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Production Performance Diagnosis of Manufacturing Workshop based on Fuzzy-Gray Correlation Degree Evaluation

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Abstract: The need for manufacturing enterprises to explore the shortcomings of their workshop production performance has become aggrandized as the fierce competition in manufacturing industry. The traditional evaluation of the production performance focused on the contrast of different enterprises. However, the problems of the worse workshops or enterprises are still unknown. Many manufacturing enterprises not only want to find out the competitive position of their workshop, but also want to find out the problems in their workshop and then improve them to enhance the production performance. This study built a Fuzzy-Gray Correlation Degree (FGCD) evaluation model based on rough set to aid enterprise to detect the problems in workshops. The FGCD model provided a comprehensive evaluation indicators system to present the competitiveness of the workshop from different views. In order to present an objective and accurate model for manufacturing enterprises, a combined empowerment method based on rough set theory for indicators has been applied. Finally, the case was used to support the available of production performance diagnosis of workshop. The model can determine the condition of production performance from different indicators and diagnose the corresponding workshop problems in manufacturing process.

Keywords: Comprehensive evaluation, fuzzy-gray correlation degree, production performance diagnosis, production performance, rough set

INTRODUCTION

The production performance of manufacturing workshop is the reflection of the competitiveness of the manufacturing enterprises, especially in the current fierce competition market environment. The manufacturing enterprises have changed the focuses on products to customer. The traditional manufacturing philosophy of oriented to products has been changed to quality, price, flexibility, service, satisfaction and so on. Manufacturing enterprises needs to face the new challenges and improve the competitiveness to survival (He *et al*., 2009). There are varieties of customers' demands for products. As a result, the traditional mass production has replaced by the small batch and customised production method. Workshop manufacturing process has also been affected by this trend. Workshop is the execution layer of the production planning. The manufacturing process in workshop is crucial for the entire strategy of manufacturing enterprises. The production performance of workshop determines the production capacity, efficiency and quality of the enterprise. It is necessary to improve the production performance of workshops. However, the first step for improvement is to diagnose the manufacturing problems in workshop and find out the weakness of the production process.

For manufacturing enterprises, it is also important to discover the gaps of production performance indicators with other opponents in the same industry. Therefore, it needs a comprehensive evaluation method to diagnose the gaps between them. However, the current evaluation methods are mainly focused on some special fields. The relationship of clean production to the business performance has been studied (Zeng *et al*., 2010). The financial performance of production is the main topics of former researchers (Hendrik *et al*., 2006; Christian *et al*., 2012). There are also some results about the quality management to the production and customer performance (Arawati and Za'faran, 2011). The above research only chose the special indicators to describe the production performance, which is unable to reflect the objective production situation of the real workshop.

Besides, some researchers focused on the special environment of the manufacturing system to study its performance. The lean performance evaluation of the manufacturing system (Asli and Nursel, 2011) and the production performance in just-in-time production environments were studied (Behrouz and Wong, 2011). For the traditional workshop, there are fewer results on the comprehensive production performance evaluation.

As a result, it is necessary to make a comprehensive production performance evaluation for the workshop of manufacturing enterprise. Through the evaluation, it can

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diagnose the bad performance of workshop in some fields. These fields will become the key in the future improvement. The diagnosis for the weak points of the workshop is benefit for enterprise to input the limited money and energy into the necessary fields.

The evaluation is the basis for diagnosis for the production process. This study uses the benchmark management theory to compare the value of each index and find out the weaker ones. In order to make an objective evaluation for the workshop, a Fuzzy-Gray Correlation Degree (FGCD) evaluation method base on rough set has been applied. FGCD evaluation can find out the weaknesses spots in workshop and then improve them to enhance the competitiveness of manufacturing enterprises. However, the traditional diagnosis methods of manufacturing performance are mainly focused on the products and neglect other indicators. As a result, they cannot make an objective and comprehensive evaluation for the workshop and enterprise cannot find out the indeed problems in manufacturing process (Li *et al.*, 2010). Through the field research, 16 evaluation indicators were chosen to fully disclosure the manufacturing performance of workshops. The evaluation model can not only diagnosis the weakness in performance, but also can determine the competitive positions of enterprises in the fierce competition environment.

CONSTRUCTION OF DIAGNOSIS EVALUATION INDICATORS

The production performance of manufacturing enterprises is mainly relying on the performance of workshop system. Manufacturing enterprises need the support of workshop fabrication system to meet the demand of customers with lower cost, higher quality and best service. However, the fierce competition environment increases the difficulty of management in manufacturing shop. With the emergence of networked manufacturing, global manufacturing, supply chain management, service manufacturing and other novel manufacturing management, many workshops found that it hard to adapt to the demand of market. They encounter many problems in production and need a method to diagnose the weakness timely to improve.

The former improvement methods of production performance are mainly from the view of financial cost management. However, customers proposed higher demand in quality, cost, delivery, service and flexibility (Chen, 2008). Lan (2010) studied the cost control and evaluation method in Toyota Production System (TPS) from the time, quality and cost. Yuan *et al.* (2007) applied the AHP model to evaluate a reconfigurable manufacturing system. Li (2008) used the throughput, cycle time, work in process and utilization indicators to describe the production performance of semiconductor package and testing production line. Yang *et al.* (2009) proposed a comprehensive performance evaluation model to describe the competitiveness of enterprise.

In order to make a systematic, reasonable and scientific evaluation for the production performance, the following principles should be followed:

- **Comprehensiveness:** The evaluation system should contain the key performance characteristics of the workshop
- **Purposiveness:** The evaluation should have the clear target
- **Uniqueness:** The indicators in the evaluation should be unique
- **Combination of qualitative and quantitative indicators:** There are some performance should use the qualitative indicators
- **Reliability:** The evaluation results should reliable

All indicators should be evaluated by qualitative or quantitative methods. According to the analysis of literatures and field survey, three layers of evaluation indicators system was built in Table 1.

PRODUCTION PERFORMANCE BASED ON FUZZY-GRAY CORRELATION DEGREE EVALUATION MODEL

Determine the value of indicators: In this evaluation system, most of indicators are quantitative and can be calculated or collected from the production process. However, the indicators: Innovative coefficient C12 is a qualitative index. The innovative coefficient usually uses the semantic description method, such as the 'high' or 'low'. It should use the membership function to transfer the qualitative information into quantitative data (Riera and Torrens, 2012). As a result, we should transfer this information into quantity relationship. We use the following fuzzy evaluation to determine the value of the indicators, as show in Table 2.

Determine the weightiness of indicators: There are two main methods to determine the weightiness of indicators. One is the objective empowerment method and the other is the subjective empowerment. This study proposed a combination empowerment method to take advantages of both subjective and objective empowerment methods. The rough set theory was used to determine the weightiness. The definition of rough set decision tables is as following:
Decision table is a knowledge expression system:

$$S = (U, C, D, V, f) \tag{1}$$

U = The non-empty finite sets of all objectives
C = The condition attributes set
D = Decision attributes set
V = $\bigcup_{\alpha \in A} V_\alpha$
V_α = The range of α

Table 1: Production performance evaluation indicators

First-grade indicator	Secondary indicator	Third-grade indicators
Production performance A	Production efficiency B1	Productivity C1Raito of effective production time C2 Capacity factor C3 Man efficiency C4 Line balancing rate C5
	Economy B2	Production cost C6 Management cost C7 Cost rate of quality C8
	Production capacity B3	Capacity C9 Equipment dependability C10 Variety of products C11 Innovative coefficient C12
	Service ability B4	Tardiness C13 Finishing rate C14
	Quality of products B5	Qualified products rate C15 Fine rate of quality C16

Table 2: Fuzzy evaluation of indicators

Describe	Value
Very high	7
High	5
General	3
Low	1
Very low	0

f : UA → V is an information function:

$$\forall a \in A, \quad x \in U, \quad f(x,a) \in V_a$$

The dependence degree of decision attribution D to arbitrarily condition attribution indicators set B ⊆ C is:

$$\gamma_B(D) = |POS_B(D)| / |U| \tag{2}$$

$\forall_c \in C$, he importance degree of condition attribute index c is:

$$Sig(c) = \gamma_c(D) - \gamma_{c-|c|}(D) \tag{3}$$

The weight of c is:

$$W(c) = \frac{Sig(c)}{\sum_{a \in C} Sig(a)} \tag{4}$$

Then the importance degree of condition attributes C_i to D can express as the following equation:

$$w_i = \gamma_C(D) - \gamma_{C-|C_i|}(D) \tag{5}$$

After normalization:

$$w_i' = w_i \Big/ \sum_{i=1}^{n} w_i \tag{6}$$

Chose of reference series: Reference series are used to represent the best performance of enterprise. For m evaluation unites and n evaluation indicators, v_{ik} is the evaluation value of index $k(k = 1,2,\ldots,n)$ of evaluation unite i $(i = 1,2,\ldots,m)$ v_{0k} is the optimum value of index k.

For:

$$V = (V_{ik})_{m\times n} = \begin{bmatrix} V_{11} & V_{12} & \ldots & V_{1n} \\ V_{21} & V_{11} & \ldots & V_{11} \\ \vdots & \vdots & & \vdots \\ V_{m1} & V_{m2} & \cdots & V_{mn} \end{bmatrix}$$

We choose the reference series as the compare object:

$$V_o = (v_{01}, v_{02}, \ldots, v_{0n})$$

Normative approach of indicators values: We use the normative approach to eliminate the effect of dimensions:

$$X_{ik} = \frac{V_{ik} - \min_i V_{ik}}{\max_i V_{ik} - \min_i V_{ik}} \tag{7}$$

After the process of normative approach, the new value of the indicators can be described as:

$$X = (X_{ik})_{m\times n} = \begin{bmatrix} X_{11} & X_{12} & \ldots & X_{1n} \\ X_{21} & X_{11} & \ldots & X_{11} \\ \vdots & \vdots & & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix}$$

We choose the new reference series according to the above principle:

$$X_o = (x_{01}, x_{02}, \ldots, x_{0n})$$

Calculation of correlation degree: Correlation degree is the reflection of the relevance between compare series and reference series. The larger of the correlation degree says the better the production performance.

As we know, $X_i = (x_{i1}, x_{i2},\ldots,x_{in})$ is the compare series, ξ_{ik} is the coefficient of association of the No. i to the index of No. k:

$$\xi_{ik} = \frac{\min_i \min_k |X_{ok} - X_{ik}| + \rho \max_i \max_k |X_{ok} - X_{ik}|}{|X_{ok} - X_{ik}| + \rho \max_i \max_k |X_{ok} - X_{ik}|} \tag{8}$$

$\rho \in [0,1]$ Resolution ratio

In this study, we set $\rho = 0.5$.

Single-tier correlation degree: For the indicators has the different weightiness, the correlation degree is calculated by the weightiness multiply by the relevance. Through the rough set theory, the weightiness of the indicators are:

$$W = (w_1, w_2, \ldots, w_n)$$

and,

Table 3: Indicators data

Indicators	A1	A2	A3	A4	A5	Reference
C1	0.46	0.45	0.36	0.16	0.25	0.46
C2	0.74	0.68	0.78	0.83	0.82	0.83
C3	0.58	0.78	0.75	0.75	0.77	0.78
C4	1.5	2.5	0.8	1.5	2.2	2.5
C5	0.75	0.80	0.85	0.82	0.78	0.85
C6	102	155	132	98	154	155
C7	0.12	0.15	0.09	0.21	0.25	0.25
C8	0.32	0.35	0.4	0.36	0.25	0.4
C9	180	150	160	180	200	200
C10	0.5	0.4	0.7	0.6	0.5	0.7
C11	4	3	5	3	2	5
C12	7	5	5	3	7	7
C13	10	15	8	12	10	15
C14	0.82	0.78	0.95	0.85	0.71	0.95
C15	0.95	0.96	0.94	0.95	0.93	0.96
C16	0.84	0.85	0.78	0.75	0.89	0.89

$$\sum_{k=1}^{t} w_k = 1$$

t = Number of the indicators

The gray correlation degree can be calculated by:

$$R = (r_i)_{1\times m} = (r_1, r_2, ..., r_m) = WE^T \quad (9)$$

Final correlation degree calculation and sequencing: The final correlation degree is calculated lay-by-layer. Correlation degree r_i presents the relation of indicators with the optimum values. According to correlation degree, the weakness of workshop in production can be found.

CASE STUDY

Production performance evaluation: Five manufacturing workshops were selected (A1, A2, A3, A4, A5) to diagnosis the problems in production performance. We want to find out the performance position of each workshop and then provide suggestion to improve the worst one. The indicators system is showing in Table 1. There are three levels of evaluation indicators to present the production performance of the workshop. The original indicators values are represented as V_{ik} , (i = 1, 2,…, m; k = 1, 2,…, n) and show in the following Table 3.

Through the analysis of rough set, the weights of secondary indicators are:

$$W = (w_1, w_2, w_3, w_4, w_5)$$

= (0.32, 0.16, 0.14, 0.23, 0.15)

Third-grade indicators weights are:

$$W_{B1C} = (0.26,\ 0.12,\ 0.21,\ 0.12,\ 0.19)$$

$$W_{B2C} = (0.28,\ 0.42,\ 0.30)$$

$$W_{B3C} = (0.26,\ 0.28,\ 0.14,\ 0.32)$$

Table 4: Indicators data of single layer relevance coefficient

Indicators	A1	A2	A3	A4	A5	Satisfaction
C1	1	0.97	0.67	0	0.3	1
C2	0.4	0	0.67	1	0.93	1
C3	0	0.91	0.77	0.77	0.86	1
C4	0.32	1	0	0.32	0.64	1
C5	0	0.5	1	0.7	0.3	1
C6	0.07	1	0.6	0	0.98	0
C7	0.19	0.38	0	0.75	1	0
C8	0.47	0.67	1	0.73	0	0
C9	0.6	0	0.2	0.6	1	1
C10	0.33	0	1	0.67	0.33	1
C11	0.67	0.3	1	0.33	0	1
C12	1	0.5	0.5	0	1	1
C13	0.28	1	0	0.57	0.28	0
C14	0.46	0.29	1	0.58	0	1
C15	0.67	1	0.33	0.67	0	1
C16	0.64	0.72	0.21	0	1	1

$$W_{B4C} = (0.42, 0.58)$$

$$W_{B5C} = (0.56, 0.44)$$

The single layer relevance coefficient is showing in Table 4. If the satisfaction vale of the indicator is ‘1’, it says that the indicators are better as the larger of the value. When satisfaction is ‘0’, the indicators are worse as the larger of the value.

The gray correlation degree of the five workshops in the first-grade indicator A can be calculated by formula (9):

Then, R = (0.602, 0.539, 0.674, 0.606, 0.522)

According to the gray correlation degree, the production performances of five manufacturing workshops are: A3>A4>A1>A2>A5, as shown in Fig. 1.

Production performance diagnosis of benchmark: The above production performance evaluation use the optimal solution as the reference series, however, the workshops cannot reach the extent of the optimum of each index. As a result, the diagnosis for the production performance with the reference series cannot acquire the accurate results to guide the improvement of manufacturing workshops. Therefore, benchmark method was applied to the evaluation. The benchmark workshop is not the workshop with the best indicators performance in each field, but the best in total production performance. Benchmark is more closely related with the real workshop situation. The benchmark workshop data was used to replace the above reference series: (0.43, 0.78, 0.78, 2.0, 0.81, 145, 0.22, 0.36, 185, 0.55, 4, 6, 12, 0.92, 0.95, 0.78), the new:

$$R' = (r_i')_{1\times 5} = (r_1', r_2', r_3', r_4', r_5')$$

= (0.616, 0.574, 0.708, 0.569, 0.507), as shown in Fig. 2.

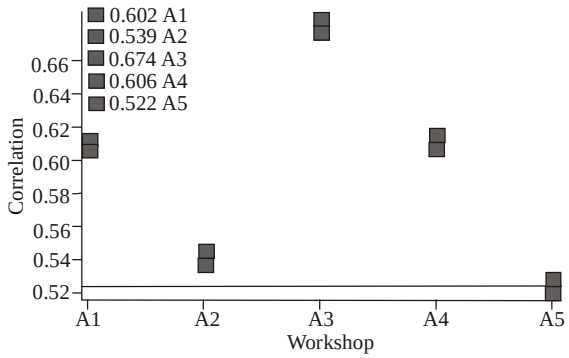

Fig. 1: Gray correlation degree chart of traditional reference series

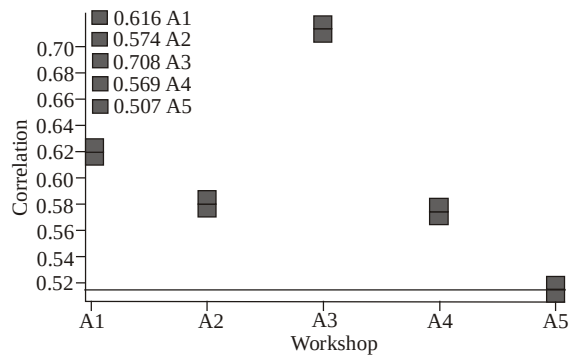

Fig. 2: Gray correlation degree chart of benchmark reference series

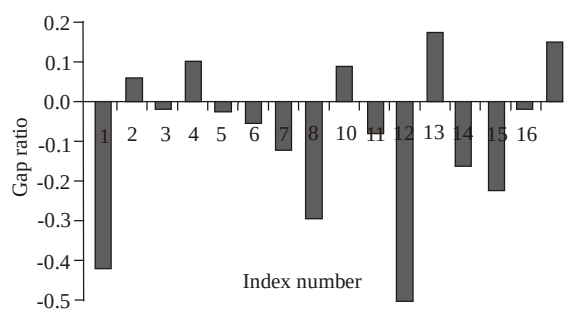

Fig. 3: Gap ratio of A5 to the benchmark workshop

From the contrast of Fig. 2 and 3, the gray correlation degree of optimal workshop is enhanced and the degree of the worst workshop is declined. As a result, the benchmark method can improve the distinguish ability of the diagnosis model.

The optimal value of the benchmark reference series can be described as:

$$V_{Bo} = (v_{B01}, v_{B02}, ..., v_{B0n})$$

The gab ration of the index i to the corresponding benchmark index is: $G_i = x_o - v_{B0i}$, if the value of satisfaction of the corresponding index is '1'; Or, $G_i = v_{B0i}$-x_o, if the value of satisfaction of the corresponding index is '1'.

For the worst workshop A5, the gap ratio of each index with the benchmark can be calculated as shown in Fig. 3. It is obvious that the indicators of C1, C5, C6, C7, C8, C10, C11, C13 and C14 are worse than the benchmark workshop. Variety of products C11 is the worst index for A5. As a result, A5 can improve its production performance firstly form the improvement of flexibility of production. Besides, C2, C4, C9, C12 and C16 are better than benchmark workshop. Innovative coefficient C12 is the best indicators and can be developed as the core competiveness for A5 workshop.

Form the gray correlation degree, we find out the competitive position of each workshop. For the workshops with bad production performance, we want to diagnose the reasons that affected it. The benchmark management provides the contrast objective to detect the bad indicators. The gap ratio of each index describes the detail performance of the workshop in production. For the worse indicators, the workshop should improve it to the level of the benchmark. However, the better indicators can develop as the competitiveness for the workshop. The evaluation should be applied periodically for the benchmark and the performance of indicators may change as the time.

CONCLUSION

This study provided a diagnosis method for the production performance of manufacturing workshops. It proved that FGCD evaluation model was effective to detect the problems in workshops. The comprehensive evaluation system can describe the production performance of workshop form different views. These indicators are the measurement of the workshop elements, such as equipment, material, people, manufacturing process and so on. After the evaluation of the FGCD model, it used the correlation degree to describe the relevance of the workshop with the optimal case. The indicators with the low value of correlation degree are diagnosed as the weakness performance in manufacturing process. The diagnosis for them can aid the engineers to find out the production problems during production and then improve the production performance of the workshop. The diagnosis for the indicators is the process to detect the detail production problems. Thirdly, the benchmark diagnosis was replaced the traditional reference series. This method is more accurate than the traditional reference series method. Gray correlation degree presented the relationship of the workshop with the benchmark and diagnoses the worse index of production process to improvement.

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