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Research on the Grey-Fuzzy Comprehensive Evaluation Model of Man-Machine Engineering In the Special Machine-Tool System

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Abstract

This paper firstly performs literature reviews on concepts, theories related to industry cluster and man-machine engineering of special machine-tool system in the research, finds the research method in this article and elaborates on it. Secondly, common elements and specific elements influencing man-machine engineering of special machine-tool system in machine-tool industry are summarized through the research and study of the innovation situation of Shenyang machine-tool city. Indices system for evaluating the man-machine engineering of special machine-tool system is built by referring to the framework for measuring enterprise's innovation in Oslo Manual. After that, questionnaire is designed based on the built index system and field research and in-depth interview are carried out to collect data needed. The method of ANP is used to measure the man-machine engineering of special machine-tool system in Shenyang machine-tool city, its evaluation value is obtained, the in-depth analysis of evaluation value is conducted using the evaluation criteria built to ultimately draw the following conclusions.

Keywords: *grey-fuzzy comprehensive evaluation，man-machine engineering，special machine-tool system*

1. Introduction

Since the 1980s, man-machine engineering in special machine-tool system, as a new form of industrial organization, has developed rapidly around the world. Man-machine engineering in special machine-tool system successively arose in many countries, such as the man-machine engineering in high-tech special machine-tool system in America's silicon valley, man-machine engineering in textile- industry special machine-tool system in north Italy, man-machine engineering in automobile-industry special machine-tool system in Germany's Munich and man-machine engineering in special machine-tool system in Taiwan's Hsinchu ,*etc*. Man-machine engineering in special machine-tool system presents various advantages in its development, including scale advantage, cost advantage and technology spillover ,*etc* (S. Bute,2008). These advantages not only drives the rapid development of man-machine engineering in special machine-tool system, but promotes the rapid development of regional economy and facilitates China's rise, which make man-machine engineering in special machine-tool system become a new development mode. In recent years, China's man-machine engineering of special machine-tool system has developed rapidly and forms numerous man-machine engineering of special machine-tool system, including equipment-manufacturing-industry man-machine engineering of special machine-tool system in Taxi, Liaoning , biopharmaceutical man-machine engineering of special machine-tool system in Harbin, Heilongjiang, artificial-leather man-machine engineering of special machine-tool system in Longwan, Zhejiang, white-spirit-brewing man-machine engineering of special machine-tool system in Chengdu, Sichuan ,*etc*. The man-machine engineering of special machine-tool system in Liaoning develops rapidly. Typical man-machine engineering of

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special machine-tool system includes: man-machine engineering of special machine-tool system in Tiexi, Shenyang, software and information technology service man-machine engineering of special machine-tool system, magnesite-products man-machine engineering of special machine-tool system in Dashiqiao.

The rapid development of this man-machine engineering of special machine-tool system play big role in the economic development of many cities in Liaoning, promotes the rapid growth of regional economy and increases the competitiveness of regional industries. The man-machine engineering of special machine-tool system in Shenyang has a great development momentum. As of November, 2011, the output value of all man-machine engineering of special machine-tool system in Shenyang City exceeded ¥409 billion, accounting for more than 35% of Shenyang's gross value of industrial output, and taxes paid amounted to ¥7.7 billion (Guan and Jun, 2014). The upgrading of industrial structure and great economic benefits brought by man-machine engineering of special machine-tool system make it receive attentions. Innovations are introduced to facilitate the development of man-machine engineering of special machine-tool system. Innovative activities, such as process innovation, product innovation and organizational innovation, promote the enterprises' product upgrading, improve their production efficiency, make their products more competitive in the market, increase the market share, bring them enormous economic benefits and ultimately drive the rapid development of the entire industry**(**Guan et.al,2014**)**. The competitiveness of man-machine engineering of special machine-tool system is derived from the innovation power of man-machine engineering. For instance, the man-machine engineering of special numerically-controlled machine-tool system in Shenyang is relatively powerful. It has achieved prominent innovative results, undertaken 121 state-level science-and-technology projects, developed more than 300 new products of numerically-controlled machine tool and achieved their commercialization, totally obtained around 500 patents and nearly 500 scientific and technical achievements. In 2009 the total output value of man-machine engineering of special machine-tool system reached ¥35 billion. Thus it can be seen that the innovation of man-machine engineering of special machine-tool system can effectively reduce the production and transaction costs of enterprises in it, and bring them more significant economic benefits (Emmanuel and Franck, 2009).

2. Strategy and Method of Evaluating Man-Machine Engineering of Special Machine-Tool System

2.1 The Principle of Building the Index System

The purpose of building index system is to have an in-depth and systematical understanding of the overall characteristics of the evaluation object. Suitable and scientific evaluation-index system is the basis of evaluation, which can evaluate the research object from multiple levels and angles. The principle of building index system is as follows.

(1) Effectiveness the principle of effectiveness refers to the design of index system must conform to the contents of evaluation objective. One of the important standards of an effective and reasonable index system is that it must meet the evaluation objective and support the ultimate evaluation criteria. For instance, the index system built in this paper to evaluate Shenyang man-machine engineering of special machine-tool system must reflect its characteristics.

(2) Scientific principle of scientific is the basis of an accurate and reasonable evaluation result. The scientific of evaluation heavily depends on the evaluation criteria, method and indices. The principle of scientific primarily covers three aspects, including accuracy, completeness and independence. Accuracy refers to clear and accurate meaning of indices; completeness refers to an overall reflection of the characteristics of evaluation

object; independence means the criterion layers must be mutually independent as far as possible to reduce repetition (Ana *et al*, 2016).

(3) Operability the principle of operability specifically includes three aspects, including availability, quantification and simplification. Among them, the availability means the data of the index system exists in real life and can be obtained by referring to the professional yearbooks (Ke *et al*, 2010), processing the existing data and doing the field survey. Quantification means the design of index system should take quantitative indices into account as much as possible and qualitative indices should be able to be quantified through some means. Simplification means the number of indices should be as small possible on the premise that the reflection of overall characteristics of the research object is ensured.

2.2. Evaluation Processes

The comprehensive evaluation of physical education is an evaluation result produced through comprehensive consideration of multi-category indices. To conduct comprehensive evaluation, single-category indices must be firstly evaluated, because specific evaluation index cannot be determined until the category of the index is differentiated. Evaluation of single-category index is to evaluate the scale each evaluation object belongs to in this category of evaluation indices. However, good or bad performance of one evaluation object on one index cannot represent the object's overall performance (K. Gure and A. Pturn, 1993). As a result, when the overall situation of the evaluation object needs to be known, a comprehensive evaluation model needs to be built to conduct comprehensive evaluation of the object combined with various evaluation indices. When the evaluation result mostly conforms to the overall evaluation of this student by his teachers and classmates, then it means the evaluation result is reasonable. Otherwise, the student's sample value should continue to be investigated and do a reevaluation. The workflow of learning-results evaluation is shown in Figure. 1.

3. Comprehensive Evaluation of Man-Machine Engineering In Special Machine-Tool System Based On the Theory of Fuzzy Evaluation

3.1. Building the Model

Definite weighted function is a function expressing the possible value of each element in the grey category. It is used to describe the preference of different value of the grey number in its value range. Generally, definite weighted function is designed by the researcher on the basis of known information without fixed design formula, but the determination of each turning point is crucial to the function. Definite weighted function has an important place in the grey system theory. Meanwhile, the determination of definite weighted function is one of the key links in the gray-clustering evaluation and is the key to the transition from qualitative analysis to quantitative modeling. The common definite weighted function has 4 basic forms: typical definite weighted function, upper-limit measuring definite weighted function, lower-limit measuring definite weighted function and moderation measuring definite weighted function.

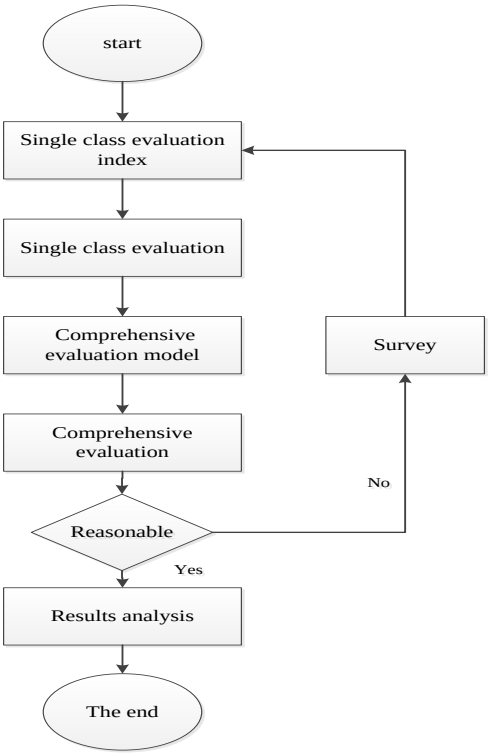

Figure 1. Grey-Fuzzy Comprehensive Evaluation Process

The key to determining definite weighted function is the determination of turning point, which reflects whether the determination of the function is scientific. The typical definite weighted function f(x) is a function that has determined starting point and end point and whose left side is an increasing function and the right side is a decreasing one, If the definite weighted function f(x) does not have the first and second turning points, then it is a lower-limit measuring definite weighted function, If the second and third turning points of the definite weighted function f(x) coincide, then it is a moderation measuring definite weighted function, If the definite weighted function f(x) does not have the third and fourth turning points, then it is an upper-limit measuring definite weighted function.

When we need to learn about the position and scale of one evaluation object in an overall index sample, the gray clustering technique in gray system needs to be used. Using gray clustering technique to build evaluation model is specifically presented as follows:

The evaluation model is expressed as: PJ=(A,B,C), among which, $A=\{A_1, A_2, A_3,\ldots,A_m\}$ is the object set evaluated; $B=\{B_1, B_2,B_3,\ldots,B_n\}$ is the evaluation-category set; $C=\{C_1, C_2,C_3,\ldots,C_t\}$ is the evaluation scale.

For instance, there are m students forming object set A, single-category evaluation is conducted among n evaluation categories and its results from $B=\{B_1,B_2,B_3,\ldots,B_n\}$. T evaluation scales are set $\{C_1,C_2,C_3,\ldots,C_t\}$, which can be excellent, good, qualified, unqualified ,*etc*.

For the n single-category evaluation indices above, values of the indices are obtained through testing and the definite weighted function is created to do clustering analysis of the m clustering objects (students), thus determining the grey category, among the t grey categories, the clustering objects belong to. M clustering objects are recorded as $A_1,A_2,A_3,\ldots,A_m$, clustering indices as $B_1,B_2,B_3,\ldots,B_n$, grey category as $C_1,C_2,C_3,\ldots,C_t$.

Now the sample matrix of all clustering objects to all indices is assumed as d, then among which the d_{ij} is the sample value of the i_{th} clustering object Ai on the j_{th} clustering index B_j.

$$d = \begin{bmatrix} d11 & d12 & \vdots & d1n \\ d21 & d22 & \vdots & d2n \\ \vdots & \vdots & \vdots & \vdots \\ dm1 & dm2 & \vdots & dmn \end{bmatrix} \quad (1)$$

L<i<m,1<j<n. Creating the definite weighted function f_{ik}, 1<j<n, 1<k<t, f_{jk} is the definite weighted function of the j_{th} index B_j belongs to the kth grey category.

Calculating the grey vector:

$$\sigma_i = (\sigma_{1i}, \sigma_{i2}, \cdots, \sigma_{it}), 1 \le i \le m \quad (2)$$

Mapping $F_{ik} \rightarrow \sigma_{ik}$ is called gray clustering, among which:

$$\sigma_{ik} = \sum_{j=1}^{n} f_{jk}(d_{ij}) \eta_{jk} \quad (3)$$

$$\eta_{jk} = \frac{\lambda_{jk}}{\sum_{j=1}^{n} \lambda_{jk}} \quad (4)$$

3.2. Processing Procedure of Fuzzy Evaluation

The steps in using learning-result comprehensive-evaluation model based on gray clustering in comprehensive evaluation are as follows:

(1) selecting evaluation sample and determining the evaluation objects, which are expressed as $A_1, A_2, A_3, \ldots, A_m$; Determining the evaluation indices, which are expressed as $B_1, B_2, B_3, \ldots, B_n$; Determining the evaluation grey categories, which expressed as $C_1, C_2, C_3, \ldots, C_t$.

(2)according to the actual sample value obtained, determining the sample matrix $d=(d_{ij})_{mn}$, D_{ij} is the sample value of the i_{th} clustering object A_i on the j_{th} clustering index B_j.

(3) Determining the whiteness function of evaluation grey categories, which is the definite weighted function of the j_{th} index B_j belonging to the kth grey category.

(4) Calculating the calibration cluster weight, λ_{jk} is the threshold value of f_{jk}, η_{ij} is the weight of the j_{th} index belonging to the kth grey category.

(5) Calculating the gray clustering weight, $f_{jk}(d_{ij})$ is the whiten weight of sample value d_{ij} belonging to the kth grey category, which comprehensively reflects the weight of the i_{th} evaluation object belonging to the kth grey category.

(6) Calculating the grey vector σ_i, $\sigma_i=(\sigma_{i1},\sigma_{i2}\ldots\ldots,\sigma_{it})$.

(7) if $\sigma_{ik}= \max\sigma_{ik}= \max\{\sigma_{i1}, \sigma_{i2}\ldots\Sigma_{ik}\}$, then the i_{th} clustering object A_i belongs to the k*th grey category C_k.

4. Case Analysis

4.1. Brief Introduction to the Case

This paper takes Shenyang special machine tool as the example and evaluates the man-machine engineering in special machine-tool system through the method of fuzzy evaluation. Indices selected are as follows:

Table 1. Specific Index System of Innovation Synergy

Rule layer	Primary index layer	Secondary index layer
Innovation environment	The government support	Policy support
		The proportion of fiscal investment in innovation
		The special funds
		The proportion of risk investment
		Technology development bank loan proportion
	Innovation base	University scientific research institution's contribution in the machine tool
		The proportion of scientific research institutions and university cooperation project
		Communication situation
		Industrial workers population proportion
	Innovation atmosphere	The machine output
		Machine peripheral services business developed
		Importance in the national, provincial planning
		Industry regulation's contribution in the machine tool

The proportion of fiscal funds in innovation refers to fiscal funds/ total science and technology expenditures of Shenyang machine-tool city. Shenyang machine-tool city is at its development and expansion stage, the value of this index is very important for the development of Shenyang man-machine engineering of special machine-tool system. Major special funds refer to the special funds that are exclusively used to solve the problems of funds shortage and risks in the innovation of the enterprises in Shenyang machine-tool city. The proportion of venture capital refers to venture capital/ total assets of Shenyang machine-tool city. The proportion of bank loan for technological development refers to bank loan for technological development of Shenyang machine-tool city / total science and technology expenditures of Shenyang machine-tool city. The degree of contribution to Shenyang machine-tool city made by universities and scientific institutions refers to the contributions made by universities and scientific institutions in innovative activities of enterprises in Shenyang machine-tool city, which is a qualitative index and is processed with five divided method of Likert scale. The proportion of cooperation projects with universities and scientific institutions refers to number of projects on which Shenyang machine-tool city cooperates with universities and scientific institutions/ total number of corporate-cooperation projects of Shenyang machine-tool city, which reflects the interaction between Shenyang machine-tool city and universities and scientific institutions.

Table 2. Specific Index System of Innovation Synergy

Rule layer	Primary index layer	Secondary index layer
Innovation synergy	Synergy	Supply chain synergy degree
		The number of companies per square kilometer
		The location factor
	The collaborative management	The member of The public service
		Collaborative management institution
	Bilateral ties	The proportion of enterprise cooperation fund

	The contact of before and after	The proportion of enterprise cooperation project with the outside world
		The degree of competition between enterprises
		The proportion of duty relationship between the companies
		The proportion of local raw materials procurement
		The proportion of local sales
	Multilateral contact	technology exchange activities organized by the government
		technology exchange activities organized by the industry association
		technology exchange activities organized by the enterprises

Under the criterion layer of innovation synergy, five aspects are subdivided, including synergy foundation, synergy management, and bilateral relations, forward and backward linkag and multilateral relations. For the synergy foundation, indices are selected mainly from three aspects, including correlation degree of industry cluster, agglomerating degree and specialization degree. The synergetic degree of supply chain is used to represent the degree of correlation between industries. Number of enterprises per square kilometer is used to represent the agglomerating degree of Shenyang machine-tool city. Location entropy coefficient is used to reflect the specialization degree of Shenyang machine-tool city. For the synergy management, indices are selected primarily from two aspects, including platform and organization that provide services for the innovation of enterprises in Shenyang machine-tool city. Public service platforms make great contributions to the innovation of enterprises in Shenyang machine-tool city. Organizations are mainly represented with synergy-management organizations, through which various services and opportunities are provided for the innovations of enterprises in Shenyang machine-tool city.

Table 3. Innovation Synergy and Innovation Environment of Global Weight

Rule layer	group	The element	The element weight	Global weight
Innovative environment	The government's support	Policy support	0.211	0.012
		Innovation of the financial investment proportion	0.362	0.025
		Significant number of special funds	0.125	0.029
	Innovation base	The proportion of risk investment	0.120	0.004
		Technology development bank loan proportion	0.198	0.007
		University scientific research institution's contribution to the enterprise	0.074	0.003
		The proportion of scientific research institutions and university cooperation projects	0.036	0.003
		Communication situation	0.058	0.002

Innovative synergy	Synergy	Industry workers	0.165	0..007
		Gross output value	0.254	0.012
		Services developed around	0.063	0.003
		In the important degree of state planning	0.500	0.06
		Contribution degree	0.500	0.016
	The collaborative management	Supply chain synergy degree	0.479	0.013
		The number of companies per square kilometer	0.205	0.014
		The location factor	0.315	0.009
	Bilateral ties	The member of The public service	0.487	0.069
		Collaborative management institution	0.203	0.147
		The proportion of enterprise cooperation fund	0.369	0.025
	The contact of before and after	The proportion of enterprise cooperation project with the outside world	0.589	0.036
		The degree of competition between enterprises	0.411	0.058
	Multilateral contact	The proportion of duty relationship between the companies	0.369	0.012
		The proportion of local raw materials procurement	0.292	0.136

Under the index layer of bilateral relations, two aspects of contents, including competition and cooperation, are primarily reflected. The proportion of corporate-cooperation funds and proportion of projects on which enterprises cooperate with the outside are used to reflect the cooperation situation of enterprises in Shenyang machine-tool city. The degree of competition between enterprises and the proportion of enterprises competing with others in Shenyang machine-tool city are used to reflect the competition situation of enterprises in the city.

(1) The evaluation objects A_1, A_2, A_3, A_4, A_5 are determined based on the evaluation sample, with the corresponding serial numbers being 1, 2, 3,……, n;

4.2. Analysis of the Results

(2) The sample matrix is obtained based on the actual sample value obtained, as is shown in Table 1.

(3) The definite weighted function $f_{jk}(x)$ of evaluation grey categories is determined based on the expertise and relevant standards.

The evaluation results show that the development of man-machine engineering of special machine-tool system in Shenyang machine-tool city in 2011 and 2012 was at moderate level. The reason is that: firstly, Shenyang machine-tool city was founded not long ago, 39 enterprises had entered it by 2011 and 80 by 2012. These enterprises developed longer than Shenyang machine-tool city did. The conception of building Shenyang machine-tool city was developed in 2010, three years has passed to this day. Whereas the enterprises entering it have undergone many years of development and some

achievements in innovation have been made. Secondly, the government provides great financial support for the enterprises' man-machine engineering of special machine-tool system in Shenyang machine-tool city. To facilitate the rapid development of man-machine engineering of special machine-tool system in the city, the municipal Science and Technology Bureau invests ¥10 million a year in building the public research & development service platform, and the government sets up special funds for innovative key projects and products and has invested ¥0.2 billion for 5 consecutive years to support the innovation in key fields. Thirdly, relevant policy support is provided. The government introduces preferential policy of "two exemptions and one halving" to enterprises entering Shenyang machine-tool city so as to attract the enterprises to enter it. Fourthly, devices, components and parts produced in Shenyang machine-tool city belong to mid- and high-end technical field and the foundation of its man-machine engineering of special machine-tool system is good. All these enable the city's man-machine engineering of special machine-tool system to reach the normal level at its take-off stage.

5. Conclusion

This paper firstly performs literature reviews on concepts, theories related to industry cluster and man-machine engineering of special machine-tool system in the research, finds the research method in this article and elaborates on it. Secondly, common elements and specific elements influencing man-machine engineering of special machine-tool system in machine-tool industry are summarized through the research and study of the innovation situation of Shenyang machine-tool city. Indices system for evaluating the man-machine engineering of special machine-tool system is built by referring to the framework for measuring enterprise's innovation in Oslo Manual. After that, questionnaire is designed based on the built index system and field research and in-depth interview are carried out to collect data needed. The method of ANP is used to measure the man-machine engineering of special machine-tool system in Shenyang machine-tool city, its evaluation value is obtained, the in-depth analysis of evaluation value is conducted using the evaluation criteria built to ultimately draw the following conclusions.

Firstly, the man-machine engineering of special machine-tool system in Shenyang machine-tool city presents an increasing trend. It is found by empirical research that the evaluation value of man-machine engineering of special machine-tool system was 0.455348 in 2011 and 0.540081 in 2012, which takes on an increasing trend. The reasons are as follows: Enterprises in Shenyang machine-tool city develop longer than the city itself and enterprises have made certain achievements in innovation; the government's financial support and policy support; Products produced by enterprises in Shenyang machine-tool city are products with mid- and high-end technologies and the city has a good foundation for innovation.

Secondly, the man-machine engineering of special machine-tool system in Shenyang machine-tool city is at intermediate level. The values of man-machine engineering of special machine-tool system in Shenyang machine-tool city obtained in 2011 and 2012 are between 0.4 and 0.6, which is an intermediate level. The reasons are as follows: good agglomerating effect, the governments financial and policy support, increasingly abundant scientific-research resources, and good development trend of three aspects, including innovation performance, innovation synergy and innovation environment.

References

[1] V.P. Emmanuel and P. Franck, "Managing engineering knowledge in special machine design companies", KMIS 2009-1st International Conference on Knowledge Management and Information Sharing, Proceedings, vol. 3, **(2009)**, pp. 123-128.
[2] S. Bute, "On Some Problems of Manufacturing and Use of Special Machine Tools in Machinery Industry", OMIKK-Technoinform, vol. 2, **(2008)**, pp. 284-293.

[3] K. Gure and A. Pturn, "Flexible Special Machine - a Possibility for Rationalization of Middle and Small Batch Manufacturing", OMIKK-Technoinform, vol. 8, **(1983)**, pp. 188-195.
[4] Y.K. Guan and S. Jun, "The design & calculation for hydraulic cylinder of a special machine for heat exchanger tube bundle drawing and assembling", Applied Mechanics and Materials, vol. 496, **(2014)**, pp. 789-792.
[5] Y.K. Guan, S. Jun and J.J. Bo, "The key technologies in designing of a special machine for heat exchanger tube bundle drawing and assembling", Applied Mechanics and Materials, vol. 496, **(2014)**, pp. 793-796.
[6] G. Kerstin, "On the threshold of 5th generation - special machine construction in Siegerland", Stahl und Eisen, vol. 120, **(2000)**, pp. 67-70.
[7] V. Ana, T.R. Majid and H. Kevin, "New cost model for feasibility analysis of utilising special purpose machine tools", International Journal of Production Research, vol. 30, pp. 1-15, **(2016)**.
[8] W. Ke, L. Guang and W.S. Xing, "Analyzing of dynamic characteristics of special CNC machine tool", Applied Mechanics and Materials, vol. 29, pp. 2037-2041, **(2010)**.

