OmniaScience

*Journal of Industrial Engineering and Management*
JIEM, 2014 – 7(1): 276-293 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423
http://dx.doi.org/10.3926/jiem.898

# Supplier Selection in Manufacturing Innovation Chain-oriented Public Procurement based on Improved PSO Method

Xin Xu, Yunlong Ding

*School of Management Harbin Institute of Technology (China)*

ecehub@hit.edu.cn, xuxinhit@yahoo.com.cn

*Received: July 2013*
*Accepted: February 2014*

***Abstract:***

***Purpose:*** At the dynamic innovation market, it is very difficult for an enterprise to accomplish innovation individually; technology innovation is shifting towards collaborative R&D chain mode. Thus, supplier selection based on individually innovation efficiency of enterprise is inapplicable to construct collaborative R&D innovation chain. This study is seeking to address how to select R&D innovation chain supplier in manufacturing industry.

***Design/methodology/approach:*** Firstly, Delphi method and AHP method are applied to establish an index system evaluating the suppliers of innovation chain, and then each index is weighted by experts with AHP method. Thirdly, optimized PSO algorithm is put forwarded based on the optimal efficiency of innovation chain to discriminate ideal suppliers meeting realistic conditions. Fourthly, innovation chain construction at generator manufacturing industry was taken as empirical case study to testify the improved PSO model.

***Findings:*** The innovation chain is comprised up by several enterprises, innovation performance of a single enterprise is not always positively correlated to that of one innovation chain, and the proposed model is capable to find out the best combination to construct an innovation chain.

***Research limitations/implications:*** The relations between these constructs with other variables of interest to the academicals fields were analyzed by a precise and credible data with a clear and concise description of the supply chain integration measurement scales.

***Practical implications:*** Providing scales that are valid as a diagnostic tool for best practices, as well as providing a benchmark with which to compare the score for each individual plant against a chain of industrial innovation from machinery.

***Originality/value:*** Innovation chain integration is an important factor in explaining the innovation performance of companies. The vast range of results obtained is due to the fact that there is no exactness to the group of scales used. An analysis of the measurement models nor clear benchmarks as to the variety of the scales used has not been published before.

***Keywords:*** public procurement, innovation policy, innovation chain-oriented public procurement, policy design

## 1. Introduction

Currently, the gaps of productivity and income among different countries and regions around the world show a trend of gradually widening (Landes, 1998). Innovation is considered as an important means to realize economy catch-up (Shin, 1996), whose benefits, however, are accompanied with risks, which mainly manifests as the uncertainty of innovation direction and market demand. In dynamic market economy, the uncertainty of innovation benefit and market demand will result in insufficient driver of innovation (Liu, 1993). Therefore, in order to rapidly improve innovation performance and realize economy catch-up, it is far from enough only by market without the support of innovation policy (Aghion, Paul & David, 2009). According to the experience from OECD countries, public procurement is one of the most common tools used by developed countries and regions to promote the innovation policy.

China has also realized the importance of public procurement for promoting innovation, and issued Public Procurement Act and Outline of the National Program for Long- and Medium-Term Scientific and Technological Development successively, to use the policy of public procurement to encourage enterprise innovation. Enterprises are the most critical practitioners to achieve the objectives of modern innovation-oriented public procurement. However, with the fast development of science and technology, come more and more challenges to R&D conditions and cost demand for researchers and developers pursuing technological innovation. In this context, it turns to be very difficult for a single enterprise to complete all activities of technological innovation in high efficiency. As a result, the global technology innovation shows a trend of chained cooperation, that multiple enterprises or main R&D bodies form an innovation chain on the basis of certain coordination relationships, and cooperate to perform specific innovation and R&D. In this case, the traditional method for supplier selection and evaluation, which is based on the innovation efficiency of single enterprise, is already unable to meet the demand of real world, and it becomes a new challenge for innovation-oriented public procurement to select and evaluate suppliers based on optimization of innovation chain.

## 2. Innovation-oriented Public Procurement and Rationality

### 2.1. Innovation-oriented Public Procurement

As a set of numerous innovation activities, innovation system provides an active platform for main innovators to learn from each other and work together. Therefore, the objective of innovation policy is to optimize the interaction efficiency among the components in this system (Arnold, Kuhlmann & van der Meulen, 2001). If the innovation policy is conceptualized, difference must exists in itself (Radosevic & Reid, 2006).In general, traditional public procurement refers to a public organization's procurement of certain products or services, while the regular public procurement means the public body’s procurement of products already produced (Edler, 2007), such as procurement of office supplies and other existing commodities. These actions would rarely promote technological innovation if not never. Consequently, we can understand that the innovation can be activated during the production only if the public sector, through purchasing offer, provides specific indices on the technical parameters of products, and requires certain functions to be realized via certain products in a certain time period (Edquist & Zabala-Iturriagagoitia, 2013).

The policy of innovation-oriented public procurement is not aimed at producing products, but promoting the development of new technology to meet the demands of people or society, and finally promote the innovation and diffusion of industrial technology (Lundvall, 1992). Therefore, the difference between innovation-oriented public procurement and regular version depends on whether the public procurement is executed to achieve the replenishment of consumptions or support the technology innovation.

Through above analysis, we assume that innovation-oriented public procurement, as one of essential tools for “innovation policy”, is an activity led by government to meet the social demands on innovation, and a main method of policy induced technology innovation to catalyze the production and diffusion of innovative products. Government body, as a critical leader to affect innovation activities, would not directly participate in the innovation process, but indirectly guide each activity in the innovation process of enterprise (Hommen, 2005).

### 2.2. Optimization of Innovation Chain of Public Procurement

Compared to traditional independent innovation of enterprise, partnership through innovation chain pays more attention to the persistence and durability of cooperation, has more information to share and immediately communicate among the partners, and realizes the win-win situation with coexistence of risks and benefits on the basis of mutual confidence. The main differences between the two innovation models are shown in Table 1.

| | Independent innovation | Partnership through innovation chain |
|---|---|---|
| Features of competition in innovation market | Price-based | Cooperative and technology-based |
| Standard for selection of innovative enterprise | Price competition | Costs and delivery performance |
| Stability | Frequent changes | Long term, stable and close cooperation |
| Information transfer and communication | Single and closed | Multi-orientation and effective communication |
| Number of innovators | A large number | A few (but can keep long-term cooperation) |
| Attitude to capacity plan | Independent | Sharing responsibilities in respect of strategic issues |
| Innovation performance | Unstable | Gradual R&D based on consultation |
| Transaction processing | Zero-sum game | Win-win game |
| Innovation quality | Trustless quality inspection | Pursuing advance |
| Relationship among the enterprises | Competitive relationship | Equal and cooperative relationship |

Table 1. Comparison of Innovation Chain and Independent Innovation of Enterprise

In terms of industry innovation, innovation chain is composed of several function nodes. Upstream and downstream enterprises, governments, colleges, scientific research institutions, technological innovation incubators and so on, which provide direct or indirect functions in the innovation activities, can be considered as innovation nodes in the "Government-industry-university-research Innovation Chain". An innovation or a series of innovations are finally achieved, and corresponding results are gained via interaction among these nodes. This interaction effect is realized on the basis of work coordination and division among the nodes. It is required that all these nodes are complementary to some extent. If knowledge complementation exists among the enterprises in the innovation chain, further information can be obtained so as to increase the usefulness of a certain part of knowledge, and improve the efficiency and scale of innovation. Therefore, establishing partnership in the innovation chain is very critical to the promotion of social technology innovation efficiency.

Innovation chain, however, depends on a certain material and technology foundations and is affected by external environment. The development of innovation chain depends on various innovation material resources, including manpower, finance, material, science and technology, information, etc. The quantity, quality, structure and configuration, and utilization mechanism of innovation resources directly affect the formation and operation efficiency of innovation chain. It is time for the public procurement to play its leading role in innovation. The functions of public procurement to promote the innovation chain include three aspects.

#### 2.2.1. Reducing risks of innovation R&D

During the birth of a new technology, developers need to undertake the risk of that the technology would not be accepted by the traditional market in early stage, while users need to undertake the risk of adaptability resulted from technology change. For example, immediate and effective empirical solutions cannot be provided for certain new problems. In this case, innovation requires a leading market which has demand preference and provides an environment which is more suitable for innovation (e.g. policy mechanism has high efficiency and feedback loop to protect intellectual property and promote the technology diffusion to general market). In this context, the innovative products can realize marketization of innovative technology earlier, while more feedbacks are obtained from users so that the innovators can make immediate adjustment. Public procurement is provided with a certain policy compulsion and purchasing scale with the purchasing sum being stable so that it is sufficient to create a leading market for the products of innovative technology, and efficiently reduce the R&D risks for enterprises in innovation chain.

#### 2.2.2. Transmitting innovation information

Public procurement can coordinate information asymmetry during market failure. In the early stage of innovative public procurement, market survey is conducted to identify the potential of market innovation; scale of innovation-based market is expanded to the critical trigger point of innovation through bulk purchasing of single products and centralized purchasing based on demands from multiple sectors; offers are issued to all innovation developers to specify the state of market demand and future orientation of technology demand. Consequently, the innovators will undertake fewer risks caused by the information asymmetry, and immediately conduct specific R&D activities. Once upon the procurement is completed, use of innovative products by the government sectors can be taken as an example of market application of products of this technology, so as to improve the image of innovative products, transfer specific signals to the private market, and promote the diffusion of new technology to the private market. This specific leading role of information is especially obvious in the emerging technology industries.

#### 2.2.3. Promoting formation of common technology innovation chain

Common industrial technology refers to a technology which is already or will likely be commonly used in several applications. Its achievements can be shared and can deeply influence technology innovation and change the integral industry or multiple industries and their enterprises. The creation and formation of industries is dependent on this common technology (Ding, 2002). However, the following challenges exist for its research and development.

- R&D of basic common technology often needs adequate time period longer than that required for the existing technologies.
- R&D process of this technology is too complex to be completed only by the core competence of single enterprise， it requires cooperation among enterprises, or even the cooperation between enterprises and research institutions or governments.
- A large amount of sunk costs are required during the R&D process of basic common technology, which are used to provide necessary equipment and R&D groups for the innovation. It is difficult for a single enterprise to undertake this amount.
- This common technology, which is widely applied and provided with positive externality, can produce “Free Rider” effect after successful innovation, and is imitated by the competitive enterprises at the expense much lower than R&D cost.

In this case, the innovation of common technology requires the government to provide leading function, so as to promote the formation of industrial technology innovation chain and reduce the risks during the R&D of common technology; to build a platform for communication and cooperation between enterprises and research institutions or colleges, for a cooperation network for common technology innovation and reduce the cost of cooperative transaction; to specify the property right of common technology by means of contract, to guarantee the ROI of R&D enterprises, to improve the enthusiasm of R&D enterprises and to promote the supply efficiency of common technology.

## 3. Supplier Selection Model in the Innovation Chain-oriented Public Procurement

### 3.1. Methodology

Selecting suitable enterprises from numerous responders of purchasing offers to form an innovation chain is critical to the success of innovation-oriented public procurement project. As determination of partners in the innovation chain is very complex with several influencing factors, some researchers use qualitative methods, such as Delphi method, SWORT analysis and so on, to investigate the evaluation indices. Such investigations are aimed at identifying the criteria, but always are not accurate enough. Other researchers tend to resolve the selection of partners in innovation chain by mathematical analysis. They consider the partner selection as an optimization problem and try to find optimal solution via mathematical methods (William, Xiaowei & Dey, 2010).

Analytic Hierarchy Process (AHP) is an analysis method for multi-objective decision which combines qualitative and quantitative analysis. Especially in assisting Delphi method survey, it is very helpful to quantify the experience-based judgment of decision maker. It is an effective evaluation method if objective structure is complex and necessary data is uncertain (Calabrese Costa & Menichini, 2013). Two defects, however, exist in this AHP method: 1) as it depends on the subjective judgments of decision maker, sometimes logic error of results being inconsistent may be caused; 2) the conflict between optimization of individual efficiency and group efficiency cannot be solved only by linear comparison of index values of each scheme. Therefore, this paper introduces binary Particle Warm Optimization (PSO) and Vector Space Model, to help public procurement decision maker to select optimal enterprises in the innovation chain.

On the basis of above analysis, issuing offers to enterprises on the public procurement in form of contracts is combined, to promote cooperation among innovation enterprises, build industrial technology innovation chain, and finally improve the policy goal of social innovation efficiency through this contracted motivation and restriction. We build a model for selecting enterprises in public procurement innovation chain on the basis of AHP and PSO algorithms. Firstly, we use AHP method to calculate the weight of each index; then, expert interviews are conducted by means of questionnaire and Delphi method, to measure the scores of candidates on each index, and to perform a dimensionless process on each score of enterprises; at last, binary PSO is applied to conduct optimization, and finally obtain results of optimized selection of enterprises forming innovation chains for different objectives of innovation-oriented public procurement.

### 3.2. Selection of Delphi Evaluation Indices

The policy of innovation-oriented public procurement is very special and aimed at fostering and supporting national or local enterprises to conduct innovation R&D, and improving the regional industry innovation ability. So this paper combines a large number of economy and policy factors at enterprise level. It considers not only the importance of accumulation of human and intellectual capital, but also the importance and other functions of national policy to the innovation ability of enterprises. Four rounds of evaluation index consultations for bidding enterprises are conducted by using Delphi method and adding variables of factors that influence the innovation according to the laws and regulations of public procurement. The results indicate that the evaluation indices for enterprises' comprehensive abilities of technology innovation should include:

- product attributes;
- innovation inputs;
- innovation outputs;
- innovation cooperation;
- innovation potential.

An evaluation index system is finally composed of 5 first level indices (criterion level) and 24 second level indices (index level) (Figure 1). These five index sets should be combined together to evaluate the supplier selection in the innovation chain. Each index is described as follows.

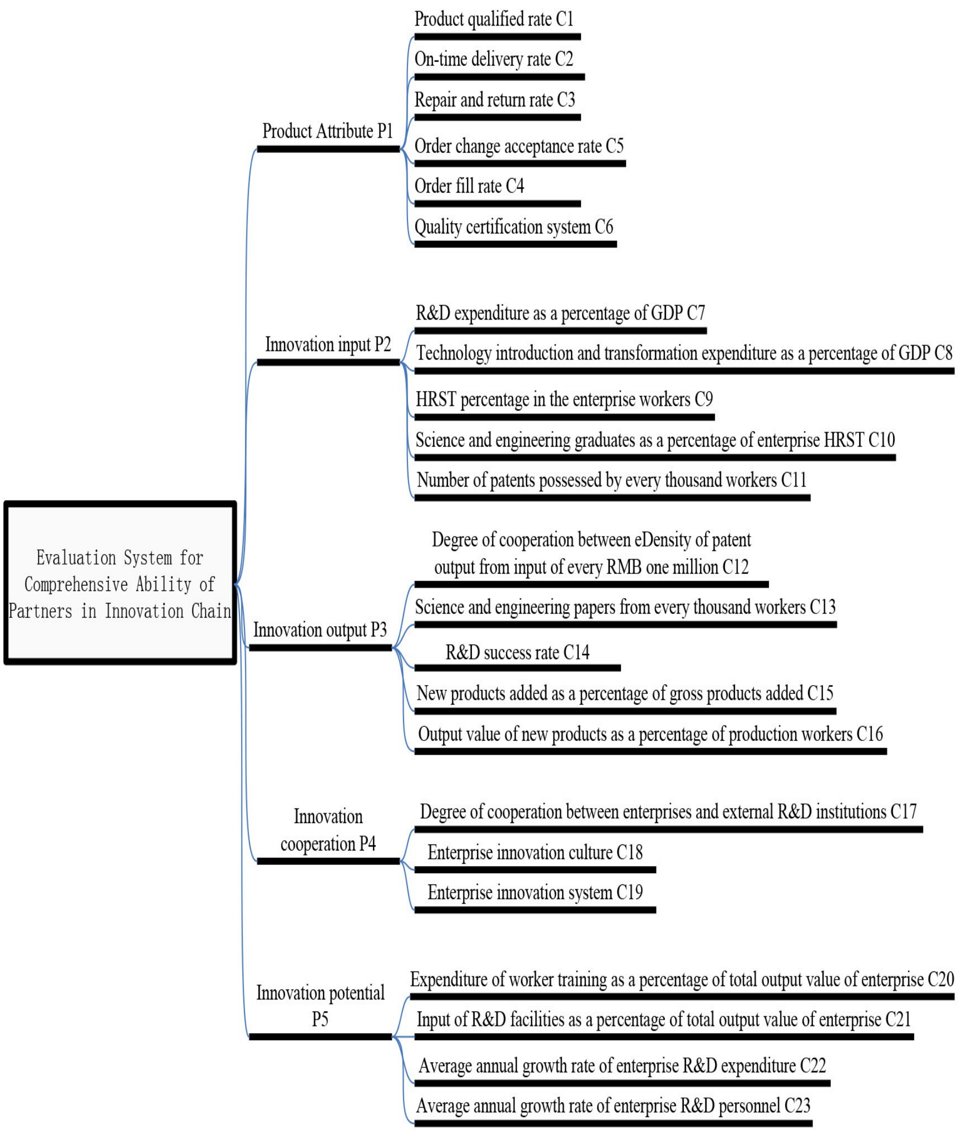



Figure 1.Evaluation Index System for Supplier in Innovation Chain-oriented Public Procurement

### 3.3. AHP Index Weighting

#### 3.3.1. Construction of Judgment Matrix

Pairwise interactive comparisons are conducted for the factors at same level in the hierarchical structure model and relative importance between indices at same level is determined according to effects of these factors on the objectives of upper hierarchy. This relative importance between factors at same hierarchy forms a judgment matrix, i.e. $bij = \frac{1}{b_{ij}}$ $(i,j = 1,2,...,n)$. Where, bij is relative importance of the ith index compared to the jth index, and it can be represented by levels in Table 2.

| Level | Description |
|---|---|
| 1 | Pi and Pj have same importance |
| 3 | Pi is slightly more important than Pj |
| 5 | Pi is more important than Pj |
| 7 | Pi is much more important than Pj |
| 9 | Pi is extremely important compared to Pj |
| 2,4,6,8 | Medians of each two adjacent relative importance levels |
| Reciprocals of above levels | The importance of Pj compared to Pi |

Table 2. Descriptions of Levels of Relative Importance

#### 3.3.2. Solution of Judgment Matrix

a) The judgment matrix is normalized by rows and columns to obtain eigenvector corresponding to its largest eigenvalue $\lambda_{max}$, i.e. weight vector W;

b) The largest eigenvalue of judgment matrix is calculated as follows:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \qquad (1)$$

c) The consistency index for judgment is calculated by the following equation:

$$CI = \frac{\lambda \max - n}{n-1} \qquad (2)$$

d) Consistency ratio is calculated as follows:

$$\text{CI-}\frac{\text{CI}}{\text{RI}} \qquad (3)$$

When $CR \leq 0.1$, the judgment matrix shows satisfactory consistency. RI value range is shown as Table 3.

| Dimension | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

Table 3. Value of Random Consistency Index

Weighting is performed by combining Delphi method and AHP method according to above steps. In this model, weight assignment of indices in innovation chain is shown as follows:

| Objective Level | Criterion Level | Index Level | Comprehensive Weight |
|---|---|---|---|
| G | P1 0.3226 | C1 0.3809 | 0.1229 |
| | | C2 0.2355 | 0.0760 |
| | | C3 0.1643 | 0.0530 |
| | | C4 0.1115 | 0.0360 |
| | | C5 0.0703 | 0.0227 |
| | | C6 0.0375 | 0.0121 |
| | P2 0.2274 | C7 0.3750 | 0.0853 |
| | | C8 0.3750 | 0.0853 |
| | | C9 0.1250 | 0.0284 |
| | | C10 0.1250 | 0.0284 |
| | P3 0.2390 | C11 0.1184 | 0.0283 |
| | | C12 0.2437 | 0.0582 |
| | | C13 0.1463 | 0.0350 |
| | | C14 0.3229 | 0.0772 |
| | | C15 0.1077 | 0.0257 |
| | | C16 0.0610 | 0.0146 |
| | P4 0.1090 | C17 0.6334 | 0.0690 |
| | | C18 0.1062 | 0.0116 |
| | | C19 0.2605 | 0.0284 |
| | | C21 0.1257 | 0.0128 |
| | | C22 0.1906 | 0.0195 |
| | | C23 0.2999 | 0.0306 |

Table 4. Weight Assignment of All Levels

### 3.4. Optimized Selection of Enterprises in Innovation Chain Based on PSO and AHP Combination Weighting

#### 3.4.1. Assumption of PSO model

A flock of birds are randomly looking for food in an area with only one piece of food. They don't know the accurate location of the piece of food, but know the distances from their current positions to the food. Then, how can a bird find the food before other birds find it? It is the most effective method to search for the area around the bird nearest to the food (Assareh, Behrang, Assari et al., 2010). This biological population behavior inspired Eberhart and Kennedy to present PSO algorithm used for optimization of solution. In PSO algorithm, initial particle swarm is randomly generated and optimal solution for issue to be optimized is obtained through iterative method. This algorithm, however, cannot solve the optimization for the multi-objective selection in the real world. Binary PSO algorithm modifies position and velocity of particle Pi by using the following two equations:

$$v_{in}{}^{k}{}_{+1} = \omega v_{in}{}^{k} + c_1 rand_1(pbest_{in}{}^{k} - x_{in}{}^{k}) + c_2 rand_2(gbest_{in}{}^{k} - x_{in}{}^{k}) \quad (4)$$

$$\text{If } x(rand < S(v_n)) = 1 \text{ then } x_{in} = 1; \text{ else } x_{in} = 0 \quad (5)$$

Where, $S(v_{in}) = \dfrac{1}{1+\exp(-v_{in})}$ is Sigmoid function, and rand is a random number within [0, 1].

Optimization of supplier selection in the innovation chain of public procurement is aimed at allowing enterprises in the innovation chain to realize social innovation efficiency with the best performance, which can also be described as a multi-objective combinational optimization problem. The optimal enterprises can be selected in terms of optimal innovation product attribute, innovation efficiency, innovation cooperation ability and innovation potential of enterprises who provide the innovation. The value activities of candidates can be divided into three parts on the basis of business structure: R&D of innovation, industrialization of innovation and diffusion of innovation. In terms of these three aspects, it assumes that the enterprises can be divided into three classes, i.e. $i = 1, 2, 3$; and there are j enterprises in each class, $j = 1, 2, 3..., J$, the set of candidates is represented by $\Omega_{i*j}$. Where, $U_{ij}$ indicates the $j_{th}$ candidate in class $i$ with $X_{ij}$ representing the state of candidate $U_{ij}$, and $X_{ij} = (X_{11}, X_{12}, \ldots, X_{4j})$ indicates the state of set of candidates.

$$X = \begin{cases} 1, \text{Candidate } U_{ij} \text{ is selected} \\ 0, \text{Candidate } U_{ij} \text{ is not selected} \end{cases}$$

In theory, set of enterprises, $x$ which also meets the following conditions, can be considered as the optimal selection result of partners in innovation chain.

a. Objective function 1: candidates provide innovative products with optimal attributes

$$\max f_1(X) = \sum_{i=1}^{3}\sum_{j=1}^{J}\sum_{l=1}^{6}(c_l\, w_l x_{ij}) \qquad (6)$$

Where, $c_1$ indicates the scores of candidate $U_{ij}$ on evaluation indices of product attribute; $w_1$ indicates weights of all attribute indices; $X_{ij}$ indicates whether the candidate $U_{ij}$ is selected; and $f_1$ calculates scores of candidate $U_{ij}$ in respect of product attribute.

b. Objective function 2: candidates provide optimal innovation efficiency, which means the ratios of innovation input and output of enterprises are the highest.

$$\min f_2(X) = \frac{\sum_{i=1}^{3}\sum_{j=1}^{J}\sum_{l=11}^{16} c_l w_l x_{ij}}{\sum_{i=1}^{3}\sum_{j=1}^{J}\sum_{l=7}^{10} c_l w_l x_{ij}} \qquad (7)$$

Where, $c_1$ indicates the scores of candidate $U_{ij}$ on indices of innovation input and output; $w_1$ indicates weights of all input and output indices; $X_{ij}$ indicates whether the candidate $U_{ij}$ is selected; and $f_2$ collects input-output ratios to measure the appropriate innovation efficiency.

c. Objective function 3: candidates have the best innovation cooperation capacity.

$$\max f_3(X) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=17}^{19} c_l w_l x_{ij} \qquad (8)$$

Where, $c_1$ indicates the scores of candidates on indices of innovation cooperation; $w_1$ indicates weights of all innovation cooperation indices; $X_{ij}$ indicates whether the candidates are selected; and $f_3$ indicates the scores of candidates on the innovation cooperation.

d. Objective function 3: candidates have the highest innovation potential

$$\max f4(X) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=20}^{23} c_l w_j x_{ij} \qquad (9)$$

Where, $c_1$ indicates the scores of candidates on indices of innovation potential; $w_1$ indicates weights of all innovation potential indices; $X_{ij}$ indicates whether the candidates are selected; and $f_4$ indicates the innovation potential scores of candidates.

#### 3.4.2. Construction of Fitness Function

Vector space is the subject of linear algebra, whose principle is that, set of n dimension vectors is represented by V, and if the set V is not empty, and is closed under the operations of addition and multiplication, then this set V is called a vector space. The cosine of vectorial angle is used to indicate the similarity between similar objects represented by these two vectors.

We build a selection model for innovation chain, in order to seek an enterprise innovation chain for public procurement, which has optimal innovation product attribute, innovation efficiency, innovation cooperation capacity and innovation potential. In reality, it is generally known as an event of low probability to find a group of chains (a set of candidate state) which meet all of above five objective functions. In order to solve the optimal combination of innovation chain, it is critical to find a set of enterprises which is the most similar to the optimal solutions of objective functions. The optimal solutions of above four functions and other feasible solutions can be deemed as vectors in the vector space. Feasible solutions of the highest similarity, which can be considered as optimal solutions of optimization issues, are found by combining the vector space model and calculation of similarity between feasible solutions of optimization issues and optimal solutions of these four objective functions. Through above analysis, we construct a fitness calculation function for the binary PSO algorithm:

$$\max S(X) = \frac{f(X) \bullet f^*}{|f||f^*|} \tag{10}$$

$$\text{s.t.} \forall i \in [1,3], \exists \sum_{j=1}^{J} x_{ij} = 1 \tag{11}$$

Where, $f^*$ indicates ideal points; S(X) indicates similarity between set of enterprise states and ideal points; condition (11) ensures only one enterprise can be selected for each link of innovation chain; and fitness function is used to find the optimal solution of enterprise selection in the innovation chain of public procurement by comprehensive survey of similarity between sets of enterprise state and ideal points.

### 3.4.3. Solution of Supplier Selection in Innovation Chain-oriented Public Procurement

In PSO algorithm, particle position is used to represent the solution of problem to be optimized. For supplier selection in the innovation chain-oriented public selection, state vector $X = (x_{11}, x_{12}, \ldots, x_{3j})$ of candidate set is used to represent particle position vector. The optimal position vector is considered as solution of this selection problem. Thus, steps for supplier selection in the innovation chain-oriented public procurement is shown as follows:

1. Initialize particle swarm and randomly generate position and velocity vectors of each particle.
2. Calculate particle fitness.
3. If it is the first time to calculate the particle fitness, consider the first position of particle as pbest. Otherwise, compare current fitness with pbest, and consider the better one as particle pbest.
4. If it is the first time to calculate the particle fitness, find out the particle of the best fitness, and consider its position as gbest. Otherwise, compare the best fitness of current particle swarm with gbest, and consider the better one as particle pbest.
5. Update particle position and velocity according to Equation 4 and 5.
6. Return to Step 2), until the specified conditions are satisfied.

### 3.4.4. Numerical Example

A project of generator procurement for X power station is taken as an example, to describe the application process of supplier selection model in the innovation chain-oriented public procurement. During the construction of X power station, large-sized generators will be purchased for its generator units, but these generators are beyond the technology in the real world market where no generator of this model and power is available in that time. As R&D and production of oversized generator units are characterized by public goods and technology diffusion, timely and effective technology innovation cannot be provided only by market R&D. In this case, the public procurement bidding is performed for different projects, to promote the construction of innovation chain by enterprises, actively participate in and cooperate in R&D of technology innovation, and realize expected objectives of technology innovation. The following sections take supplier selection in innovation chain of oversized generator units as an example to describe the whole selection process. 4 candidates participate in competition of innovation R&D project, which are represented by A~D respectively; 3 candidates participate in production, which are represented by E~G respectively; and 3 participate in innovation diffusion, which are represented by H~J respectively (see Table 5 for detail). Enterprises can compete in biddings for all of above three projects, which mean they have a certain competitive capacity in each process of innovation.

At first, expert interviews and questionnaire surveys are conducted to obtain the original data of each index presented by enterprises for this paper, and these data are nondimensionalized by Equation (12) and (13).

$$\text{Positive index:}\quad R_i = \left\{\frac{1}{2} + \frac{1}{2}\sin\left[\frac{\pi}{X_{i\max} - X_{i\min}}\left(x_i - \frac{X_{i\max} + X_{i\min}}{2}\right)\right]\right\} \tag{12}$$

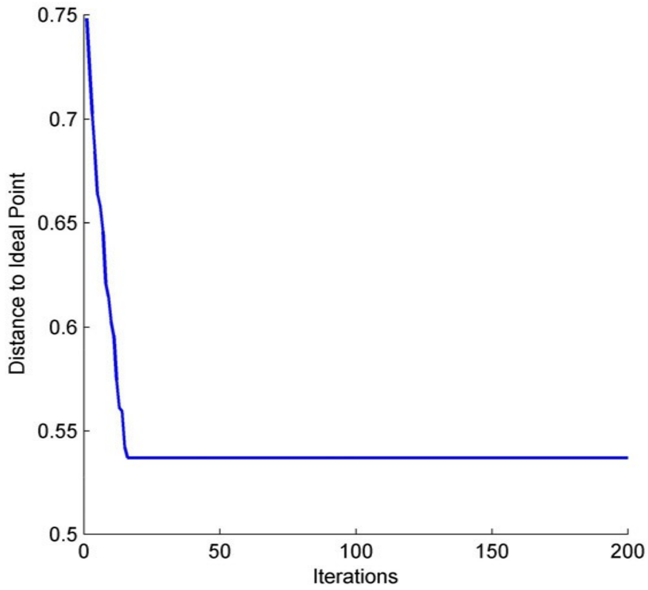
$$\text{Negative index:}\quad R_i = \left\{\frac{1}{2} - \frac{1}{2}\sin\left[\frac{\pi}{X_{i\max} - X_{i\min}}\left(x_i - \frac{X_{i\max} + X_{i\min}}{2}\right)\right]\right\} \tag{13}$$

Where, $X_{i\max}$ is the maximum score of i index, while $X_{i\min}$ is the minimum score. $x_i$ is score of candidate on $i$ index.

See Table 6 for results. In this numerical example, particle scale $n$ = 20 N = 20, inertia weight $\varpi$ = 1, learning factor $c_1$ = 2, and $c_2$ = 2. Maximum number of iterations is 200. Optimized enterprise state set is {0, 0, 1, 0, 0, 0, 1, 0, 0, 1}. This solution result indicates that optimal supplier combination in the innovation chain is {C, G, J}.

## 4. Conclusion

In this paper, we firstly discuss the leading role of public procurement in innovation chain, and the reasonability of innovation chain-oriented public procurement. For the complicated technology innovation, R&D efficiency of single enterprise is much lower than that of innovation chain mode. Therefore, in order to build an innovation chain by means of contract offer for the public procurement, it is critical to conduct evaluation and selection of suppliers in the innovation chain. Evaluation index system for suppliers in the innovation chain is designed and weighted by combining the AHP and Delphi methods. Selection model for suppliers in the innovation chain-oriented public procurement is built by applying the binary PSO algorithm and vector space method. This model can effectively describe the construction process of innovation chain in the real world, highlight public procurement’s guiding and promoting functions in innovation chain， effectively overcome the defects of traditional procurement in respect of diffusion and guiding functions of suppliers and optimize the policy design for innovation-oriented public procurement.




| Index level | Innovation R&D | | | | Innovation product | | | Innovation diffusion | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J |
| C1 | 0.982 | 0.973 | 0.964 | 0.961 | 0.956 | 0.955 | 0.861 | 0.836 | 0.895 | 0.872 |
| C2 | 1 | 0.863 | 0.924 | 0.915 | 0.942 | 0.983 | 0.866 | 0.917 | 0.923 | 0.896 |
| C3 | 0.017 | 0.019 | 0.021 | 0.022 | 0.021 | 0.02 | 0.021 | 0.029 | 0.022 | 0.026 |
| C4 | 0.896 | 0.912 | 0.899 | 0.955 | 0.936 | 0.933 | 0.924 | 0.922 | 0.937 | 0.926 |
| C5 | 0.852 | 0.918 | 0.897 | 0.884 | 0.893 | 0.875 | 0.916 | 0.923 | 0.904 | 0.899 |
| C6 | 96.5 | 94.6 | 92.6 | 92.1 | 91.8 | 93.6 | 93.2 | 88.4 | 92.7 | 93.4 |
| C7 | 6.62 | 3.58 | 7.55 | 6.55 | 5.58 | 6.20 | 4.15 | 4.85 | 6.90 | 6.86 |
| C8 | 0.2588 | 0.2532 | 0.1527 | 0.2542 | 0.2483 | 0.265 | 0.158 | 0.253 | 0.26 | 0.262 |
| C9 | 33.3 | 32.7 | 25.5 | 27.4 | 33.8 | 30.3 | 32.4 | 28.3 | 29.7 | 27.6 |
| C10 | 61.924 | 76.869 | 43.841 | 52.862 | 65.912 | 73.852 | 67.862 | 72.913 | 54.887 | 69.855 |
| C11 | 10.586 | 12.623 | 9.637 | 20.615 | 19.644 | 11.685 | 8.667 | 20.643 | 8.557 | 12.593 |
| C12 | 0.185 | 0.183 | 0.179 | 0.176 | 0.178 | 0.193 | 0.188 | 0.184 | 0.162 | 0.179 |
| C13 | 38.5 | 35.5 | 33.4 | 32.2 | 35.4 | 41.5 | 42.5 | 28.2 | 30.4 | 39.3 |
| C14 | 2.25 | 2 | 2 | 1.75 | 2 | 1.25 | 2 | 1.75 | 1.5 | 1.25 |
| C15 | 73.3 | 70.2 | 71.6 | 73.7 | 72.4 | 71.3 | 73.5 | 72.1 | 73.4 | 71.7 |
| C16 | 92.7 | 90.4 | 88.4 | 85.7 | 83.4 | 89.7 | 88.5 | 87.3 | 86.2 | 88.7 |
| C17 | 54.6 | 43.3 | 42.5 | 53.7 | 32.8 | 49.5 | 31.2 | 53.5 | 51.7 | 33.2 |
| C18 | 4 | 3 | 2 | 3 | 1 | 3 | 3 | 4 | 2 | 2 |
| C19 | 4 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| C20 | 3.23 | 2.15 | 1.65 | 2.5 | 3.08 | 2.75 | 2.68 | 1.53 | 2.06 | 1.49 |
| C21 | 1.57 | 1.02 | 1.15 | 0.78 | 0.98 | 3.22 | 1.38 | 1.79 | 2.68 | 1.03 |
| C22 | 28.5 | 25.4 | 30.7 | 30.9 | 18.6 | 30.27 | 15.78 | 16.5 | 12.4 | 10.3 |
| C23 | 20.3 | 17.2 | 16.4 | 9.5 | 8.7 | 13.74 | 14.78 | 10.3 | 9.13 | 10.86 |

Table 5. Original Data of Suppliers in Innovation Chain-oriented Public Procurement

| Index level | Innovation R&D | | | | Innovation product | | | Innovation diffusion | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J |
| C1 | 1.0000 | 0.9907 | 0.9630 | 0.9498 | 0.9238 | 0.9180 | 0.0706 | 0.0000 | 0.3516 | 0.1427 |
| C2 | 1.0000 | 0.0000 | 0.4144 | 0.3153 | 0.6192 | 0.9625 | 0.0012 | 0.3368 | 0.4032 | 0.1365 |
| C3 | 1.0000 | 0.9330 | 0.7500 | 0.6294 | 0.7500 | 0.8536 | 0.7500 | 0.0000 | 0.6294 | 0.1464 |
| C4 | 0.0000 | 0.1707 | 0.0064 | 1.0000 | 0.7652 | 0.6944 | 0.4601 | 0.4074 | 0.7874 | 0.5133 |
| C5 | 0.0000 | 0.9878 | 0.7040 | 0.4229 | 0.6205 | 0.2373 | 0.9762 | 1.0000 | 0.8335 | 0.7436 |
| C6 | 1.0000 | 0.8703 | 0.5291 | 0.4323 | 0.3753 | 0.7157 | 0.6434 | 0.0000 | 0.5484 | 0.6801 |
| C7 | 0.8706 | 0.0000 | 1.0000 | 0.8514 | 0.5059 | 0.7408 | 0.0500 | 0.2320 | 0.9353 | 0.9273 |
| C8 | 0.9925 | 0.9730 | 0.0000 | 0.9774 | 0.9464 | 1.0000 | 0.0055 | 0.9721 | 0.9951 | 0.9982 |
| C9 | 0.9911 | 0.9573 | 0.0000 | 0.1238 | 1.0000 | 0.6218 | 0.9314 | 0.2555 | 0.5095 | 0.1498 |
| C10 | 0.5743 | 1.0000 | 0.0000 | 0.1731 | 0.7522 | 0.9796 | 0.8275 | 0.9650 | 0.2515 | 0.8928 |
| C11 | 0.0679 | 0.2542 | 0.0196 | 1.0000 | 0.9832 | 0.1564 | 0.0002 | 1.0000 | 0.0000 | 0.2508 |
| C12 | 0.8445 | 0.7645 | 0.5757 | 0.4243 | 0.5253 | 1.0000 | 0.9372 | 0.8061 | 0.0000 | 0.5757 |
| C13 | 0.8191 | 0.5165 | 0.2923 | 0.1809 | 0.5055 | 0.9880 | 1.0000 | 0.0000 | 0.0573 | 0.8814 |
| C14 | 1.0000 | 0.8536 | 0.8536 | 0.5000 | 0.8536 | 0.0000 | 0.8536 | 0.5000 | 0.1464 | 0.0000 |
| C15 | 0.9681 | 0.0000 | 0.3455 | 1.0000 | 0.6965 | 0.2246 | 0.9920 | 0.5671 | 0.9820 | 0.3887 |
| C16 | 1.0000 | 0.8565 | 0.5590 | 0.1435 | 0.0000 | 0.7645 | 0.5757 | 0.3747 | 0.2075 | 0.6089 |
| C17 | 1.0000 | 0.5268 | 0.4732 | 0.9964 | 0.0115 | 0.8873 | 0.0000 | 0.9946 | 0.9626 | 0.0179 |
| C18 | 1.0000 | 0.7500 | 0.2500 | 0.7500 | 0.0000 | 0.7500 | 0.7500 | 1.0000 | 0.2500 | 0.2500 |
| C19 | 1.0000 | 0.5000 | 0.0000 | 0.0000 | 0.5000 | 0.5000 | 0.5000 | 0.5000 | 0.5000 | 0.5000 |
| C20 | 1.0000 | 0.3149 | 0.0207 | 0.6250 | 0.9818 | 0.8237 | 0.7731 | 0.0013 | 0.2422 | 0.0000 |
| C21 | 0.2371 | 0.0237 | 0.0557 | 0.0000 | 0.0165 | 1.0000 | 0.1419 | 0.3664 | 0.8839 | 0.0257 |
| C22 | 0.9669 | 0.8342 | 0.9998 | 1.0000 | 0.3498 | 0.9977 | 0.1647 | 0.2073 | 0.0254 | 0.0000 |
| C23 | 1.0000 | 0.8339 | 0.7461 | 0.0117 | 0.0000 | 0.3978 | 0.5379 | 0.0462 | 0.0034 | 0.0831 |

Table 6. Dimensionless Results of Innovation Chain Supplier Data

## Acknowledgement

This was supported by the National Natural Science Foundation of China (Grant#71073038).

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