^{(B)}, \mathrm{b}^{(B)}; \vec{\mathrm{g}}^{(B)}\right)} \tag{9}$$

In the three-stage supply chain structure study, the expected output of the retailer stage is the final output, and there is no longer any intermediate output. The intermediate connection products at the manufacturer stage also serve as inputs for the retailer stage. As inputs, we hope that the fewer the better.

$$\vec{D}^{(C)}_{non\text{-}radial}\left(x^{(C)}, Z^{(B)}, y^{(C)}, Z^{(C)}, \mathrm{b}^{(C)}; \vec{\mathrm{g}}^{(\mathrm{C})}\right)$$
$$= \max\left(\sum_{i=1}^{m} \mathrm{w}_{x_{\mathrm{j}}^{(C)}} \beta_{x_{\mathrm{ij}}^{(C)}} + \sum_{r=1}^{s} \mathrm{w}_{y_{\mathrm{j}}^{(C)}} \beta_{y_{\mathrm{rj}}^{(C)}} + \sum_{l=1}^{L} \mathrm{w}_{Z_{\mathrm{j}}^{(B)}} \beta_{Z_{\mathrm{lj}}^{(B)}} + \sum_{f=1}^{F} \mathrm{w}_{b_{\mathrm{j}}^{(C)}} \beta_{b_{\mathrm{fj}}^{(C)}}\right)$$
$$s.t.\begin{cases} \sum_{j=1}^{\mathrm{n}} \lambda_{3j} x_{\mathrm{ij}}^{(C)} \le x_{\mathrm{i0}}^{(C)}\left(1 - \beta_{x_{\mathrm{i0}}^{(C)}}\right) \\ \sum_{j=1}^{n} \lambda_{3j} y_{rj}^{(B)} \ge y_{r0}^{(B)}\left(1 + \beta_{y_{r0}^{(B)}}\right) \\ \sum_{j=1}^{n} \lambda_{3j} Z_{lj}^{(B)} \le Z_{l0}^{(B)}\left(1 - \beta_{Z_{l0}^{(B)}}\right) \\ \sum_{j=1}^{n} \lambda_{3j} b_{fj}^{(C)} = b_{f0}^{(C)}\left(1 - \beta_{b_{f0}^{(C)}}\right) \\ \lambda_{2j} \ge 0, \mathrm{j} = 1, \ldots, n \\ \beta_{x_{i0}^{(C)}}, \beta_{Z_{l0}^{(B)}}, \beta_{\mathrm{y}_{r0}^{(C)}}, \beta_{b_{j0}^{(C)}} \ge 0 \\ \mathrm{i} = 1, \ldots, m, \mathrm{r} = 1, \ldots, s, \\ \mathrm{f} = 1, \ldots, F, l = 1, \ldots, L \end{cases} \tag{10}$$

The efficiency at the retailer stage is:

$$\mathrm{E}^{(C)} = \frac{1}{1 + \vec{D}^{(C)}\left(x^{(C)}, Z^{(B)}, y^{(C)}, \mathrm{b}^{(C)}; \vec{\mathrm{g}}^{(C)}\right)} \tag{11}$$

In order to evaluate the system efficiency of the supply chain, the three stages of the supply chain should be considered as a whole. According to Fare's principle of establishing a network direction distance function [19], a non-radial network DEA model based on a directional distance function can be established:

$$\vec{D}\left[\left(x^{(A)}, y^{(A)}, \mathrm{b}^{(A)}\right), \left(x^{(B)}, y^{(B)}, Z^{(A)}, \mathrm{b}^{(B)}\right), \left(x^{(C)}, y^{(C)}, Z^{(B)}, \mathrm{b}^{(C)}\right); \vec{g}^{(A)}, \vec{g}^{(B)}, \vec{g}^{(C)}\right]$$
$$= \max\left(\sum_{k=1}^{3}\sum_{i=1}^{m} \mathrm{w}_{x_{\mathrm{j}}^{(k)}} \beta_{x_{\mathrm{ij}}^{(k)}} + \sum_{k=1}^{3}\sum_{r=1}^{s} \mathrm{w}_{y_{\mathrm{j}}^{(k)}} \beta_{y_{\mathrm{rj}}^{(k)}} + \sum_{k=1}^{2}\sum_{l=1}^{L} \mathrm{w}_{Z_{\mathrm{j}}^{(k)}} \beta_{Z_{\mathrm{lj}}^{(k)}} + \sum_{\mathrm{k}=1}^{3}\sum_{f=1}^{F} \mathrm{w}_{b_{\mathrm{j}}^{(k)}} \beta_{b_{\mathrm{fj}}^{(k)}}\right)$$

$$s.t.\begin{cases} \sum_{\mathrm{k}=1}^{3}\sum_{j=1}^{n} \lambda_{kj} y_{\mathrm{rj}}^{(k)} \geq \sum_{k=1}^{3}\left(y_{\mathrm{r0}}^{(k)}\left(1+\beta_{y_{\mathrm{r0}}^{(k)}}\right)\right) \\ \sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n} \lambda_{kj} x_{\mathrm{ij}}^{(k)} \leq \sum_{k=1}^{3}\left(x_{\mathrm{i0}}^{(k)}\left(1-\beta_{x_{\mathrm{i0}}^{(k)}}\right)\right) \\ \sum_{k=1}^{2}\sum_{j=1}^{n} \lambda_{1j} Z_{lj}^{(k)} \geq \sum_{k=1}^{2} Z_{l0}^{(k)} \\ \sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n} \lambda_{kj} \mathrm{b}_{f\mathrm{j}}^{(k)} = \sum_{k=1}^{3}\left(b_{f0}^{(k)}\left(1-\beta_{b_{f0}^{(k)}}\right)\right) \\ \sum_{\mathrm{j}=1}^{n} \lambda_{2j} Z_{\mathrm{lj}}^{(A)} \leq Z_{l0}^{(A)}\left(1-\beta_{Z_{l0}^{(A)}}\right) \\ \sum_{\mathrm{j}=1}^{n} \lambda_{3j} Z_{lj}^{(B)} \leq Z_{l0}^{(B)}\left(1-\beta_{Z_{l0}^{(B)}}\right) \\ \lambda_{\mathrm{kj}} \geq 0, k=1,2,3, j=1,\ldots,n \\ \beta_{x_{\mathrm{ij}}^{(k)}}, \beta_{Z_{l0}^{(A)}}, \beta_{Z_{l0}^{(B)}}, \beta_{y_{\mathrm{rj}}^{(k)}}, \beta_{b_{f\mathrm{j}}^{(k)}} \geq 0 \end{cases} \tag{12}$$

If $\beta^*_{x^{(A)}}, \beta^*_{\mathrm{Z}^{(A)}}, \beta^*_{\mathrm{y}^{(A)}}, \beta^*_{b^{(A)}}, \beta^*_{x^{(B)}}, \beta^*_{Z^{(B)}}, \beta^*_{y^{(B)}}, \beta^*_{b^{(B)}}, \beta^*_{x^{(C)}}, \beta^*_{y^{(C)}}, \beta^*_{b^{(C)}}$ is the optimal solution of the model (13), the system efficiency of the three-stage supply chain is defined as the geometric mean of the sum of the three-stage efficiency.

$$E_0 = \sqrt{E^{(A)} * E^{(B)} * E^{(C)}} \tag{13}$$

3.3 Non-radial Fuzzy Network DEA Model Based on Directional Distance Function

Currently, most DEA models use defined input and output data. However, in the actual evaluation, it is generally necessary to consider many non-deterministic input and output indicators, such as the evaluation of the supplier's reputation, it is difficult to use a definite value to represent, can only use {very good, good, average, poor, very poor} Equivalent to fuzzy language to describe. In the problems studied in this paper, the expected output contains individual fuzzy indicators. For example, the retailer's service level can only be expressed as {excellent, good, medium, poor}.

3.3.1 Triangular Fuzzy Number

In this paper, the triangular fuzzy number is applied to express the fuzzy information.

Suppose that the output of the *j*th supply chain is a fuzzy indicator $\tilde{y}_{rj}(r = 1, 2, \ldots s)$, That is, $\tilde{y}_j = \left(\tilde{y}_{1j}, \tilde{y}_{2j}, \ldots, \tilde{y}_{sj}\right)$ from $y_j = \left(y_{1j}, y_{2j}, \ldots, y_{sj}\right)$, where $\tilde{y}_{rj} = \left(\left(\tilde{y}_{rj}\right)^L, \left(\tilde{y}_{rj}\right)^U\right)$, therefore, the model (13) can be organized as:

$$\vec{D}\left[\left(x^{(A)}, \tilde{y}^{(A)}, b^{(A)}\right), \left(x^{(B)}, \tilde{y}^{(B)}, Z^{(A)}, b^{(B)}\right), \left(x^{(C)}, Z^{(B)}, \tilde{y}^{(C)}, b^{(C)}\right); \vec{g}^{(A)}, \vec{g}^{(B)}, \vec{g}^{(C)}\right]$$
$$= \max\left(\sum_{k=1}^{3}\sum_{i=1}^{m} w_{x_j^{(k)}}\beta_{x_{ij}^{(k)}} + \sum_{k=1}^{3}\sum_{r=1}^{s} w_{\tilde{y}_j^{(k)}}\beta_{\tilde{y}_{rj}^{(k)}} + \sum_{k=1}^{2}\sum_{l=1}^{L} w_{Z_j^{(k)}}\beta_{Z_{lj}^{(k)}} + \sum_{k=1}^{3}\sum_{f=1}^{F} w_{b_j^{(k)}}\beta_{b_{fj}^{(k)}}\right)$$
$$s.t.\begin{cases} \sum_{k=1}^{3}\sum_{j=1}^{n} \lambda_{kj}\tilde{y}_{rj}^{(k)} \geq \sum_{k=1}^{3}\left(\tilde{y}_{r0}^{(k)}\left(1 + \beta_{\tilde{y}_{r0}^{(k)}}\right)\right) \\ \sum_{k=1}^{3}\sum_{j=1}^{n} \lambda_{kj}x_{ij}^{(k)} \leq \sum_{k=1}^{3}\left(x_{i0}^{(k)}\left(1 - \beta_{x_{i0}^{(k)}}\right)\right) \\ \sum_{k=1}^{2}\sum_{j=1}^{n} \lambda_{kj}Z_{lj}^{(k)} \geq \sum_{k=1}^{2} Z_{l0}^{(k)} \\ \sum_{k=1}^{3}\sum_{j=1}^{n} \lambda_{kj}b_{fj}^{(k)} = \sum_{k=1}^{3}\left(b_{f0}^{(k)}\left(1 - \beta_{b_{f0}^{(k)}}\right)\right) \\ \sum_{j=1}^{n} \lambda_{2j}Z_j^{(A)} \leq Z^{(A)}\left(1 - \beta_{Z_{l0}^{(A)}}\right) \\ \sum_{j=1}^{n} \lambda_{3j}Z_j^{(B)} \leq Z^{(B)}\left(1 - \beta_{Z_{l0}^{(B)}}\right) \\ \lambda_{kj} \geq 0, k = 1, 2, 3, j = 1, \ldots, n \\ \beta_{x_{ij}^{(k)}}, \beta_{Z_{l0}^{(A)}}, \beta_{Z_{l0}^{(B)}}, \beta_{y_{rj}^{(k)}}, \beta_{b_{fj}^{(k)}} \geq 0 \end{cases} \quad (14)$$

The solution of the model (13) is a fuzzy number form, and the efficiency value of the supply chain j is also a fuzzy number form.

$$\tilde{E}_0 = \sqrt{\tilde{E}^{(A)} * \tilde{E}^{(B)} * \tilde{E}^{(C)}} \quad (15)$$

3.3.2 Solution of the Model

In this paper, the simplest triangular fuzzy number is used to express the evaluation language of qualitative indicators. Using the method of α cut set, the fuzzy numbers are converted into interval numbers, and then the model is solved (13). Because the input indicator is the interval number, the final efficiency value is also the interval number.

For a given level of confidence $\alpha \in [0, 1]$, there are $(\tilde{c})_\alpha = \{x|\mu_c(x) \geq \alpha\}$. Therefore, the fuzzy output index $\tilde{y}_{rj}$ can be transformed into α cuts at different levels:

$$\tilde{y}_{rj} \in \left[\left(y_{rj}\right)^L + \alpha\left(\left(y_{rj}\right)^M - \left(y_{rj}\right)^L\right), \left(y_{rj}\right)^U - \alpha\left(\left(y_{rj}\right)^U - \left(y_{rj}\right)^M\right) \right]$$

where α is the confidence given in advance, the closer α is to 1, the closer the indicator is to a certain value. The closer α is to 0, the stronger the ambiguity of the indicator is, and the larger the interval value of the cut set is. Substituting the minimum value $\tilde{y}_{rj}$ of the fuzzy output $\left(y_{rj}\right)^L + \alpha\left(\left(y_{rj}\right)^M - \left(y_{rj}\right)^L\right)$ into the model (14) yields and finds the maximum value $\left(\vec{D}\right)_\alpha^U$ of the distance function value of the supply chain j for the model (16).

$$\vec{D}\left[\left(x^{(A)},\tilde{y}^{(A)},\mathrm{b}^{(A)}\right),\left(x^{(B)},\tilde{y}^{(B)},Z^{(A)},\mathrm{b}^{(B)}\right),\left(x^{(C)},Z^{(B)},\tilde{y}^{(C)},\mathrm{b}^{(C)}\right);\vec{g}^{(A)},\vec{g}^{(B)},\vec{g}^{(C)}\right]$$
$$=\max\left(\sum_{k=1}^{3}\sum_{i=1}^{m}\mathrm{w}_{x_{\mathrm{j}}^{(k)}}\beta_{x_{\mathrm{ij}}^{(k)}}+\sum_{k=1}^{3}\sum_{r=1}^{s}\mathrm{w}_{\tilde{y}_{\mathrm{j}}^{(k)}}\beta_{\tilde{y}_{\mathrm{rj}}^{(k)}}+\sum_{k=1}^{2}\sum_{l=1}^{L}\mathrm{w}_{Z_{\mathrm{j}}^{(k)}}\beta_{Z_{\mathrm{lj}}^{(k)}}+\sum_{\mathrm{k}=1}^{3}\sum_{f=1}^{F}\mathrm{w}_{b_{\mathrm{j}}^{(k)}}\beta_{b_{\mathrm{fj}}^{(k)}}\right)$$
$$s.t.\begin{cases}\sum_{\mathrm{k}=1}^{3}\sum_{j=1}^{n}\lambda_{kj}\left(\left(\mathrm{y}_{\mathrm{rj}}\right)^{L}+\alpha\left(\left(\mathrm{y}_{\mathrm{rj}}\right)^{M}-\left(\mathrm{y}_{\mathrm{rj}}\right)^{L}\right)\right)\geq\sum_{k=1}^{3}\left(\left(\left(\mathrm{y}_{\mathrm{rj}}\right)^{L}+\alpha\left(\left(\mathrm{y}_{\mathrm{rj}}\right)^{M}-\left(\mathrm{y}_{\mathrm{rj}}\right)^{L}\right)\right)\left(1+\beta_{\tilde{y}_{\mathrm{r0}}^{(k)}}\right)\right)\\ \sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n}\lambda_{kj}x_{\mathrm{ij}}^{(k)}\leq\sum_{k=1}^{3}\left(x_{\mathrm{i0}}^{(k)}\left(1-\beta_{x_{\mathrm{i0}}^{(k)}}\right)\right)\\ \sum_{\mathrm{k}=1}^{2}\sum_{j=1}^{n}\lambda_{\mathrm{k}j}Z_{lj}^{(k)}\geq\sum_{\mathrm{k}=1}^{2}Z_{l0}^{(k)}\\ \sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n}\lambda_{kj}\mathrm{b}_{f\mathrm{j}}^{(k)}=\sum_{k=1}^{3}\left(b_{f0}^{(k)}\left(1-\beta_{b_{f0}^{(k)}}\right)\right)\\ \sum_{\mathrm{j}=1}^{n}\lambda_{2j}Z_{j}^{(A)}\leq\mathrm{Z}^{(\mathrm{A})}\left(1-\beta_{Z_{l0}^{(A)}}\right)\\ \sum_{\mathrm{j}=1}^{n}\lambda_{3j}Z_{j}^{(B)}\leq\mathrm{Z}^{(\mathrm{B})}\left(1-\beta_{Z_{l0}^{(B)}}\right)\\ \lambda_{\mathrm{kj}}\geq0,k=1,2,3,\,j=1,\ldots,n\\ \beta_{x_{\mathrm{ij}}^{(k)}},\beta_{Z_{l0}^{(A)}},\beta_{Z_{l0}^{(B)}},\beta_{y_{\mathrm{rj}}^{(k)}},\beta_{b_{f\mathrm{j}}^{(k)}}\geq0\end{cases}\tag{16}$$

Substituting the solution of model (16) into model (15) yields the minimum efficiency of supply chain j.

Substituting the minimum value $\tilde{\mathrm{y}}_{\mathrm{rj}}$ of the fuzzy output $\left(\mathrm{y}_{\mathrm{rj}}\right)^{U}-\alpha\left(\left(\mathrm{y}_{\mathrm{rj}}\right)^{U}-\left(\mathrm{y}_{\mathrm{rj}}\right)^{M}\right)$ into the model (14) yields and finds the minimum value $\left(\vec{D}\right)_{\alpha}^{L}$ of the distance function value of the supply chain j for the model (17).

$$\begin{aligned}
&\vec{D}\left[\left(x^{(A)},\tilde{y}^{(A)},\mathrm{b}^{(A)}\right),\left(x^{(B)},\tilde{y}^{(B)},Z^{(A)},\mathrm{b}^{(B)}\right),\left(x^{(C)},Z^{(B)},\tilde{y}^{(C)},\mathrm{b}^{(C)}\right);\vec{g}^{(A)},\vec{g}^{(B)},\vec{g}^{(C)}\right]\\
&=\max\left(\sum_{k=1}^{3}\sum_{i=1}^{m}\mathrm{w}_{x_{\mathrm{j}}^{(k)}}\beta_{x_{\mathrm{ij}}^{(k)}}+\sum_{k=1}^{3}\sum_{r=1}^{s}\mathrm{w}_{\tilde{y}_{\mathrm{j}}^{(k)}}\beta_{\tilde{y}_{\mathrm{rj}}^{(k)}}+\sum_{k=1}^{2}\sum_{l=1}^{L}\mathrm{w}_{Z_{\mathrm{j}}^{(k)}}\beta_{Z_{\mathrm{lj}}^{(k)}}+\sum_{k=1}^{3}\sum_{f=1}^{F}\mathrm{w}_{b_{\mathrm{j}}^{(k)}}\beta_{b_{\mathrm{fj}}^{(k)}}\right)\\
&s.t.\begin{cases}
\sum_{\mathrm{k}=1}^{3}\sum_{j=1}^{n}\lambda_{kj}\left(\left(\mathrm{y_{rj}}\right)^{U}-\alpha\left(\left(\mathrm{y_{rj}}\right)^{U}-\left(\mathrm{y_{rj}}\right)^{M}\right)\right)\geq\sum_{k=1}^{3}\left(\left(\left(\mathrm{y_{rj}}\right)^{U}-\alpha\left(\left(\mathrm{y_{rj}}\right)^{U}-\left(\mathrm{y_{rj}}\right)^{M}\right)\right)\left(1+\beta_{\tilde{y}_{\mathrm{r0}}^{(k)}}\right)\right)\\
\sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n}\lambda_{kj}x_{\mathrm{ij}}^{(k)}\leq\sum_{k=1}^{3}\left(x_{\mathrm{i0}}^{(k)}\left(1-\beta_{x_{\mathrm{i0}}^{(k)}}\right)\right)\\
\sum_{\mathrm{k}=1}^{2}\sum_{j=1}^{n}\lambda_{\mathrm{k}j}Z_{lj}^{(k)}\geq\sum_{\mathrm{k}=1}^{2}Z_{l0}^{(k)}\\
\sum_{\mathrm{k}=1}^{3}\sum_{\mathrm{j}=1}^{n}\lambda_{kj}\mathrm{b}_{f\mathrm{j}}^{(k)}=\sum_{k=1}^{3}\left(b_{f0}^{(k)}\left(1-\beta_{b_{f0}^{(k)}}\right)\right)\\
\sum_{\mathrm{j}=1}^{n}\lambda_{2j}Z_{j}^{(A)}\leq\mathrm{Z^{(A)}}\left(1-\beta_{Z_{l0}^{(A)}}\right)\\
\sum_{\mathrm{j}=1}^{n}\lambda_{3j}Z_{j}^{(B)}\leq\mathrm{Z^{(B)}}\left(1-\beta_{Z_{l0}^{(B)}}\right)\\
\lambda_{\mathrm{kj}}\geq0,k=1,2,3,j=1,\ldots,n\\
\beta_{x_{\mathrm{ij}}^{(k)}},\beta_{Z_{l0}^{(A)}},\beta_{Z_{l0}^{(B)}},\beta_{y_{\mathrm{rj}}^{(k)}},\beta_{b_{f\mathrm{j}}^{(k)}}\geq0
\end{cases}
\end{aligned}\tag{17}$$

Substituting the solution of model (17) into model (15) yields the maximum efficiency value of supply chain j.

4 Case Study

4.1 Evaluation Indicators

This article selected 10 agricultural product supply chains, the data is from the study of Wei [26]. Each supply chain consists of suppliers, manufacturers, and retailers. The fuzzy indicator selects the supplier's comprehensive ability (1–100), the manufacturer's brand reputation (1–100), and the retailer's service level. The input and output indicators at each stage are shown in Table 2.

4.2 Data Processing

For the fuzzification of the qualitative evaluation indicators in the output (supplier's comprehensive ability, manufacturer's credit level, retailer's service level), refer to

Table 2 Input and output indicators

Stage	Indicator	Variable	Definition
Supplier	Input	$x_{1j}^{(A)}$	Raw material purchase cost (ten thousand yuan)
		$x_{2j}^{(A)}$	Fixed assets repair costs (ten thousand yuan)
		$x_{3j}^{(A)}$	Transportation costs (ten thousand yuan)
	Output	$y_{1j}^{(1)}$	Profit (million yuan)
		$\tilde{y}_{2j}^{(1)}$	Comprehensive capacity of suppliers (1–100)
		$b_{1j}^{(A)}$	Environmental pollution emission control costs (ten thousand yuan)
	Link	$Z_{1j}^{(A)}$	Supplier-to-manufacturer production (tons)
Manufacturer		$x_{1j}^{(B)}$	Transportation costs (ten thousand yuan)
		$x_{2j}^{(B)}$	Manufacturing cost (ten thousand yuan)
	Output	$y_{1j}^{(B)}$	Profit (million yuan)
		$\tilde{y}_{2j}^{(B)}$	Brand reputation (1–100)
		$b_{1j}^{(B)}$	Fixed assets maintenance costs (ten thousand yuan)
		$b_{2j}^{(B)}$	Environmental pollution emission control costs (ten thousand yuan)
	Link	$Z_{1j}^{(2)}$	Producer-to-retailer production (tons)
Retailer	Input	$x_{1j}^{(3)}$	Transportation costs (ten thousand yuan)
		$x_{2j}^{(3)}$	Storage costs (ten thousand yuan)
	Output	$y_{1j}^{(3)}$	Profit (million yuan)
		$\tilde{y}_{2j}^{(3)}$	Service level (1–100)

the method of Li [27]. The fuzzy evaluation language chosen this time is {very good, good, average, poor, very poor}, with quantified values of {90, 70, 50, 30, 10}. Then there are the triangular fuzzy numbers of the evaluation language for each indicator {very good, good, average, poor, very poor} = {(80, 90, 100), (70, 80, 90), (50, 60, 70), (30, 40, 50), (10, 20, 30)}. The indicators obtained after processing are shown in Table 3.

4.3 Efficiency and Overall Efficiency Values at Each Stage and Their Contrastive Analysis

Because the three stages of the supply chain are connected by intermediate products, they are connected with each other. Every stage is equally important. Therefore, the weights of suppliers, manufacturers, and retailers are all 1/3. We

Table 3 Input and output indicators after processing

Stage	Variable	1	2	3	4	5	6	7	8	9	10
Supplier	$x_{1j}^{(A)}$	60,519	360	6942	288	332	11,527	9923	9,400,562	601	93,347
	$x_{2j}^{(A)}$	69,954	1488	458	34	4376	208	2372	9,376,759	211	5811
	$x_{3j}^{(A)}$	26,557	16,202	3182	2716	618	4196	1986	19,597,075	102	3698
	$y_{1j}^{(1)}$	93,358	5735	19,765	98,051	51,192	9479	1101	5,507,108	5169	31,907
	$y_{2j}^{(A)}$	(43,57)	(23,37)	(23,37)	(43,57)	(43,57)	(83,97)	(43,57)	(43,57)	(83,97)	(63,77)
	$b_{1j}^{(A)}$	4502	3502	544	200	234	56	90	1,700,000	110	654
	$Z_{1j}^{(A)}$	640	884	705	602	940	923	1024	789	1367	560
Manufacturer	$x_{1j}^{(B)}$	12,167	2106	14,621	1137	5176	5741	3517	9,516,385	778	2466
	$x_{2j}^{(B)}$	86,178	10,693	19,023	4081	4928	98,653	4852	12,399,828	1439	53,353
	$y_{1j}^{(B)}$	98,856	41,302	97,236	93,009	97,481	9077	1344	9,033,315	38,849	91,493
	$y_{2j}^{(B)}$	(63,77)	(43,57)	(23,37)	(23,37)	(43,57)	(63,77)	(83,97)	(23,37)	(83,97)	(23,37)
	$b_{1j}^{(B)}$	5201	149	2224	76	2986	20	457	9,599,123	53	1100
	$b_{2j}^{(B)}$	2967	1567	6452	58	234	546	190	6765	11	234
	$Z_{1j}^{(2)}$	780	1023	900	994	1200	1142	1450	890	1350	796
Retailer	$x_{1j}^{(3)}$	7299	2005	9132	1970	2426	5356	1808	218,250	653	4206
	$x_{2j}^{(3)}$	469	259	13,960	377	828	2183	500	567	47	102
	$y_{1j}^{(3)}$	94,528	51,302	30,323	30,487	93,488	13,884	23,543	4,869,185	28,147	93,860
	$y_{2j}^{(3)}$	(63,77)	(43,57)	(3,17)	(23,37)	(63,77)	(43,57)	(83,97)	(43,57)	(63,77)	(23,37)

believe that the inputs of each stage, expected output, unintended output, and intermediate connection variables are equally important, and the weights in the model are set as:

$$\left(w_{x^{(1)}}, w_{y^{(1)}}, w_{b^{(1)}}, w_{x^{(2)}}, w_{Z^{(1)}}, w_{y^{(2)}}, w_{b^{(2)}}, w_{x^{(2)}}, w_{Z^{(2)}}, w_{y^{(3)}}, w_{b^{(3)}}\right) = \left(\frac{1}{6}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}\right)$$

According to the data in Table 3, using the models (17), we can obtain the interval value of the distance function value of the supply chain. Using Lingo software, shows the interval values for efficiency obtained during the various stages of the relative efficiency interval and the overall efficiency interval of the supply chain are shown in Table 4.

Taking the CCR model as the traditional DEA model, the sum of all inputs in the three stages is regarded as the total input of the supply chain. The sum of the expected output is taken as the total output of the supply chain, and the unintended output is not taken into consideration. Fuzzy index takes the maximum interval (Non-Archimedean infinite parameter $\varepsilon = 10^{-6}$).

From the above table, we can see that from the overall efficiency point of view, in the measured overall efficiency range of the supply chain, the company 9 is fuzzy

Table 4 Comparison of non-radial fuzzy network model based on directional distance function and traditional DEA model efficiency

DMU		$E^{(A)}$	$E^{(B)}$	$E^{(C)}$	E	CCR-E
1	L	0.124	1.000	1.000	0.352	0.984
	U	0.138	1.000	1.000	0.371	
2	L	1.000	0.710	0.852	0.778	1.000
	U	1.000	0.712	0.863	0.784	
3	L	0.445	0.682	0.180	0.234	0.883
	U	0.487	0.682	0.375	0.353	
4	L	1.000	1.000	0.681	0.825	1.000
	U	1.000	1.000	0.732	0.856	
5	L	1.000	0.771	1.000	0.878	1.000
	U	1.000	0.798	1.000	0.893	
6	L	1.000	1.000	0.832	0.912	0.485
	U	1.000	1.000	0.844	0.919	
7	L	0.417	1.000	1.000	0.646	0.956
	U	0.419	1.000	1.000	0.647	
8	L	0.000	0.876	1.000	0.000	1.000
	U	0.000	1.000	1.000	0.000	
9	L	1.000	1.000	1.000	1.000	1.000
	U	1.000	1.000	1.000	1.000	
10	L	0.501	1.000	0.817	0.640	0.994
	U	0.508	1.000	0.862	0.662	

DEA effective at the $\alpha = 0.3$ level. The rest of the companies are invalid. Of the 10 selected supply chains, except for company 1, company 3, and company 8, the efficiency values of other companies are relatively high. The overall efficiency range of company 1 and company 3 is less than 0.4, and the efficiency of company 8 is the lowest. From the aspect of stage efficiency, it is obvious that the overall efficiency is 0 because the efficiency at the supplier stage is zero.

From a vertical perspective, in the supplier stage, companies 2, 4, 4, 5, 6, and 9 are fuzzy DEA and other companies are ineffective. Among them, company 1 and company 8 have the lowest efficiency interval, and company 8 has the lowest efficiency, which is 0. The maximum efficiency range of Company 3, Company 7 and Company 10 is around 0.4; at the manufacturer stage, Company 1, Company 4, Company 6, Company 7, Company 9 and Company 10 are effective, and the maximum efficiency of Company 8 is also Effective. The remaining companies, although ineffective, are all around 0.7; at the retailer stage, Company 1, Company 5, Company 7, Company 8 and Company 9 are effective, and the rest of the companions are invalid, except that the efficiency interval of Company 3 is less than 0.38. In addition, the minimum value of the efficiency range of other companies was greater than 0.68.

4.3.1 Comparison of the Efficiency of Non-radial Network DEA Model Based on Directional Distance Function and Two-Stage DEA Model Based on Directional Distance Function

In order to more clearly highlight the advantages of the model we have established, this section compares the two-stage DEA model efficiency values based on the directional distance function. In the two-stage DEA model based on the directional distance function, the supply chain is divided into two main bodies: supplier and manufacturer. The input and output change in the same proportion, and the undesired output from the supplier stage is regarded as the manufacturer. The input of the stage is calculated, and the fuzzy index is taken as the maximum value. The Lingo software is used to solve the problem. The obtained efficiency results are shown in Table 5.

As shown in the table, the efficiency of the company 5 with the efficiency closest to 1 needs to be improved at the supplier stage and effective at the manufacturer stage. However, in the non-radial network DEA model based on the directional distance function, the company 5 is effective at the supplier stage, and the efficiency at the manufacturer stage still needs to be improved. There is a clear feature in the radial two-stage DEA model efficiency results that in the manufacturer stage, 10 companies are valid, but in the non-radial network DEA model, companies 2, 3, and 5 still need to be improved. It shows that the efficiency of the non-radial network DEA model based on the directional distance function is more accurate than that of the radial two-stage DEA model, and the requirement for validity is higher.

The efficiency of most radial two-stage DEA models is higher than that of non-radial network DEA models. In the radial model, both input and output are in

Table 5 Comparison of efficiency

DMU	$E^{(A)}_{radial}$	$E^{(B)}_{radial}$	E_{radial}	$E_{non\text{-}radial}$
1	0.605	1.000	0.778	0.371
2	1.000	1.000	1.000	0.784
3	0.622	1.000	0.788	0.353
4	1.000	1.000	1.000	0.856
5	1.000	1.000	0.995	0.893
6	1.000	1.000	1.000	0.919
7	0.860	1.000	0.927	0.647
8	0.504	1.000	0.710	0.000
9	1.000	1.000	1.000	1.000
10	0.605	1.000	0.778	0.662

the same direction and are scaled down or expanded in a proportion, however, in real life, the output is not necessary expand in line with the reduction of the input while the undesired output is considered as adjacent. The next stage of investment will also affect the efficiency of the next stage, which proves the flaw of the radial model. The non-radial network DEA model based on the directional distance function eliminates the estimation error of the radial measurement model, makes the measurement result is more accurate, and more evaluation information can be reflected from the perspective of input and expected output and unintended output.

The non-radial network DEA model based on the directional distance function combines the advantages of the non-radial directional distance function and the network DEA method. It not only improves the accuracy of the efficiency, but also provides evaluation information from various aspects, opens the "black box" structure of the supply chain, and analyzes the reasons for inefficiency internally.

4.3.2 Analysis Based on Environmental Factors

This section analyzes the impact of environmental factors on the supply chain efficiency evaluation. The environmental indicators are reflected in the undesired output of this paper as environmental pollution emission control costs. We will remove the environmental indicators and then perform the efficiency measurement. The fuzzy indicators take the maximum value. Table 6 shows the efficiency value before removing the indicator is denoted by E, and the efficiency after removal is denoted by e. Because the retailer stage of this article does not consider environmental governance costs, the efficiency value does not change.

From the comparative analysis of Table 6, we can see that from the perspective of the overall efficiency of the company, the overall efficiency value of company 1, company 3, company 7 and company 10 after removing environmental factors is greater than the overall efficiency before removing environmental factors. E is low, which shows that these companies pay attention to the protection of the environment. The overall efficiency value of the company 7 has fallen the most, from the

Table 6 Efficiency after removing environmental factors

DMU	Staged efficiency					Overall efficiency	
	$E^{(A)}$	e	$E^{(B)}$	e	$E^{(C)}$	E	e
1	0.138	0.031	1.000	1.000	1.000	0.371	0.176
2	1.000	1.000	0.712	0.756	0.863	0.784	0.808
3	0.487	0.340	0.682	0.722	0.180	0.353	0.210
4	1.000	1.000	1.000	1.000	0.732	0.856	0.856
5	1.000	1.000	0.798	0.805	1.000	0.893	0.897
6	1.000	1.000	1.000	1.000	0.844	0.919	0.919
7	0.419	0.058	0.147	1.000	1.000	0.647	0.241
8	0.000	0.000	1.000	1.000	1.000	0.000	0.000
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	0.508	0.133	1.000	1.000	0.862	0.662	0.339

original 0.647 to 0.261. This shows that the company 7 pays great attention to environmental governance during the production and transportation of the entire supply chain, minimizes the damage to the environment, and minimizes Environmental pollutant emissions. The overall efficiency E of company 2 and 5 after removing environmental factors is higher than the overall efficiency E before removing environmental factors. This shows that the two companies do not pay attention to environmental governance during the entire supply chain process, and the environmental pollution is very serious. The overall efficiency value of the company 9 has not changed, which shows that the environment pollution of the company 9 in the supply chain process is not very serious, there is pollution, but the proportion of governance costs is not large.

From the aspect of stage efficiency, in the supplier stage, the overall efficiency value e of the 10 companies after the removal of environmental factors is lower than the overall efficiency E before the removal of environmental factors, indicating that 10 companies pay attention to environmental governance in the supplier stage and reduce pollution emissions. In the manufacturer stage, the efficiency of the 10 companies has basically increased, indicating that the treatment costs of the environmental pollution emissions from the 10 companies mainly occur in the manufacturing process, and the environmental protection should be emphasized in the manufacturer stage.

5 Summary

In the current market, business competition is fierce. Effective management and evaluation of the supply chain is the main channel for gaining competitive advantage. In this paper, we propose a new network DEA model. There are three subsystems in each supply chain: supplier systems, manufacturer systems, and retailer systems. In the proposed three-stage DEA model, the first stage is the supplier's procurement of raw materials, the second stage is the manufacturer's manufacturing stage, and the third stage is the retailer's sales stage. The fuzzy network DEA model established in this paper is based on the non-radial directional distance function and the non-radial model used later facilitates the handling of inconstant changes in input and output. Inputs, desired outputs, unintended outputs, and intermediate products can change in their respective proportions, resulting in inputs, expected outputs, and unexpected outputs. Outlet and intermediate products reach the production frontier at the same time.

During the evaluation process, some qualitative evaluation indicators cannot be described with precise numerical values. The traditional DEA model is no longer applicable. We introduce the concept of fuzzy numbers, after fuzzifying the qualitative evaluation language, convert it into interval numbers, and then use the α cut set to solve the non-radial fuzzy network DEA model based on the directional distance function to calculate the efficiency of each supply chain. The model proposed by us can analyze the distance between the input and output of each main body of the supply chain and the best production frontier. It can not only measure the efficiency of the supply chain in stages, but also measure the overall efficiency of the supply chain, thus analyzing the impact of the supply chain. The specific stage of overall efficiency, starting from the weak links, can analyze the specific factors that cause low efficiency and make recommendations on the adjustment ratio of input and output.

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Relationship Between β-Efficient Solution and Minimum Risk Efficient Solution for Uncertain Multi-objective Problem

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Abstract The minimum risk efficient solution for uncertain multi-objective problem is difficult to obtain due to the constraint of uncertain variables, while β-efficient solution provide a possible alternative. This paper studies the relationship between the minimum risk efficient solution and β-efficient solution, the internal connections and transformation conditions are explored, and theoretical proof is presented, which provide theoretical basis for the practical appliance of minimum risk model in uncertain environment.

Keywords Uncertain programming · Uncertainty theory · Multi-objective programming · β-efficient solution · Minimum risk efficient solution

1 Introduction

In recent years, the multi-objective programming (MOP) problem is receiving increasing attention in the field of optimization theory. Primarily, the most researches focus on deterministic multi-objective programming [1–4], and extensive researches have been made including optimality conditions, duality, non-smooth nonlinear multi-objective programming [5], multi-objective linear fractional programming [6–8], convex multi-objective programing [9], etc. The appliance of MOP achieved great successes in various practical fields, such as automated schematic map drawing [10], water distribution [11], portfolio selection [12], production scheduling [13]. However, real world scenarios are often indeterministic, and some decisions have to be made when included elements are uncertain. Later, the prob-

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ability theory is widely applied to MOP due to the improvement of probability theory, researches concerning stochastic multiple objective programming is gaining increasing attention, especially the efficient solution theories and the corresponding solution approaches.

However, the probability theory is not always suitable for application in practice, especially when the numbers of samples are limited or the available information is not complete. In the mentioned scenarios, no reliable probability distribution can be determined. Therefore, belief degree evaluated by human experts is the only viable method to provide estimation solution. The indeterminacy introduced in the process of human evaluation is called uncertainty. According to surveys [14], it was found that domain experts tend to overestimate unlikely events, and the belief degrees evaluated by human usually have larger variance. Liu [15] found both probability theory and fuzzy set theory are inapplicable to this kind of uncertainty due to the deduced counterintuitive results. To solve this kind of uncertainty, Liu [16] founded the uncertainty theory, which provides a novel perspective to handle subjective imprecision instead of objective randomness.

The minimum risk model is applicable to minimum risk programming problem, which is valuable in practice. However, it can be impossible to obtain mathematical solution for minimum risk efficient solution due to the uncertain variables and inequalities in the model, while the $\boldsymbol{\beta}$-efficient solution is applicable to various uncertain environment because they can be conveniently transformed into equivalent expectation model [17]. To obtain minimum risk efficient solution by a viable approach for uncertain multi-objective problem, the relationship between $\boldsymbol{\beta}$-efficient solution and minimum risk solution for uncertain multi-objective problem is investigated, the internal connections and transformation conditions are explored and proved, which lays foundation for practical appliance in uncertain environment for the minimum risk models.

Remaining contents of this paper is organized as follows: in Sect. 2, some useful definitions and properties about uncertain theory with application to uncertain MOP problem are introduced; in Sect. 3, the $\boldsymbol{\beta}$-efficient solution and minimum risk efficient solution for uncertain multi-objective problem are defined, and their relationship is subsequently explored and proved; finally, this paper is summarized in Sect. 4, and open opinions for future researches are provided.

2 Preliminaries

Some definitions and theorems such as uncertain measure, uncertainty space, uncertain variable, and uncertain distribution are presented in this section.

Definition 1 Let Γ be a nonempty set, and $\mathcal{L}$ a σ-algebra over Γ. Each element Λ in $\mathcal{L}$ is called an event. The set function $\mathcal{M}$ from $\mathcal{L}$ to $[0, 1]$ is uncertain measure if it satisfies the following axioms [16]:

Axiom 1 $\mathcal{M}\{\Gamma\} = 1$ for the universal set Γ.

Axiom 2 $\mathcal{M}\{\Lambda\} + \mathcal{M}\{\Lambda^c\} = 1$ for any event Λ.

Axiom 3 For every countable sequence of events $\Lambda_1, \Lambda_2, \ldots$, we have

$$\mathcal{M}\left\{\bigcup_{i=1}^{\infty} \Lambda_i\right\} \le \sum_{i=1}^{\infty} \mathcal{M}\{\Lambda_i\}.$$

The triplet $(\Gamma, \mathcal{L}, \mathcal{M})$ is called an uncertainty space. Furthermore, defined a product uncertain measure by the fourth axiom [16]:

Axiom 4 Let $(\Gamma_k, \mathcal{L}_k, \mathcal{M}_k)$ be uncertainty space for $k = 1, 2, \ldots$. The product uncertain measure M is an uncertain measure satisfying

$$\mathcal{M}\left\{\prod_{k=1}^{\infty} \Lambda_k\right\} = \wedge_{k=1}^{\infty} \mathcal{M}\{\Lambda_k\}.$$

where Λ_k are arbitrarily chosen events from $(\Gamma_k, \mathcal{L}_k, \mathcal{M}_k)$ for $k = 1, 2, \ldots$, respectively.

Definition 2 (Liu [16]) An uncertain variable is a function ξ from an uncertainty space $(\Gamma, \mathcal{L}, \mathcal{M})$ to the set of real numbers such that $\{\xi \in B\}$ is an event for any Borel set B of real numbers.

Definition 3 (Liu [16]) The uncertainty distribution Φ of an uncertain variable ξ is defined by $\Phi(x) = \mathcal{M}(\xi < x)$ for any real number x.

Definition 4 (Liu [18]) The uncertain variables $\xi_1, \xi_2, \ldots, \xi_n$ are said to be independent if

$$\mathcal{M}\left\{\bigcap_{i=1}^{n} (\xi_i \in B_i)\right\} = \wedge_{i=1}^{n} \mathcal{M}\{\xi_i \in B_i\}$$

For any Borel sets $B_1, B_2, \ldots, B_n$ of real numbers.

Theorem 1 (Liu [19]) *Let ξ be an uncertain variable with regular uncertainty distribution Φ. Then*

$$E[\xi] = \int_0^1 \Phi^{-1}(\alpha) d\alpha$$

3 Investigation of Relationship Between $\boldsymbol{\beta}$-Efficient Solution and Minimum Risk Efficient Solution

Based on the purpose to investigate the relationship between -efficient solution and minimum risk efficient solution, we firstly provide definitions necessary for theoretical proof. Subsequently, the investigated relationship is presented and proved, the relationship is summarized and expressed in Theorem 2.

3.1 β-Efficient Solution and Minimum Risk Solution for Uncertain Multi-objective Problem

Definition 1 (*efficient solution with minimum risk under risk level* $\boldsymbol{\mu}$) $\boldsymbol{x}^* \in D$ is considered as an efficient solution under risk level $\mu_1, \mu_2, \ldots, \mu_p$, if it is a Pareto efficient solution of the following problem:

$$\max_{\boldsymbol{x}\in D}(\mathcal{M}\{f_1(\boldsymbol{x},\xi_1)\le\mu_1\},\mathcal{M}\{f_2(\boldsymbol{x},\xi_2)\le\mu_2\},\ldots,\mathcal{M}\{f_p(\boldsymbol{x},\xi_p)\le\mu_p\})\quad (MR(\boldsymbol{\mu})) \tag{1}$$

where $\boldsymbol{\mu}=(\mu_1,\mu_2,\ldots,\mu_p)\in R^p$ is a predefined risk level vector. The efficient solution set under risk level $\mu_1, \mu_2, \ldots, \mu_p$ is denoted as $E_{MR(\boldsymbol{\mu})}$.

Definition 2 (*efficient solution based on belief degree* $\boldsymbol{\beta}$) $\boldsymbol{x}^* \in D$ is considered as an efficient solution of an uncertain multi-objective problem based on belief degree $\boldsymbol{\beta}$, if $\exists\boldsymbol{\mu}\in R^s$, $(\boldsymbol{x}^T, \boldsymbol{\mu}^T)^T$ is an efficient solution of the following problem:

$$\begin{cases} \min\limits_{\boldsymbol{x},\boldsymbol{\mu}} & (\mu_1,\ldots,\mu_s) \\ \text{s.t.} & \mathcal{M}\{f_i(\boldsymbol{x},\xi_i)\leqq\mu_i\}=\beta_i, i=1,2,\ldots,s \\ & \boldsymbol{x}\in E \end{cases}\qquad (K(\boldsymbol{\beta})) \tag{2}$$

where $\boldsymbol{\beta}=(\beta_1,\ldots,\beta_s)^{\mathrm{T}}\in R^s$ denotes the belief degree vector, and the $\boldsymbol{\beta}$-efficient solution set is denoted by $E_{K(\boldsymbol{\beta})}$.

Remark $\boldsymbol{\beta}$-efficient solution and minimum risk efficient solution requires vector level indexes $\boldsymbol{\mu}$ and $\boldsymbol{\beta}$, which makes it necessary for decision makers to obtain rich practical experience. Different risk level vector and belief degree vector would generate different efficient solution set, i.e.:

$$\begin{aligned} &\boldsymbol{\mu}\ne\boldsymbol{\mu}'\Rightarrow E_{\boldsymbol{\mu}}\ne E_{\boldsymbol{\mu}'},\\ &\boldsymbol{\beta}\ne\boldsymbol{\beta}'\Rightarrow E_{\boldsymbol{\beta}}\ne E_{\boldsymbol{\beta}'}. \end{aligned} \tag{3}$$

3.2 Relationship of β-Efficient Solution and Minimum Risk Efficient Solution

Theorem 2 *assume uncertain variable* $f_i(\boldsymbol{x}, \xi_i)$ *is continuous and strictly monotonous increasing, and then* $\tilde{\boldsymbol{x}}$ *is an efficient solution of problem* $MR(\boldsymbol{\mu})$ *if an only if* $(\tilde{\boldsymbol{x}}^T, \tilde{\mu}^T)^T$ *is an efficient solution of problem* $K(\boldsymbol{\beta})$*, where* $\boldsymbol{\mu}$ *and* $\boldsymbol{\beta}$ *satisfy the following constraint:*

$$\mathcal{M}\{f_i(\boldsymbol{x}, \xi_i) \leq \mu_i\} = \beta_i, i = 1, 2, \ldots s \tag{4}$$

Proof Set $\tilde{\boldsymbol{x}}$ as an efficient solution of problem $MR(\boldsymbol{\mu})$, i.e. $\beta_i = \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}, \xi_i) \leq \mu_i\}, j = 1, 2, \ldots, s$, we can easily know that $(\tilde{\boldsymbol{x}}^T, \tilde{\boldsymbol{\mu}}^T)^T$ is a feasible solution of the following $K(\boldsymbol{\beta})$ problem:

$$\begin{cases} \min\limits_{\boldsymbol{x},\boldsymbol{\mu}} & (\mu_1, \ldots, \mu_s) \\ \text{s.t.} & \mathcal{M}\{f_i(\boldsymbol{x}, \xi_i) \leqq \mu_i\} = \beta_i, i = 1, 2, \ldots, s \\ & \boldsymbol{x} \in E \end{cases} \quad (K(\boldsymbol{\beta})) \tag{5}$$

Proof by contradiction: assume that $(\tilde{\boldsymbol{x}}^T, \tilde{\boldsymbol{\mu}}^T)^T$ is not an efficient solution of $K(\boldsymbol{\beta})$, thus $\exists$ $(\tilde{\boldsymbol{x}}'^{\mathrm{T}}, \tilde{\boldsymbol{\mu}}'^{\mathrm{T}})^{\mathrm{T}}$ where

$$\tilde{\boldsymbol{x}}' \in \boldsymbol{E}, \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i'\} = \beta_i, \tag{6}$$

that satisfy:

$$\tilde{\mu}_i' \leqq \tilde{\mu}_i, \tilde{\mu}_{i_0}' < \tilde{\mu}_{i_0}, i, i_0 \in \{1, 2, \ldots, s\} \tag{7}$$

Due to the fact that $f_i(\boldsymbol{x}, \xi_i)$ is continuous and strictly monotonous, we can obtain:

$$\mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i'\} \leqq \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i\}, \tag{8}$$

and $\exists i_0 \in \{1, 2, \ldots, s\}$,

$$\mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}', \xi_{i0}) \leqq \tilde{\mu}_i'\} < \mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}', \xi_{i0}) \leqq \tilde{\mu}_{i_0}\}. \tag{9}$$

therefore,

$$\mathcal{M}\{f_i(\tilde{\boldsymbol{x}}, \xi_j) \leqq \tilde{\mu}_i\} = \beta_i = \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i'\} \leqq \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i\}, \tag{10}$$

and $\exists i_0 \in \{1, 2, \ldots, s\}$ that satisfy

$$\mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}, \xi_i) \leqq \tilde{\mu}_i\} = \beta_{i0} = \mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_i'\} < \mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}_{i_0}\}, \tag{11}$$

It shows that $\tilde{\boldsymbol{x}}$ is not the efficient solution of $MR(\boldsymbol{\mu})$, which demonstrates the contradiction. Thus $(\tilde{\boldsymbol{x}}^T, \tilde{\boldsymbol{\mu}}^T)^T$ is the efficient solution of $\mathrm{K}(\boldsymbol{\beta})$.

Conversely, if $(\tilde{\mathbf{x}}^T, \tilde{\boldsymbol{\mu}}^T)^T$ is an efficient solution of $K(\boldsymbol{\beta})$, it is easy to obtain that $\tilde{\boldsymbol{x}} \in \boldsymbol{E}$.

Proof by contradiction: assume that $\tilde{\boldsymbol{x}}$ is not an efficient solution of $MR(\boldsymbol{\mu})$, according to the definition of efficient solution, we can deduce $\exists \tilde{\boldsymbol{x}}' \in D$ that satisfies:

$$\beta_i = \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}, \xi_i) \leqq \tilde{\mu}_i\} \leqq \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \boldsymbol{\xi}_i) \leqq \tilde{\mu}_i\}, \tag{12}$$

and $\exists i_0 \in \{1, 2, \ldots, s\}$,

$$\beta_{i_0} = \mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}, \xi_{i_0}) \leqq \tilde{\mu}_{i_0}\} < \mathcal{M}\{f_{i_0}(\tilde{\boldsymbol{x}}', \xi_{i_0}) \leqq \tilde{\mu}_{i_0}\}. \tag{13}$$

Due to the fact that $f_i(\boldsymbol{x}, \xi_i)$ is continuous and strictly monotonous, we can obtain that $\exists \tilde{\mu}'_1, \tilde{\mu}'_2, \ldots, \tilde{\mu}'_s, \tilde{\mu}'_i \leq \tilde{\mu}_i$, and at least $\exists 1 \leqq i_0 \leqq s, \tilde{\mu}'_{i_0} < \tilde{\mu}_{i_0}$ that satisfy

$$\beta_i = \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}, \xi_i) \leqq \tilde{\mu}_i\} = \mathcal{M}\{f_i(\tilde{\boldsymbol{x}}', \xi_i) \leqq \tilde{\mu}'_i\}. \tag{14}$$

and $\exists i_0 \in \{1, 2, \ldots, s\}$

$$\beta_{i0} = \mathcal{M}\{f_{i0}(\tilde{\boldsymbol{x}}, \xi_{i0}) \leqq \tilde{\mu}_{i0}\} = \mathcal{M}\{f_{i0}(\tilde{\boldsymbol{x}}', \xi_{i0}) \leqq \tilde{\mu}'_{i0}\}. \tag{15}$$

However, it is contradictory to the assumption that $(\tilde{\boldsymbol{x}}^T, \tilde{\boldsymbol{\mu}}^T)^T$ is set to be an efficient solution of $K(\boldsymbol{\beta})$. Thus $\tilde{\boldsymbol{x}}$ is the efficient solution of $MR(\boldsymbol{\mu})$.

After transforming the minimum risk efficient solution into the corresponding $\boldsymbol{\beta}$-efficient solution, the initial problem can be mathematically solvable because the $\boldsymbol{\beta}$-efficient solution can be solved by the corresponding expectation model.

4 Conclusion

This paper investigates the relationship between $\boldsymbol{\beta}$-efficient solution and minimum risk efficient solution for uncertain multi-objective problem, which provides a viable approach to solve minimum risk efficient solution by a transformation method with experts' belief information. Future work would focus on the possibility to apply the proposed approach into various practical scenarios.

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An Advanced Simulation and Optimization for Railway Transportation of Passengers: Crowdfunding Train

Jiawei Gui and Qunqi Wu

Abstract Railway transportation is an important mechanical infrastructure around the globe and is becoming more and more popular with citizens because of reliability and punctuality. However, it is practically challenging and theoretically important to increase efficiency of railway operations and the utilization efficiency of the existing infrastructures. Crowdfunding Train is the train based on crowdfunding method, which caters to the real demand of passengers. Xi'an Railway Bureau drove two crowdfunding trains between Xi'an and Yulin for the first attempt in China from Oct. 7th to Oct. 8th in 2017. This article describes this event and a series of mathematical models is built for the economic simulations of crowdfunding trains, especially about incomes, costs and profits, and then takes the crowdfunding train K8188 and K8187 in China as a case analysis to utilize models.

Keywords Passenger · Crowdfunding · Train · Railway · Transportation

Notations

A	The ticket rank called Hard seat
B	The ticket rank called Hard sleeper
C	The ticket rank called Soft berth
C_Q	The total costs, unit: yuan
C_Q^F	The total fixed costs, unit: yuan
C_Q^V	The total variable costs, unit: yuan
C_R^{VC}	The variable cost by carriage in the rank R, unit: yuan per carriage
C_R^{VT}	The variable cost by quantity in the rank R, unit: yuan per ticket

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$f_i(\cdots)$	The function for the individual decisions of passengers
FB	The feed backs for passengers who buy tickets of the crowdfunding train, unit: yuan
i	The through variable with no meaning
I_Q	The total income of tickets, unit: yuan
Int(number)	The function to calculate the maximum integer below the number
L_R	The ticket quota of train carriages in the rank R, unit: ticket(s) per carriage
$maxQ_R^C$	The maximum train carriage quantity in the rank R, unit: carriage(s)
$maxQ_R^T$	The maximum sold ticket quantity in the rank R, unit: ticket(s)
Mod (*number*, *divisor*)	The function to calculate the remainder of the number after it is divided by the divisor, e.g. *Mod*(3,2) = 1, *Mod*(–3,2) = 1
n_P	The number of passengers who may participate in the crowdfunding train x
n_R	The number of ticket ranks
P	The total profit of the crowdfunding train, unit: yuan
P_R	The price of the ticket in the rank R, unit: yuan per ticket
Q_R^C	The quantity of train carriages in the rank R, unit: carriage (s)
Q_R^T	The quantity of sold tickets in the rank R, unit: ticket(s)
R	The rank of tickets that passengers could participate in
s	The identification of railway stations
t_s^{AE}	The arrival point-in-time of the train at the Railway Station s
t_s^{DC}	The deadline point-in-time of checking tickets at the Railway Station s
t_s^{DE}	The departure point-in-time of the train at the Railway Station s
t_x^B	The beginning point-in-time of the crowdfunding train x
t_x^C	The current point-in-time of the crowdfunding train x
t_x^D	The deadline point-in-time of the crowdfunding train x
t_x^F	The first point-in-time of the crowdfunding train x when the target achieved
W_i	The individual decisions of passengers whether to purchasing the ticket in the rank R or not, which equals to 1 when yes and equals to 0 for when not
x	The code of the crowdfunding train
ΔP	The changes of the total profit of the crowdfunding train, unit: yuan

ΔQ_R^C	The changes of the quantity of train carriages in the rank R, unit: carriage(s)
ΔQ_R^T	The changes of the quantity of sold tickets in the rank R, unit: ticket(s).

1 Introduction

Railway transportation is an important mechanical infrastructure around the globe. The total railway mileage all over the world was more than 1 million kilometers by 2016, while the European Union, the United States of America, China and Russia took the lead positions. Train transportation, especially high-speed rail, is becoming more and more popular with citizens in China because of its reliability and punctuality, compared with motor vehicles and aircrafts.

However, it is practically challenging and theoretically important to increase efficiency of railway operations and the utilization efficiency of the existing infrastructures. For instance, many passengers fail to buy tickets on holidays and festivals in China, such as the Spring Festival and the National Day, owing to supply shortages, although railway bureaux have already optimized schedules. For another example, railway bureaux sometimes fail to sell all the train tickets as arranged because of supply surplus. As for one of the reasons, it is not accurate enough to forecast train and pedestrian traffic flows by modelling and simulation only, because some of them change periodically while the others change aperiodically.

To solve this problem, it is vital for railway bureaux to ensure that train supply meets the real demand of passengers. Crowdfunding Train can be regarded as an option to practice.

1.1 Crowdfunding Method Research

To solve this problem, it is vital for railway bureaux to ensure that train supply meets the real demand of passengers. Crowdfunding Train can be regarded as an option to practice.

Crowdfunding is a novel method and has become a valuable alternative source of funding in recent years [1, 2]. The concept of crowdfunding evolves from crowdsourcing, which was simply defined by Howe (2006) as "the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined and generally large network of people in the form of an open call" (see the websites "https://www.wired.com/2006/06/crowds/" and "http://crowdsourcing.typepad.com/cs/2006/06/crowdsourcing_a.html").

Crowdfunding, as an advanced and efficient method, has been applied in numerous research fields, including small business ventures financing [3], philanthropy [4], medical expense [5], ecology and evolutionary biology [6] and so forth.

In recent years, quite a few researchers investigated the crowdfunding method. In Gerber and Hui, three emergent design principles were suggested to inform the design of effective crowdfunding platforms and support tools [7]. In Belleflamme et al. current business models in crowdfunding were enumerated and emerging relevant literature was discussed [8]. In Calic and Mosakowski, it was found that a sustainability orientation positively affects funding success of crowdfunding projects, and this relationship is partially mediated by project creativity and endorsements of third parties [9]. In Sheng et al. it was found that online information have significant positive effects on funder investment decisions of reward-based crowdfunding, and signals of quality is as important as electronic word of mouth [10].

Besides, the crowdfunding platform was also concerned by researches. Crowdfunding platforms are becoming more and more popular and helpful for fund-raising. According to a comparative study in China and the U.S., online crowdfunding platforms are important social network communities to raise money to support projects [11]. And several online crowdfunding platforms around the world have risen to prominence.

Crowdfunding method is quickly emerging as an alternative to traditional methods of funding new products. In a crowdfunding campaign, a seller solicits financial contributions from a crowd, usually in the form of pre-buying an unrealized product, and commits to producing the product if the total amount pledged is above a certain threshold [12].

In brief, crowdfunding method caters to the genuine demand of participants.

1.2 Railway Optimization Research

In recent years, quite a few researchers investigated railway optimization from several aspects and made great achievements, which are described as follows:

(i) Routing and Scheduling. Relevant literature about train routing and scheduling solved with the problem that where train runs and when train moves. In Corman et al. the effectiveness of advanced strategies was investigated to solve the compound train rerouting and rescheduling problem [13]. In Meng and Zhou an innovative mathematical programming model was proposed for simultaneous train rerouting and rescheduling based on network-wide cumulative flow variables [14]. In Larsen et al. a framework was proposed for evaluating the robustness of a given solution to the train scheduling problem with an economical computational cost [15]. In Corman et al. train scheduling and delay management approaches were integrated into a microscopic delay management model to control railway traffic in real-time with the objective of minimizing passenger travel time by attempting to fully incorporate the passengers' point of view into a microscopic train scheduling model [16]. In Xu et al. a new mathematical formulation with a switchable scheduling rule was proposed for increasing the train operational efficiency on the double-track railway corridor [17].

(ii) Train dispatching. Relevant literature about train dispatching solved with the problem that whom train transports and which train executes. In Meng and Zhou a robust single-track train dispatching problem was solved under stochastic segment running times and capacity loss duration [18]. In Corman et al. a novel approach was presented to solve the problem of coordinating the task of multiple dispatchers in presence of disturbances which is formulated as a 2-level program with the objective of minimizing delay propagation [19]. In Wang et al. a multi-time point optimization model is proposed, with the objective of maximizing the total revenue based on the time space service network of empty railcar distribution [20].

(iii) Railway Management. Relevant literature about railway management solved with the problem that what to manage and how to control. In D'Ariano et al. a branch and bound optimization algorithm was described for the real-time management of a complex rail network [21]. In Pellegrini et al. instances in which the infrastructure represented with fine granularity was solved by a mixed-integer linear programming formulation for the real-time railway traffic management problem [22]. In Lu et al. the multi-cell coordinated beamforming design was investigated for high-speed railway communications, where a high-mobility train went through a multi-user system in urban areas [23].

There was a phenomenon that very few researches, bridging the gap between theory and practice, were actually implemented and used in railway operations [24]. It was investigated that only 13% of articles from the two leading policy journals in the transportation literature, namely Transportation Research Part A and Transport Policy, met the realities on the ground and considered specific aspects of the policy cycle [25]. Most of existing research models tend to be dedicated to one issue and look for global optimality, rather than global feasibility taking into account extra constraints typical in the railway world [26].

As the technology develops, modern railway optimization is increasingly dependent on the real demand of passengers. For instance, the generalized journey time index still has merit within forecasting for the rail demand based on a very large data set of rail ticket sales [27]. Furthermore, the existing literature is not applicable absolutely to train operation in new methods. And more importantly, literature about models considering detailed descriptions of passenger demand is sparse because of the newness of the field [28]. In brief, ordinary trains do not cater to the real demand of passengers.

1.3 Crowdfunding Train Event

During the China's National Day and Mid-Autumn festival, Xi'an Railway Bureau drove two crowdfunding trains between Xi'an and Yulin for the first attempt in China from October 7th to October 8th in 2017, that is the event. In other words, the crowdfunding method has been applied to railway optimization by Xi'an Railway Bureau in China.

In brief, Crowdfunding Train is the train based on crowdfunding method, which caters to the real demand of passengers.

There is a lack of underlying theories and theoretical models in the current literature of Crowdfunding Train, and this article is one of the first to introduce the elaboration methods. Crowdfunding trains are different from ordinary trains because its operation depends largely on passengers, rather than railway bureaux or railway stations. Thus, it is practically challenging and theoretically important. And then threes questions arise: "How did this event happen?", "What did citizens talk about this event" and "How to analyze this event?".

2 Event Review

2.1 Event Beginning

Xi'an Railway Bureau released information of the activity "Attending the crowdfunding and taking the train" from their official SINA Weibo, which is one of the China's versions of Twitter, at 12:33:45 PM on Thursday, September 28th, 2017. The poster for the Crowdfunding Train event is shown in Supplementary Materials.

According to the information, all the participants need to prepare both SINA Weibo and Alipay account in advance. Main steps are as below.

(i) Entering the activity page by your SINA Weibo and checking in your name, mobile phone number and corresponding ID card number. The activity page was designed by Xi'an Railway Bureau and a team from Tsinghua University.

(ii) Choosing the grade of the tickets you confirm from several options, and pay the bill by your Alipay account. The ticket prices of Crowdfunding Train were the same as the normal that 81 yuan for hard seat, at least 144 yuan for hard sleeper, and at least 222 yuan for soft berth. The crowdfunding activity would be successful when the participants or the crowdfunding funds were more than half the target.

(iii) Transferring your railway ticket down by the railway station after you have received a mobile phone message telling you the success of the activity called Crowdfunding Train. The railway ticket would be a special pink one with a special seal for crowdfunding trains. A Ticket for the crowdfunding train K8188 is shown in Supplementary Materials.

2.2 Event Procedure

As of 12:00 AM on Friday, October 6th, it raised the end of the activity. However, there were 122 participants and the crowdfunding funds added up to 14,691 yuan only, which was no more than 10% of the target. Hence, those participants received a mobile phone message telling them the failure of the activity and all the crowdfunding funds would be sent back to their Alipay accounts that evening.

At about that time, many other passengers who were not good at using the Internet expressed their demands for crowdfunding trains to Xi'an Railway Bureau. Consequently, Xi'an Railway Bureau made a decision that the activity called Crowdfunding Train succeeded, and reserved corresponding seats for the passengers above mentioned according to the appointment.

Actually, Xi'an Railway Bureau adjusted the previous plan of Crowdfunding Train according to the passenger demands in many ways. And specific adjusting aspects are as below.

(i) According to the original scheduled departure, the crowdfunding train K8188 would leave Xi'an for Yulin at 14:52 PM on Saturday, October 7th. However, many travelers expressed their dissatisfaction because it would be at midnight when they arrived in Yulin and there would be no local bus or taxi by then. Hence, Xi'an Railway Bureau, with the consideration of the passenger demands, changed the departure time to 23:33 so as to meet passengers' conveniences.

(ii) Railway staffs found there were 6 passengers from northern Shaanxi plateau wanting to buy tickets of lower soft berth. Hence, Xi'an Railway Bureau, with the consideration of the passenger demands, added a carriage of soft berth and adjusted the proportion of carriages.

(iii) Due to the large holiday traffic, there were quite a few passengers expressing their demands for the return trip. Hence, Xi'an Railway Bureau, with the consideration of the passenger demands, decided to drive the second crowdfunding train K8187 from Yulin back to Xi'an, except for the crowdfunding train K8188 driven from Xi'an to Yulin.

(iv) Because the crowdfunding train was an attempt, existing automated ticketing machine did not adapt to special tickets. Hence, Xi'an Railway Bureau, with the consideration of the passenger demands, opened the counter No. 10 to 11 in Xi'an Railway Station and the counter No. 1 to 5 in Yulin Railway Station by human service and special waiting areas for those passengers who bought the tickets for crowdfunding trains. The counter No. 10 to 11 in Xi'an Railway Station is shown in Supplementary Materials.

2.3 Event Result

Xi'an Railway Bureau drove crowdfunding trains twice. The first is the train K8188 from Xi'an to Yulin that departed at 23:33 PM on Saturday, October 7th and arrived at 6:22 AM on Sunday, October 8th. And the second is the train K8187 from Yulin back to Xi'an that departed at 9:20 AM on Sunday, October 8th and arrived at 16:39 PM on Sunday, October 8th.

As a result, all the tickets of the first crowdfunding train K8188 with seat reservation were sold out, including 218 tickets for hard seat, 817 tickets for hard sleeper, and 22 tickets for soft berth. Moreover, Xi'an Railway Bureau sold some tickets without seat reservation, but within the upper limit of security. And the situation of second crowdfunding train K8187 was the same as the first crowdfunding train K8188 in general. Eventually, both of them were occupied by the passengers, adding up to 2500 totally. There are the trains K8182 and K8181 following the route of the trains K8188 and K8187 and reserving as ordinary trains at present.

It can be concluded that the activity "Attending the crowdfunding and taking the train" organized by Xi'an Railway Bureau achieved success in general. As a reward for those participants, Xi'an Railway Bureau selected 2% of them randomly and provided each one 5,000 bonus points which can exchange various prizes in the online railway mall in return. Prizes include teas, handkerchiefs, slippers and services at railway stations.

3 Economic Simulation

3.1 Basic Formula

3.1.1 Profit

Step 1. Calculating incomes. There is always not only one rank of tickets that passengers can choose, and the income of trains usually comes from selling tickets. The symbol R represents the rank of tickets that passengers could participate in. The variable P_R represents the price of the ticket in the rank R, unit: yuan per ticket. The variable Q_R^T represents the quantity of sold tickets in the rank R, unit: ticket(s). The variable I_Q represents the total income of tickets, unit: yuan. And then I_Q can be computed, as is shown in the Eq. (1).

$$I_Q = \sum_{R=1}^{n_R} \left(P_R Q_R^T\right) \tag{1}$$

Step 2. Calculating costs. Costs include fixed costs and variable costs in practice. The variable C_Q^F represents the total fixed costs, unit: yuan. The variable C_Q^V

represents the total variable costs, unit: yuan. The variable C_Q represents the total costs, unit: yuan. And then C_Q can be computed, as is shown in the Eq. (2).

$$C_Q = C_Q^F + C_Q^V \tag{2}$$

In the Eq. (2), C_Q^V can be broken down into smaller parts. The one is from carriages, and the other is from tickets. The variable n_R represents the number of ticket ranks. The variable Q_R^C represents the quantity of train carriages in the rank R, unit: carriage(s). The variable C_R^{VC} represents the variable cost by carriage in the rank R, unit: yuan per carriage. The variable C_R^{VT} represents the variable cost by quantity in the rank R, unit: yuan per ticket. And then C_Q^V can be computed in the Eq. (3).

$$C_Q^V = \sum_{R=1}^{n_R} \left(C_R^{VC} Q_R^C + C_R^{VT} Q_R^T \right) \tag{3}$$

Step 3. Calculating profits. There is another expense of trains except costs above mentioned, including the discounts, extraordinary expenditures, occasional fees, etc. The variable *FB* represents the feed backs for passengers who buy tickets of the crowdfunding train, unit: yuan. The variable *P* represents the total profit of the crowdfunding Train, unit: yuan. And then *P* can be computed in the Eq. (4).

$$P = I_Q - C_Q - FB \tag{4}$$

Furthermore, *P* can be computed in a more detailed way, as is shown in the Eq. (5).

$$P = \sum_{R=1}^{n_R} \left(P_R Q_R^T \right) - \left(C_Q^F + \sum_{R=1}^{n_R} \left(C_R^{VC} Q_R^C + C_R^{VT} Q_R^T \right) + FB \right) \tag{5}$$

3.1.2 Passenger

It is not certain that all the passengers in the railway stations will buy tickets, and only those who are willing to will do. The variable n_p represents the number of passengers who may participate in the crowdfunding train x. The variable i represents the through variable with no meaning. The variable W_i represents the individual decisions of passengers whether to purchasing the ticket in the rank R or not, which equals to 1 when yes and equals to 0 for when not. And then Q_R^T can be computed, as is shown in the Eq. (6).

$$Q_R^T = \sum_{i=1}^{n_P} W_i \tag{6}$$

In the Eq. (6), W_i can be influenced diversely by several factors, including the prices of tickets, the feed backs, the individual preferences and so on, as is shown in the Eq. (7).

$$W_i = f_i(P_R, FB, \cdots) \tag{7}$$

In the Eq. (7), the symbol $f_i(\cdots)$ represents the function for the individual decisions of passengers.

3.1.3 Carriage

One of the disparities between crowdfunding trains and ordinary trains is that the quantity of train carriages is not fixed, but adjustable, that is to say, the quantity of carriages of crowdfunding trains depends on the quantity of sold tickets. Therefore, it is quite necessary to consider the adjustable carriage costs as one of the significant elements of the total variable costs.

The quantity of sold tickets should be equivalent to the number of passengers who may participate in the crowdfunding train x. And the quantity of train carriages depends on the quantity of sold tickets and the ticket quota of train carriages. The variable L_R represents the ticket quota of train carriages in the rank R, unit: ticket(s) per carriage. And then Q_R^C can be computed, as is shown in the Eq. (8).

$$Q_R^C = \begin{cases} Int\left(\frac{Q_R^T}{L_R}\right), when\ Mod\left(Q_R^T, L_R\right) = 0 \\ Int\left(\frac{Q_R^T}{L_R}\right) + 1, when\ Mod\left(Q_R^T, L_R\right) \neq 0 \end{cases} \tag{8}$$

where *Int*(*number*) is the function to calculate the maximum integer below the number, e.g. *Int*(8.9) = 8, $Int(-8.9) = -9$. *Mod*(*number*, *divisor*) is the function to calculate the remainder of the number after it is divided by the divisor, e.g. *Mod* (3,2) = 1, $Mod(-3, 2) = 1$.

In practice, there are limitations for the quantity of train carriages and he quantity of sold tickets. The variable $maxQ_R^C$ represents the maximum train carriage quantity in the rank R, unit: carriage(s). The variable $maxQ_R^T$ represents the maximum sold ticket quantity in the rank R, unit: ticket(s). And then limitations can be expressed, as is shown in the inequation (9) and (10).

$$Q_R^C \leq maxQ_R^C \tag{9}$$

$$Q_R^T \leq maxQ_R^T \tag{10}$$

3.1.4 Time

There is a specific sequence for point-in-times because the activity should be finished before trains depart from railway stations.

The symbol x represents the code of the crowdfunding train. The symbol s represents the identification of railway stations. The variable t_x^B represents the beginning point-in-time of the crowdfunding train x. The variable t_x^D represents the deadline point-in-time of the crowdfunding train x. The variable t_s^{DC} represents the deadline point-in-time of checking tickets at the Railway Station s. The variable t_s^{DE} represents the departure point-in-time of the train at the Railway Station s. And then the specific sequence can be expressed, as is shown in the in Eq. (11).

$$t_x^B < t_x^D < t_s^{DC} < t_s^{DE} \tag{11}$$

The variable t_x^C represents the current point-in-time of the crowdfunding train x. And there is a specific range for current point-in-time in actual, as is shown in the in Eq. (12).

$$t_x^B \le t_x^C \le t_s^{DC} \tag{12}$$

The variable t_x^F represents the first point-in-time of the crowdfunding train x when the target achieved. And then t_x^F can be computed, as is shown in the Eq. (13).

$$t_x^F = \begin{cases} t_s^{DE}, when\, P < 0 \\ t_x^C, when\, P \ge 0\, and\, t_x^F = t_s^{DE} \\ t_x^F, when\, P \ge 0\, and\, t_x^F \ne t_s^{DE} \end{cases} \tag{13}$$

Furthermore, different positions of t_x^F result in different situations of the crowdfunding train x, which are described as follows:

(i) When $t_x^B \le t_x^F \le t_x^D$, it means that the activity of the crowdfunding train x achieved success during the setting time of the activity.

(ii) When $t_x^D < t_x^F \le t_s^{DC}$, it means that the setting time of the activity was up, but had not reach the deadline point-in-time of checking tickets yet. Thus, the activity would still achieve success once the deadline point-in-time of the crowdfunding train x could be extended.

(iii) When $t_x^C > t_s^{DC}$ and $t_x^F = t_s^{DE}$, it means that the setting time for the crowdfunding train x to departure from the Railway Station s has been coming soon, and simultaneously, the crowdfunding train x would not make profits even though the activity could proceed unless the departure point-in-time of the train at the Railway Station s could be extended.

3.2 Multiple Situation About Profit

3.2.1 Profit in Simple Consideration

The symbol A represents the ticket rank called Hard seat. The symbol B represents the ticket rank called Hard sleeper. The symbol C represents the ticket rank called Soft berth. And then the detail calculation of profits can be described as follows.

When $n_R = 1$, according to the Eq. (1), I_Q can be computed in a more detailed way, as is shown in the Eq. (14).

$$I_Q = P_A Q_A^T \tag{14}$$

And according to the Eq. (5), P can be computed in more detailed ways, as are shown in the Eqs. (15) and (16).

$$P = P_A Q_A^T - \left(C_Q^F + C_A^{VC} Q_A^C + C_A^{VT} Q_A^T + FB \right) \tag{15}$$

$$P = \left(P_A - C_A^{VT} \right) Q_A^T - \left(C_Q^F + C_A^{VC} Q_A^C + FB \right) \tag{16}$$

The detail calculations of profits are similar to the Eqs. (15) and (16) when $n_R \geq 2$.

3.2.2 Profit in Sophisticated Consideration

According to the Eq. (8), Q_R^C depends on Q_R^T and L_R. Thus, there are two further conditions Con 1 and Con 2 to consider when calculating P in sophisticated considerations.

Con 1: if $Mod\left(Q_R^T, L_R\right) = 0$

In the Con 1, it can be deduced that $Mod\left(Q_R^T, L_R\right) = 0 \overset{(8)}{\Leftrightarrow} Q_R^C = Int\left(\frac{Q_R^T}{L_R}\right) = \frac{Q_R^T}{L_R}$..

And then according to the Eq. (5), P can be computed in more detailed ways, as are shown in the Eq. (17) and (18).

$$P = \sum_{R=1}^{n_R} \left(P_R Q_R^T \right) - \left(C_Q^F + \sum_{R=1}^{n_R} \left(C_R^{VC} \frac{Q_R^T}{L_R} + C_R^{VT} Q_R^T \right) + FB \right) \tag{17}$$

$$P = \sum_{R=1}^{n_R} \left(\left(P_R - \frac{C_R^{VC}}{L_R} - C_R^{VT} \right) Q_R^T \right) - \left(C_Q^F + FB \right) \tag{18}$$

Con 2: if $Mod\left(Q_R^T, L_R\right) \neq 0$

In the Con 2, it can be deduced that $Mod\left(Q_R^T, L_R\right) \neq 0 \overset{(8)}{\Leftrightarrow} Q_R^C = Int\left(\frac{Q_R^T}{L_R}\right) + 1$.

And according to the Eq. (5), P can be computed in a more detailed way, as is shown in the Eq. (19).

$$P = \sum_{R=1}^{n_R} \left(P_R Q_R^T\right) - \left(C_Q^F + \sum_{R=1}^{n_R} \left(C_R^{VC}\left(Int\left(\frac{Q_R^T}{L_R}\right) + 1\right) + C_R^{VT} Q_R^T\right) + FB\right) \quad (19)$$

3.2.3 Profit Change in Simple Consideration

When Q_R^T changes, P changes simultaneously. The variable ΔP represents the changes of the total profit of the crowdfunding train, unit: yuan. The variable ΔQ_R^T: The changes of the quantity of sold tickets in the rank R, unit: ticket(s). ΔP depends on ΔQ_R^T and ΔP can be computed, as is shown in the Eq. (20).

$$\Delta P = \Delta(I_Q - C_Q - FB) = \Delta\left(I_Q - C_Q^V\right) \quad (20)$$

According to the Eq. (8), Q_R^C depends on Q_R^T and L_R. Thus, there are two further conditions Con 3 and Con 4 to consider when calculating P. Simple considerations in 5.2.3 are based on Con 3 and sophisticated considerations in 5.2.4 are based on Con 4.

Con 3: if $Int\left(\frac{Q_R^T}{L_R}\right) = Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right)$

In the Con 3, it can be deduced that $Int\left(\frac{Q_R^T}{L_R}\right) = Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) \overset{(8)}{\Leftrightarrow} \Delta Q_R^C = 0.$

Furthermore, different values of n_R result in different calculating formulas of ΔP, which are described as follows.

(i) When $n_R = 1$, according to the Eqs. (16) and (20), ΔP can be computed in a more detailed way, as is shown in the Eq. (21).

$$\Delta P = \left(P_A - C_A^{VT}\right)\Delta Q_A^T \quad (21)$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequation (22).

$$\Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq 0 \quad (22)$$

(ii) When $n_R = 2$, according to the Eqs. (16) and (20), ΔP can be computed in a more detailed way, as is shown in the Eq. (23).

$$\Delta P = \left(P_A - C_A^{VT}\right)\Delta Q_A^T + \left(P_B - C_B^{VT}\right)\Delta Q_B^T \tag{23}$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequation (24).

$$\Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq -\frac{P_B - C_B^{VT}}{P_A - C_A^{VT}} \Delta Q_B^T \tag{24}$$

(iii) When $n_R \geq 3$, according to the Eqs. (16) and (20), ΔP can be computed in a more detailed way, as is shown in the Eq. (25).

$$\Delta P = \Delta \sum_{R=1}^{n_R} \left(P_R Q_R^T - C_R^{VT} Q_R^T\right) = \left(P_A - C_A^{VT}\right)\Delta Q_A^T + \Delta \sum_{R=2}^{n_R} \left(P_R Q_R^T - C_R^{VT} Q_R^T\right) \tag{25}$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequation (26).

$$\Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq -\sum_{R=2}^{n_R} \left(\frac{P_R - C_R^{VT}}{P_A - C_A^{VT}} \Delta Q_R^T\right) = -\frac{\sum_{R=2}^{n_R} \left(\left(P_R - C_R^{VT}\right)\Delta Q_R^T\right)}{P_A - C_A^{VT}} \tag{26}$$

3.2.4 Profit Change in Sophisticated Consideration

According to the Eq. (8), Q_R^C depends on Q_R^T and L_R, and sophisticated considerations in 5.2.4 are based on Con 4.

Con 4: if $Int\left(\frac{Q_R^T}{L_R}\right) \neq Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right)$

In the Con 4, it can be deduced that $Int\left(\frac{Q_R^T}{L_R}\right) \neq Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) \overset{(8)}{\Leftrightarrow} \Delta Q_R^C \neq 0$, and ΔQ_R^C can be computed in a direct way, as is shown in the Eq. (27).

$$\Delta Q_R^C = Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) - Int\left(\frac{Q_R^T}{L_R}\right) \tag{27}$$

Furthermore, different values of n_R result in different calculating formulas of ΔP, which are described as follows.

(i) When $n_R = 1$, according to the Eqs. (16) and (20), ΔP can be computed in a more detailed way, as is shown in the Eq. (28).

$$\Delta P = \left(P_A - C_A^{VT}\right)\Delta Q_A^T - C_A^{VC}\Delta Q_A^C \tag{28}$$

According to the Eqs. (27) and (28), it can be deduced that $\Delta Q_A^C = Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)$ and ΔP. can be computed in a more detailed way, as is shown in the Eq. (29).

$$\Delta P = \left(P_A - C_A^{VT}\right)\Delta Q_A^T - C_A^{VC}\left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)\right) \tag{29}$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequation (30).

$$\Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq \frac{C_A^{VC}}{P_A - C_A^{VT}}\left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)\right) \tag{30}$$

(ii) When $n_R = 2$, according to the Eqs. (16) and (20), ΔP can be computed in a more detailed way, as is shown in the Eqs. (31).

$$\Delta P = \left(P_A - C_A^{VT}\right)\Delta Q_A^T - C_A^{VC}\Delta Q_A^C + \left(P_B - C_B^{VT}\right)\Delta Q_B^T - C_B^{VC}\Delta Q_B^C \tag{31}$$

According to the Eqs. (27) and (31), it can be deduced that $\Delta Q_A^C = Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)$, $\Delta Q_B^C = Int\left(\frac{Q_B^T + \Delta Q_B^T}{L_B}\right) - Int\left(\frac{Q_B^T}{L_B}\right)$, and ΔP can be computed in a more detailed way, as is shown in the Eqs. (32).

$$\begin{aligned}\Delta P = {} & \left(P_A - C_A^{VT}\right)\Delta Q_A^T - C_A^{VC}\left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)\right) \\ & + \left(P_B - C_B^{VT}\right)\Delta Q_B^T - C_B^{VC}\left(Int\left(\frac{Q_B^T + \Delta Q_B^T}{L_B}\right) - Int\left(\frac{Q_B^T}{L_B}\right)\right)\end{aligned} \tag{32}$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequation (33).

$$\Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq -\frac{P_B - C_B^{VT}}{P_A - C_A^{VT}}\Delta Q_B^T + \frac{C_A^{VC}\left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right)\right) + C_B^{VC}\left(Int\left(\frac{Q_B^T + \Delta Q_B^T}{L_B}\right) - Int\left(\frac{Q_B^T}{L_B}\right)\right)}{P_A - C_A^{VT}} \tag{33}$$

(iii) When $n_R \geq 3$, according to the Eqs. (16) and (20), ΔP can be computed in more detailed ways, as are shown in the Eqs. (34) and (35).

$$\Delta P = \Delta \sum_{R=1}^{n_R} \left(P_R Q_R^T - C_R^{VT} Q_R^T - C_R^{VC} Q_R^C \right) \tag{34}$$

$$\Delta P = \left(P_A - C_A^{VT} \right) \Delta Q_A^T - C_A^{VC} Q_A^C + \sum_{R=2}^{n_R} \left(P_R Q_R^T - C_R^{VT} Q_R^T - C_R^{VC} Q_R^C \right) \tag{35}$$

According to the Eq. (35), and the Eq. (27) $\Delta Q_R^C = Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) - Int\left(\frac{Q_R^T}{L_R}\right)$, ΔP can be computed in a more detailed way, as is shown in the Eq. (36).

$$\begin{aligned} \Delta P = {} & \left(P_A - C_A^{VT} \right) \Delta Q_A^T - C_A^{VC} \left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right) \right) \\ & + \sum_{R=2}^{n_R} \left(\left(P_R - C_R^{VT} \right) \Delta Q_R^T - C_R^{VC} \left(Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) - Int\left(\frac{Q_R^T}{L_R}\right) \right) \right) \end{aligned} \tag{36}$$

And then it can be deduced that the condition of ΔQ_A^T when the inequation $\Delta P \geq 0$ holds, as is shown in the inequations (37) and (38).

$$\begin{aligned} & \Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \\ & \geq - \frac{\sum_{R=2}^{n_R} \left(\left(P_R - C_R^{VT} \right) \Delta Q_R^T \right) + \sum_{R=2}^{n_R} \left(C_R^{VC} \left(Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) - Int\left(\frac{Q_R^T}{L_R}\right) \right) \right) + C_A^{VC} \left(Int\left(\frac{Q_A^T + \Delta Q_A^T}{L_A}\right) - Int\left(\frac{Q_A^T}{L_A}\right) \right)}{P_A - C_A^{VT}} \end{aligned} \tag{37}$$

$$\begin{aligned} & \Delta P \geq 0 \Leftrightarrow \Delta Q_A^T \geq \\ & - \frac{\sum_{R=2}^{n_R} \left(\left(P_R - C_R^{VT} \right) \Delta Q_R^T \right)}{P_A - C_A^{VT}} + \frac{\sum_{R=1}^{n_R} \left(C_R^{VC} \left(Int\left(\frac{Q_R^T + \Delta Q_R^T}{L_R}\right) - Int\left(\frac{Q_R^T}{L_R}\right) \right) \right)}{P_A - C_A^{VT}} \end{aligned} \tag{38}$$

3.3 *Case Analysis*

3.3.1 Basic Information

The case analysis takes the crowdfunding train K8188 above mentioned as an example.

According to the event beginning in Sect. 2.1 about the crowdfunding train K8188, there was 3 ticket ranks that passengers could participate in, including hard seat, hard sleeper, and soft berth. Thus, it can be seen that $n_R = 3$.

According to the price list of the crowdfunding train K8188, it can be computed that $P_A = \frac{81 + 81}{2} = 81.00\,(yuan\,per\,ticket)$, $P_B = \frac{144 + 148 + 154}{3} \approx 148.67\,(yuan\,per\,ticket)$, $P_C = \frac{222 + 231}{2} = 226.50\,(yuan\,per\,ticket)$.

According to the seat amount of the crowdfunding train K8188, it can be seen that $maxQ_A^T = 230\,(tickets)$, $maxQ_B^T = 390\,(tickets)$, $maxQ_C^T = 36\,(tickets)$. And then it can be deduced that $maxQ_A^C = 2\,(carriages)$, $maxQ_B^C = 6\,(carriages)$, and $maxQ_C^C = 1\,(carriage)$.

Furthermore, according to the event analyses in Sect. 4.4.3, it can be deduced that $FB \approx 0$, and since the raising target was set at 50%, it was supposed that $C_Q \approx \frac{1}{2} I_Q$, when $Q_R^T = maxQ_R^T$.

3.3.2 Expected Profit

According to the Eq. (8), it can be deduced that $Q_R^C = maxQ_R^C$, when $Q_R^T = maxQ_R^T$. Meanwhile, it can be also deduced that $Mod\left(Q_R^T, L_R\right)|_{Q_R^T = maxQ_R^T} = 0$.

According to the Eq. (1), I_Q can be computed, as is shown in the Eq. (39).

$$I_Q|_{Q_R^T=maxQ_R^T} = \sum_{R=1}^{n_R} \left(P_R Q_R^T\right)|_{Q_R^T=maxQ_R^T} = 84{,}764.00\,(yuan) \tag{39}$$

Coupled with the crowdfunding train K8187, the total ticket income of the round trip should be doubled, and in other words, $2I_Q|_{Q_R^T=maxQ_R^T} = 169{,}528.00\,(yuan)$.

According to the basic information, when $C_Q = \frac{1}{2} I_Q$, P can be computed, as is shown in the Eq. (40).

$$P|_{Q_R^T=maxQ_R^T} = I_Q|_{Q_R^T=maxQ_R^T} - \frac{1}{2} I_Q|_{Q_R^T=maxQ_R^T} = \frac{1}{2} I_Q|_{Q_R^T=maxQ_R^T} = 42{,}382.00\,(yuan) \tag{40}$$

3.3.3 Profit in Process

According to the event procedure in Sect. 2.2, when $t_x^C = t_x^D$, $\sum_{R=1}^{n_R} Q_R^T|_{t_x^C=t_x^D} = 122\,(tickets)$ and $I_Q|_{t_x^C=t_x^D} = 14{,}691.00\,(yuan)$. And the ratio can be computed, as is shown in the inequation (41).

$$\frac{I_Q|_{t_x^C=t_x^D}}{2I_Q|_{Q_R^T=maxQ_R^T}} = \frac{14691}{169528} \approx 8.67\% < 50\% \tag{41}$$

Whereas, $I_Q|_{t_x^C=t_x^D}$ in the inequation (41) only included the amounts of passengers who buy tickets online until $t_x^C = t_x^D$, but did not take the other passengers who were at railway station or exactly on the way into consideration. And as a matter of fact, it should be $\frac{I_Q|_{t_x^C=t_x^D}}{2I_Q|_{Q_R^T=maxQ_R^T}} \geq 50\%$, if all the passengers could be involved in.

3.3.4 Eventual Profit

According to the event results in Sect. 2.3, it can be seen that $Q_A^T|_{t_x^C=t_s^{DC}} \geq 218\,(tickets)$, $Q_B^T|_{t_x^C=t_s^{DC}} \geq 817\,(tickets)$, $Q_C^T|_{t_x^C=t_s^{DC}} \geq 22\,(tickets)$ and $2\sum_{R=1}^{n_R} Q_R^T|_{t_x^C=t_s^{DC}} \geq 2500\,(tickets)$. And thus $I_Q|_{t_x^C=t_s^{DC}}$ can be estimated, as is shown in the inequation (42) and (43).

$$I_Q|_{t_x^C=t_s^{DC}} = \sum_{R=1}^{n_R}\left(P_R Q_R^T\right)|_{t_x^C=t_s^{DC}} \geq 81 \times 218 + 148.67 \times 817 + 226.5 \times 22\,(yuan) \tag{42}$$

$$I_Q|_{t_x^C=t_s^{DC}} \geq 144,104.39\,(yuan) \tag{43}$$

And the ratio can be computed, as is shown in the inequation (44).

$$\frac{2I_Q|_{t_x^C=t_s^{DC}}}{2I_Q|_{Q_R^T=maxQ_R^T}} \geq \frac{144104.39}{84764} \approx 170.01\% > 100\% \tag{44}$$

It can be also deduced that $Q_B^T|_{t_x^C=t_x^F} > maxQ_B^T|_{t_x^C=t_s^{DC}}$. It means that passengers of the crowdfunding train K8188 would like the ticket rank called hard sleeper much better than the ticket rank called hard seat or soft berth because of its advantage in economy.

Afterwards, according to the inequation (44), it can be deduced that $t_x^D < t_x^F \leq t_s^{DC}$. And according to the different positions of t_x^F discussed in Sect. 5.1.3, it means that the activity would still achieve success once the deadline point-in-time of the crowdfunding train K8188 could be extended because the setting time of the activity was up but had not reach the deadline point-in-time of checking tickets yet. Actually, it can be found in Sect. 2.2 that Xi'an Railway Bureau adjusted the plan of crowdfunding train according to the passenger demand in many ways, including extending the deadline point-in-time of the crowdfunding train, and it was the key to success. There was certainly a better situation if they could realize the strong requirements of passengers before the deadline and made decisions faster.

3.4 Profit Simulation Analysis

According to the popularity of the ticket rank called hard sleeper, it is taken as an example, and Partial data has been simplified to facilitate the calculations. Basic data is listed as below.

$$P_B = 150\,(yuan\,per\,ticket),\; C_Q^F = 10,000\,(yuan),\; C_B^{VC} = 2,000\,(yuan\,per\,carriage),$$
$$C_R^{VT} = 50\,(yuan\,per\,ticket),\; FB = 2,000\,(yuan),\; L_R = 60(tickets\,per\,carriage),$$
$$maxQ_R^C = 6\,(carriages),\; maxQ_R^T = 360\,(tickets).$$

According to the inequation (9) and (10), it can be deduced that $Q_R^C \leq 6$, and $Q_R^T \leq 360$.

According to the Eq. (5), P can be computed in detailed in the Eqs. (45) and (46).

$$P = 150 \times Q_R^T - \left(10000 + 2000 \times Q_R^C + 50 \times Q_R^T + 2000\right) \tag{45}$$

$$P = 100 \times Q_R^T - 2000 \times Q_R^C - 12000 \tag{46}$$

According to the Eq. (8), P can be computed in more detailed ways in the Eq. (47).

$$P = \begin{cases} 100 \times Q_R^T - 14000, 0 \leq Q_R^T \leq 60 \\ 100 \times Q_R^T - 16000, 60 < Q_R^T \leq 120 \\ 100 \times Q_R^T - 18000, 120 < Q_R^T \leq 180 \\ 100 \times Q_R^T - 20000, 180 < Q_R^T \leq 240 \\ 100 \times Q_R^T - 22000, 240 < Q_R^T \leq 300 \\ 100 \times Q_R^T - 24000, 300 < Q_R^T \leq 360 \end{cases} \tag{47}$$

A detailed diagram of the profits in the Eq. (47) is shown in Fig. 1.

It can be deduced that $Q_R^T > 180$ when $P > 0$. Furthermore, different value of Q_R^T result in different values of P, examples are as follows.

(i) When $Q_R^T = 0(ticket)$, $P = -14,000\,(yuan)$
(ii) When $Q_R^T = 180\,(tickets)$, $P = 0\,(yuan)$
(iii) When $Q_R^T = 190\,(tickets)$, $P = -1,000\,(yuan)$
(iv) When $Q_R^T = 200\,(tickets)$, $P = 0\,(yuan)$
(v) When $Q_R^T = 360\,(tickets)$, $P = 12,000\,(yuan)$

According to the Eq. (47) and Fig. 1, it can be found that the quantity of carriages of crowdfunding trains really depends on the quantity of sold tickets. There is an abnormal phenomenon that the total profit of the crowdfunding train sometimes

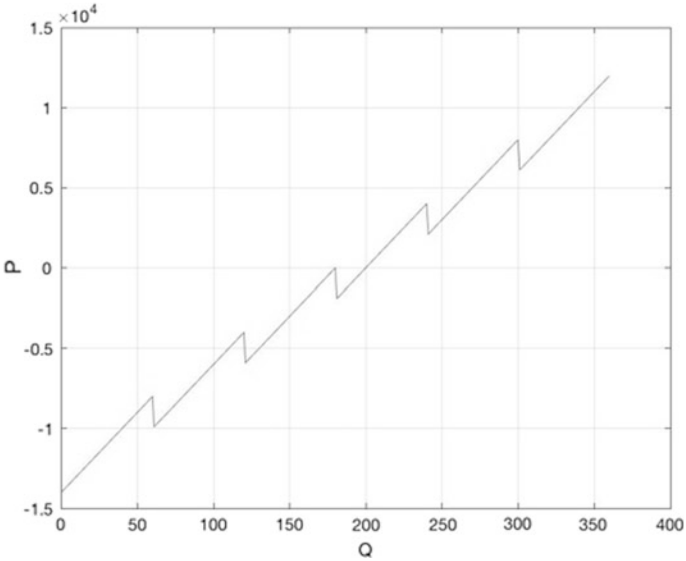

Fig. 1 Detailed diagram of the profits in the case analysis

reduces when the quantity of sold tickets increases. Thus, it is extremely considerable in optimizing the process of the crowdfunding train.

4 Conclusion

This article describes Crowdfunding Train and a series of mathematical models is built for the economic simulations. To summarize, the major findings in this article are described as follows.

(i) The carriage quantity of crowdfunding trains is uncertain because the quantity of train carriages depends on the quantity of sold tickets and the ticket quota of train carriages, and that is one of the significant distinctions between the profits of crowdfunding trains and ordinary trains.

(ii) The relationship between the total profit and the quantity of sold tickets is not always monotonically increasing but oscillatory, because the total profit sometimes reduces when the quantity of train carriages is increased by selling excessive tickets.

Besides, Crowdfunding Train needs information technology as well as Bike-sharing [29], and the deficiencies of the crowdfunding train K8188 and K8187 include hysteretic data reaction, internet technology limitation and ineffective feed backs [30]. Thus, it is necessary to develop information technology for comprehensive transportation.

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