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Evaluation systems and methods of enterprise informatization and its application

Jian Fu Zhang *, Zhi Jun Wu, Ping Fa Feng, Ding Wen Yu

Institute of Manufacturing Engineering, Department of Precision Instruments and Mechanology, Tsinghua University, Beijing 100084, China

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ABSTRACT

An efficient evaluation index system and evaluation method for enterprise informatization is critically important for guiding the implementation and development tasks of enterprise information systems. This paper, based on pre-research for a group of typical enterprises and item, factor and reliability analysis of acquired samples, presents a comprehensive evaluation index system which includes three key first-level indicator sets (consisting of the current status of enterprise informatization, the production management characteristics and the system functional requirements), 16 second-level indicators and 80 third-level indicators. According to the characteristics of the designed objectives in the evaluation index system, we propose to use the grey relative correlation analysis method to evaluate the influencing factors of the enterprise informatization, employ the grey comprehensive correlation analysis method to determine the production management characteristics of the enterprise and adopt the grey clustering assessment technology to assess the information system functional requirements based on Grey System Theory. Moreover, case studies for enterprise informatization that mainly focus on the process enterprises in southwest China were illustrated. The research results show that the proposed evaluation system and evaluation method is reliable, practical, and able to better reflect the level of enterprise information and demand characteristics.

1. Introduction

The main purposes of enterprise informatization are to enhance and optimize the enterprise business process management level by using advanced information technology and modern management methods. Nowadays/currently, with strong international competition, China is accelerating its pace in adopting enterprise informatization processes. These have become important in improving Chinese manufacturing enterprises' competitiveness in the global market (Xiao, Yin, Wang, & Shi, 2005). However, many enterprises have difficulty in understanding enterprise informatization due to their poor understanding of information technology and modern management methods, and they do not know how to implement and evaluate enterprise informatization correctly to meet their requirements (Chen, Ma, & Fan, 2004). Therefore, establishing scientific and systematic enterprise information evaluation index systems and efficient evaluation methods is critical in guiding the implementation and development tasks of enterprise information.

Recently, many researchers and scholars have contributed methods for investigating enterprise informatization. ERP selection is one of the most important research topics in this area. Yazgan, Bora, and Goztepe (2009) proposed the use of artificial neural networks based on an analytic network process approach to select Enterprise Resource Planning (ERP) software. Wei, Chien, and Wang (2005) and Cebeci (2009) presented a comprehensive framework for selecting a suitable ERP system based on an Analytic Hierarchy Process (AHP) for decision analysis. Karsak and Özogul (2009) developed a novel decision framework for ERP software selection based on quality function deployment (QFD), fuzzy linear regression and zero–one goal programming. Shuai and Kao (2008) analyzed the factors of ERP system selection in the fast changing technology industry and explored the potential of applying the decision making trial and evaluation laboratory approach. Uwizeyemungu and Raymond (2009) proposed and tested an alternative evaluation method to measure the contribution of an ERP system to organizational performance in all its aspects. The proposed method was designed from a literature review of information systems evaluation. Chen and Lin (2009) proposed a fuzzy linguistic performance index based on a flow network model to evaluate the performance of an ERP system. Most of the above proposed frameworks enabled both company demands and ERP system characteristics to be considered, and provided the means for incorporating the relationship between company demands and ERP system characteristics. The proposed methods allowed a company to identify the elements of an ERP system selection, formulated the fundamental-objective hierarchy and made decisions at the ERP pre-implementation stage such as the date when the system would go online. All the proposed decision frameworks and evaluation methods were then validated and refined through a case study or an application.

* Corresponding author. Tel.: +86 10 62781099.
E-mail addresses: zhjfmail@gmail.com, zhjf@tsinghua.edu.cn (J.F. Zhang).

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In addition, Deng and Wang (2008) analyzed the characteristics of an E-commerce information system, and built up a set of evaluation indices. This approach chose the AHP and fuzzy evaluation method, carried out an integrated evaluation including confirming the fuzzy evaluation matrix, the fuzzy calculation, and the quantified evaluation result. Chen et al. (2004) presented the evaluation model and used a multilevel fuzzy-evaluating method to determine the grades of enterprise informatization. The evaluation matrixes were confirmed by either the Delphi method or expert systems. Li, Chen, and Qi (2008) proposed an index selection method for social economic evaluation systems. In their research, induction and deduction were used initially to select indicators, and mathematical statistics and consultation were adopted to modify and optimize the index system. Antunes and Aves (2008) proposed a qualitative method to evaluate the enterprise performance and the intangible assets based on a sample of 37 managers of large Brazilian companies. The general objective of this work was to study the contribution of the ERP to the quality of the managerial accounting information, through the perceptions of these managers. Darlington, Culley, Zhao, Austin, and Tang (2008) proposed a framework for the evaluation of information. It identified the dimensions influencing the information evaluation process and provided the foundation for a context-sensitive evaluation framework. Bendoly, Rosenzweig, and Stratman (2009) examined the efficient use of different types of enterprise information in realizing their strategic performance. To calculate a measure of efficient information use, they employed data envelopment analysis using data collected from ERP system adopters at two different points. In summary, all of the above mentioned research activities were guided by addressing the following questions: Why is the evaluation is being done? What is being evaluated? What affects the evaluation? When is the evaluation taking place? How is the evaluation to be carried out? (Stockdale & Standing, 2006).

Based on the above literature reviews, we can see that these researches can be classified into two general areas. The first is to investigate the evaluation index system of the enterprise informatization, and the performance evaluation or selection method of the information system. Although a considerable number of studies have been conducted emphasizing the influencing factors for enterprise informatization on the performance and effectiveness evaluation of a selected ERP system, it is not hard to see that the research on evaluation index systems mainly focus on the ERP systems while few of them specifically aim at the whole level of enterprise informatization. At the same time, we can also see that some of the proposed evaluation frameworks or models are mainly oriented to either the ERP system or to one type of company. When it is used for another information system, such as Management Information Systems (MIS), Product Data Management (PDM) or Supply Chain Management (SCM), and/or for any another enterprise or industry, some adjustments or modifications are needed. Moreover, the selection and setting of the evaluation indicators are also mainly based on the assessment of the current informatization level or analysis of the influencing factors. There is a lack of consideration for the production management characteristics and the functional requirements of the information systems. In effect the evaluation results could not adequately support the development and implementation of the information management systems.

The second area of research concerns the evaluation method. The commonly used evaluation methods mainly include AHP, Fuzzy Mathematics, Economic Value Added (EVA), Probability Statistics, Balanced Scorecard, Data Envelopment Analysis (DEA) and Mathematical Programming. Although these methods have been used successfully in studying random and uncertainty phenomena, there are still some limitations when they are used for informatization evaluation. They focus too much on quantifiable calculations and ignore the differences in the indicators of the selected index system. And due to the evaluation results being mainly based on the analysis of historical data, most of the above methods need much more data. At the same time, they seldom consider the process method of the research data and usually regard them as precision number index types. The applicability of these methods is often weakened by sophisticated mathematical models or limited attributes to carry out real world enterprise informatization decision-making, especially when some attributes or indicators are not readily quantifiable (Amin & Razmi, 2009; Sharifa & Irani, 2006; Wei et al., 2005; Yang, Lin, Pai, & Yeh, 2007).

Thus, in this paper we analyze the requirement characteristics of enterprise informatization, present a comprehensive evaluation index system based on the design discipline of analyzing the critical ratio, and construct the validity and reliability of the evaluation indexes. The evaluation indexes are mainly considered in three parts: the current status of the enterprise informatization, the characteristics of production management and the functional requirements of the enterprise information system. Then, based on Grey System Theory (Deng, 2005), we propose a series of methods on how to evaluate the enterprise information influencing factors, the production management mode and the system functional requirements. Moreover, to identify the validity of the presented methods, a case study that mainly focuses on the process enterprises in the southwest China is discussed.

The remainder of the paper is organized as follows: the next section describes the enterprise information evaluation index systems and discusses the design discipline and data processing methods of the evaluation index. The following section presents the evaluation methods including how to evaluate the key factors influencing enterprise informatization, production management characteristics and system function requirements based on the Grey System Theory. The subsequent section discusses the case study and our findings. We finish the paper with some conclusions.

2. Enterprise informatization evaluation systems

2.1. Design discipline

Correct or not, the results for the enterprise informatization evaluation, as is well known, depend for their validity on the selected target system and the designed evaluation indexes. Therefore, each indicator must correctly and scientifically reflect one aspect or characteristic of the evaluated objects. At the same time, the selection of the indicators should be comprehensive, and as far as possible avoid duplication between indicators (Guo, Hu, Wang, & Li, 2004). In this paper, the design of the evaluation system relies on the following principles (Han, 2007): it is based on pre-research and analysis for a small group of acquired samples, it successively excludes the inappropriate indicators through item analysis, factor analysis and reliability analysis, and identifies a defined set of indicators and their values for the evaluation system.

(1) Item analysis of the evaluation index system: through an appropriate test, obtains the critical ratio (CR) of the evaluation indicators, and then excludes the items that have not met the required level of the CR value. The method is to rank the sum scores of the indicators for the predicting evaluation index system, then identify those whose scores lie in the first 27% as the high group and the remaining indicators as the low group. We further calculate the CR value of the indicator by testing the difference between the high and low groups for their average scores. If the CR value of the indicator meet the significance levels ($\alpha < 0.5$ or $\alpha < 0.1$), this indicator can identify the degree of the response for the different subjects.

(2) Factor analysis of the evaluation index system: this involves testing the Construct Validity (CV) of the evaluation system, and carrying out the factor analysis. The CV here refers to the manner in which the evaluation system measures the target. The purpose of the factor analysis is to analyze and optimize the structure of the evaluation system, and adopt a group of fewer indicators for which there is a high degree of correlation between the indexes.

(3) Reliability analysis of the evaluation index system: this analyzes the reliability and stability of the overall evaluation system and all its indicators. Assuming K is the number of the evaluation index, δ is the measured total scores variance of the evaluation system, δ_i is the measured total scores variance of each indicator, and R is the Reliability, and $R \in [0,1]$, then:

$$R = \frac{K}{K-1}\left(1 - \frac{\sum \delta_i^2}{\delta^2}\right) \tag{1}$$

Generally, if the value of R is more than 0.7, we consider the reliability of the object to be high. Based on the above analysis method, the evaluation system is divided into three large projects, and includes 80 specific indicators. The reliability of the evaluation system is about 0.81.

2.2. Evaluation index systems

Based on the above design principles, the proposed evaluation systems in this paper follow three objectives: to evaluate the current level of the enterprise informatization, to evaluate the production management characteristics of the enterprise and to assess the functional requirements of the information management. Therefore, the evaluation systems are divided into three indicator sets. The first is the current status of enterprise informatization (G_1). It includes seven second-level indicators and 39 third-level indicators. The second is the production management characteristics set (G_2). It includes six second-level indicators and 25 third-level indicators. The third is the system functional requirements indicator set (G_3). It includes three second-level indicators and 16 third-level indicators. For the above three evaluation indicator sets, we make the following assumptions:

$G = \{G_1, G_2, G_3\}$ is the evaluation indicators set
$G_k = \{G_{k1}, G_{k2}, \ldots, G_{kn}\}$, $k = 1,2,3$, where n is the number of second-level indicators,
and
$G_{kn} = \{G_{kn1}, G_{kn2}, \ldots, G_{knm}\}$, where m is the number of the third-level indicators that belong to the nth second-level indicators.

The contents of the evaluation index systems are as shown in Table 1.

2.3. Data processing methods

Due to the three evaluation indicator sets focusing on different targets, we adopt different methods for dealing with the acquisition of indicator data to more precisely reflect the real level of the enterprise informatization, production management characteristics and functional requirements of the enterprise. The processing and calculation method of each indicator is as follows:

(1) For the enterprise informatization level indexes, the indicator G_{11} is mainly used to qualitatively analyze the nature and size of the enterprise, and its evaluation value is given by "expert" scoring. The values of the other second-level evaluation indicators (G_{12} –G_{17}) are obtained by calculating the mean values of the weighted third-level indicators, and the third-level indicators values are given in the form of percentiles or percentages. The formula is as follows:

$$g_{kn} = \frac{1}{m}\sum_{i=1}^{m} \mu g_{knm} \tag{2}$$

where, g_{kn} denotes the value of the second-level indicator, μ weight coefficient, and g_{knm}denotes the value of the third-level indicator.
Since the value of the third-level indicator is given as a percentile, we use the Scoring method to score the values of the third-level indicators as it is intuitive and easy to use. For example, the third-level indicator (G_{121}) is in the second-level indicator (G_{12}). If the CEO participates directly in the construction of the enterprise informatization, its value is recorded as 100 points, while if the CEO only participates in major decision-making, the recorded value is 70 points, for occasional participation, the recorded value is 50 points, and for seldom participation, the recorded value is 20 points. These values are denoted by g_{121}.
The value of the third-level indicator is given as a percentage. For example, the calculation of the third-level indicator (G_{142}) in the second-level indicator (G_{14}) is determined as follows:

$$g_{142} = \frac{t_{infor}}{t_{all}} \times 100 \tag{3}$$

where, g_{142} indicates the indicator value, t_{infor} denotes annual total investment in the enterprise information technology, and t_{all} indicates the total amount of business investment within the year.

(2) For the evaluation of the production management characteristics, because its main purpose is to define which management mode should be adopted in the implementation of enterprise informatization by analyzing the production management characteristics, the third-level indicator value is given by analyzing its degree of importance based on a five-grade marking method. The Selection criteria are divided into five grades, such as highest, higher, high, low, and lower, and the indicator values are correspondingly recorded as five points, four points, three points, two points and one point. The value of second-level indicator is gained by calculating the mean value of its third-level indicators.

(3) For the evaluation of the functional requirements in the enterprise informatization, we adopt the standard ten-grade marking system to grade the value of the proposed 16 third-level functional indicators based on expert experiences, and then use the acquired data to assess the system functional requirements and problems to be solved during the process of enterprise informatization.

3. Grey System Theory based evaluation methods

Grey System Theory was developed by Professor Deng in the 1980s (Deng, 1989). This theory focuses on studying uncertainty problems with a small number of samples or a system with poor information such as when partial information is both known and unknown. The Grey Correlation Analysis process has strong function characteristics that need limited sample data and need not be obedient to typical distributions, but can achieve reliable evaluation results. And Grey system theory has been applied successfully in many fields to take advantage of the analysis and decision-making that were difficult to deal with using the other evaluation methods mentioned in Section 1. For example, Huang, Chiu, and Chen (2008) proved that the results of software effort estimation using an integration of the grey relational analysis with the genetic algorithm method were more precise than the results

Table 1
Informatization evaluation index systems.

Top(G_k)	Second-level(G_{kn})	Third-level indexes(G_{knm})	Evaluation target
Informatization influencing factors indexes (G_1)	Enterprise scale level	Enterprise's property, number of employees, type of industry, types of production processes, and number of similar enterprises in the region	Level and status of the enterprise informatization
	Attention from leader	Degree of CEO involvement in the informatization process, whether the company has a CIO or not, staff of the enterprise's information management team, functions of the information management department, position and role of the CIO, and technical training and implementation tasks for enterprise informatization	
	Infrastructure facilities level	Numbers of computers used for information management, main use of the computers, current network environment of the enterprise, bandwidth of the desktops' access to the internal LAN, external internet access bandwidth, information equipment routine maintenance operations, and availability of corporate websites and e-mail	
	Proportion of investment for informatization	Proportion of the accumulative asset investments in information technology out of the enterprise's total assets, proportion of annual informatization investment out of annual total investment, scale of the enterprise's total assets and annual sales revenue, and proportion of the fixed assets out of the enterprise's total assets	
	Ownership of existing software	Current stage of the enterprise informatization, information system's application scope, currently implemented informatization projects, ERP system, PDM system, CAD/CAM/CAE/CAPP systems, CNC Equipment, and OA System	
	Institutional standards construction	Standardization of the enterprise's product code, standardization of the business activities, level of the information technology supporting business decisions, and business process specification	
	Informatization programming level	Informatization planning, budget for informatization, investment for informatization over two years, and information systems planned to be built over two years	
Production management characteristic indexes (G_2)	Production technology characteristics	Basic level of automation, product design characteristics, structure design characteristics, and production design methods	Operation of the production management
	Production process characteristics	Production patterns, process styles, supply relationships, product structure, and material flow styles	
	Production control characteristics	Production style, production running environment, production control method, production quality management, and product tracking method	
	Manufacturing characteristics	Production planning, material's processing characteristics, inventory style, BOM structure characteristics, and manufacturing style	
	Equipment characteristics	Equipment type, repair period, and production stopping influences	
	Marketing characteristics	Customer service, product sales mode, and requirement of quality safety	
Information system functional requirements indexes (G_3)	System support functions	Supplier management, human resource management, customer management, user management, and marketing forecasting	Functional requirements of information system
	Business functions	Inventory management, purchasing management, production planning management, BOM management, equipment maintenance, financial management, sales management, and material management	
	Control functions	Product tracking, manufacturing process, and quality control	

using case-based reasoning (CBR), classification and regression trees (CART), and artificial neural networks (ANN) methods. Hsu and Wang (2009) proposed a prediction approach using the multivariate grey model combined with grey relational analysis. Tseng (2010) proposed using a combined fuzzy grey relational analysis method to evaluate the environmental knowledge management capacity. And experiment results indicated that this method provided a significant improvement over the traditional methods both in forecasting techniques and in scanning variables. Tsaur (2010) and Kayacan, Ulutas, and Kaynak (2010) proposed using the Grey system theory-based models to forecast time series. The simulation results show that modified grey models perform better not only for model fitting but also for forecasting.

In this paper, by improving and revising the precise application of Grey System Theory, we propose to use the grey relative correlation analysis method to evaluate the influencing factors of the enterprise informatization, employ the grey comprehensive correlation analysis method to appraise the production management characteristic of the enterprise and adopt the grey clustering assessment technology to assess the functional requirements of the information system.

3.1. Evaluation method of informatization influencing factors

During the implementation of enterprise informatization, the primary task for enterprises is to analyze what factors are blocking the development of the enterprise's information. There are many factors that influence the level of an enterprise's informatization. How to identify and seize these key influencing factors is of great significance for the enterprises to improve their core competitiveness. According to the technical advantages of the Grey correlation analysis method (Xiao, Song, & Li, 2005; Kung, Yan, & Huang, 2008), which can analyze the unclear grey relationships of running mechanisms and physical prototypes of the evaluation indicators, the main purpose of the evaluation method of informatization influencing factors is outlined as follows: let the value of the enterprise informatization level g_{10} be a reference sequence, and the second-level indexes $g_{1i}(i = 1,2,\ldots,7)$ be used to compare with the reference sequence as a comparative sequence, then calculate the grey degree of correlation r_i between them. The greater the value of r_i, the closer the relationship between the indicators g_{1i} and g_{10}. That is to say the influencing degree of g_{1i} on g_{10} is much greater.

Definition 1. Assuming $g_1 = \{g_{10}, g_{11}, \ldots, g_{17}\}$ is the evaluation indicator set of the information influencing factors, g_{10} is the reference sequence, g_{1i} is the comparison sequence, and its value achieved by calculating the 3rd level indicators of the informatization index, $g_{10}(k)$ and $g_{1i}(k)$ are the indicator values of g_{10} and g_{1i} for the kth enterprise, then:

$$\begin{aligned} g_{10} &= (g_{10}(1), g_{10}(2), \ldots, g_{10}(k)) \\ g_{11} &= (g_{11}(1), g_{11}(2), \ldots, g_{11}(k)) \\ g_{12} &= (g_{12}(1), g_{12}(2), \ldots, g_{12}(k)) \\ &\cdots\cdots \\ g_{17} &= (g_{17}(1), g_{17}(2), \ldots, g_{17}(k)) \end{aligned} \tag{4}$$

For the indicator values of each sequence achieved, they should be normalized as follows:

$$g'_{1i} = g_{1i}/1/k\sum_{j=1}^{k} g_{1i}(j) = (g'_{1i}(1), g'_{1i}(2), \ldots, g'_{1i}(k)), \quad i = 0,1,2,\ldots,7 \tag{5}$$

Assuming $\Delta_{0i}(k) = |g'_{10}(k) - g'_{1i}(k)|$ is the absolute difference of the indicator value, $\Delta_{\min} = \min_i \min_k \Delta_{0i}(k)$ and $\Delta_{\max} = \max_i \max_k \Delta_{0i}(k)$ are the smallest difference and the maximum difference for the two poles, ρ is the identify coefficient, and $\rho \in (0,1)$, then we call:

$$r(g_{10}(k), g_{1i}(k)) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(k) + \rho\Delta_{\max}} \tag{6}$$

the grey correlation coefficient of the kth enterprise, and:

$$r(g_{10}, g_{1i}) = \sum_{k=1}^{7} \omega_k r(g_{10}(k), g_{1i}(k)) \tag{7}$$

is the grey degree of correlation between the indicator g_{1i} and the enterprise informatization level g_{10}, that is the influencing level. We define, ω_k as the kth enterprise weight, and it satisfies the following formula:

$$0 \leqslant \omega_k \leqslant 1, \sum_{k=1}^{n} \omega_k = 1 \tag{8}$$

Based on the above definitions, we can calculate the correlation between the enterprise informatization level and all the factors that influence the enterprise informatization level. The evaluation process is shown in Fig. 1. We can also further analyze and compare the values of $r(g_{10},g_{1i})$ to establish which factors affect the level of the enterprise information, and guide the enterprise's focus on the key points during the implementation and development of the enterprise information systems.

3.2. Production management characteristic evaluation

3.2.1. Production characteristic indexes

Generally, the production characteristics decide what kind of management model an enterprise should adopt. These production management diversities among enterprises also determine that different types of enterprises should adopt corresponding management models to promote their informatization processes according to their own requirements, such as realizing the purposes that optimize resource allocation and promote business process reengineering. Based on the evaluation index systems presented in Section 2.2, we select 25 third-level characteristics as the evaluation indicators according to the 6 second-level characteristics which included production technology, production processes, production control, manufacturing, equipment maintenance and marketing. The characteristic indicators and value ranges are shown in Table 2.

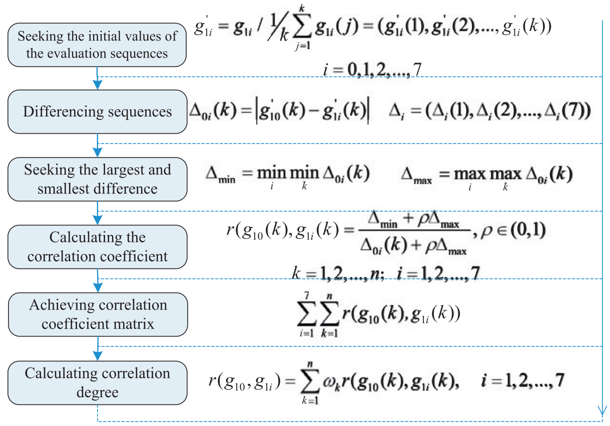

Fig. 1. Evaluation process of the informatization influencing factors.

3.2.2. Evaluation method of production characteristics

Based on the above composition characteristics of the evaluation indexes, the evaluation method is defined as follows:

Definition 2. Assuming $g_2(k) = (g_{21}(k), g_{22}(k), \ldots, g_{26}(k))$ is the evaluation indicator set of the enterprise production characteristics, where $k = 1,2,\ldots,p$ is the sample number of the evaluation enterprise, and it satisfies the following equations:

$$\begin{aligned} g_{21}(k) &= (g_{211}(k), g_{212}(k), g_{213}(k), g_{214}(k)) \\ g_{22}(k) &= (g_{221}(k), g_{222}(k), g_{223}(k), g_{224}(k), g_{225}(k)) \\ g_{23}(k) &= (g_{231}(k), g_{232}(k), g_{233}(k), g_{234}(k), g_{235}(k)) \\ g_{24}(k) &= (g_{241}(k), g_{242}(k), g_{243}(k), g_{244}(k), g_{245}(k)) \\ g_{25}(k) &= (g_{251}(k), g_{252}(k), g_{253}(k)) \\ g_{26}(k) &= (g_{261}(k), g_{262}(k), g_{263}(k))) \end{aligned} \tag{9}$$

Assuming D is the sequence operator, and:

$$g_2(k)D = (g_{211}(k)d, g_{212}(k)d, \ldots, g_{2mn}(k)d) \tag{10}$$

where:

$$g_{2mn}(k)d = \left| g_{2mn}(k) - 1/25p\sum_{k=1}^{p}\sum g_{2mn}(k) \right| \tag{11}$$

Here, $m = 1,2,\ldots,6$; $n \leqslant 5$ (n take the corresponding values according to m).

We call D the mean value operator of the sequence, and $g_2(k)D$ is the mean value image of $g_2(k)$, and expressed as follows:

$$g_2^0(k) = (g_{211}^0(k), g_{212}^0(k), \ldots, g_{2mn}^0(k)) \tag{12}$$

If we let the sample enterprise k and $l(l = 1,2,\ldots,p$; and $l \neq k)$ select the same time–distance and length in the index sequence $g_2(k)$ and $g_2(l)$, we can satisfy the following conditions:

$$\begin{aligned} |s_k| &= \left| \sum_{n=1/m=1}^{4} g_{2mn}^0(k) + \sum_{m=2}^{4}\sum_{n=1}^{5} g_{2mn}^0(k) + \sum_{m=5}^{6}\sum_{n=1}^{3} g_{2mn}^0(k) \right| \\ |s_k - s_l| &= \left| \sum_{n=1/m=1}^{4} (g_{2mn}^0(k) - g_{2mn}^0(l)) + \sum_{m=2}^{4}\sum_{n=1}^{5} (g_{2mn}^0(k) - g_{2mn}^0(l)) \right. \\ &\quad \left. + \sum_{m=5}^{6}\sum_{n=1}^{3} (g_{2mn}^0(k) - g_{2mn}^0(l)) \right| \end{aligned} \tag{13}$$

We call ε_{kl}, illustrated in Eq. (14), the grey absolute degree of correlation between the sequences $g_2(k)$ and $g_2(l)$:

$$\varepsilon_{kl} = \frac{1 + |s_k| + |s_l|}{1 + |s_k| + |s_l| + |s_k - s_l|} \tag{14}$$

Moreover, if $g'_2(k)$ and $g'_2(l)$ satisfy the following equations, and they are the initial images of the enterprise's evaluation index sequences, we name the grey absolute degree of correlation of $g'_2(k)$ and $g'_2(l)$ as the grey relative degree of correlation, and denote it as r_{jl}.

Table 2
Characteristic indicators and value ranges.

Values	Basic automation (G_{211})	Product design (G_{212})	Structure design (G_{213})	Design method (G_{214})	Production pattern (G_{221})	Process style (G_{222})	Supply relationship (G_{223})	Product structure (G_{224})
5	Intelligent control	Single design	Very complicated	Very different	Mass	Frequent change	Coupling variable	Structure variable
4	Automatic production line	Constantly changing	Complicated	Require re-design	In bulk	Occasional change	Close relationship	Frequent change
3	Workshop automation	Changing	Common	Complicated	Batch	Little change	Occasional relationship	Occasional changing
2	Flexible manufacturing cell	Occasional changing	Simple	Simple process route	Small batch	Seldom change	Beat discrete relaxation	Seldom change
1	CNC	No changing	Very simple	Single process route	Single product	No change	Unrelated	No change

Material flow (g_{225})	Production style (g_{231})	Production environment (g_{232})	Control method (g_{233})	Quality management (g_{234})	Product tracking (g_{235})	Production planning (g_{241})	Material characteristic (g_{242})
auto-continuous	Continuous	Extremely bad	Very complicated	Extremely rigorous	Full life-cycle	Variable	Mixed
Continuous	Generally continuous	Bad	Complicated	Very rigorous	Inter-enterprises	Make to stocks	Non-standard
Auto-intermittent	Semi-continuous	Toxic pollution	Common	Rigorous	Intra-enterprise	Customization	Need pretreatment
Intermittent	Seldom continuous	Pollution	Easy	General	Production process	Fixed ordering	Physical sorting
scattered	Intermittent	Less pollution	Very easy	Less stringent	Workshop	Make to order	Standard

Inventory style (g_{243})	Bom structure (g_{244})	Manufacturing style (g_{245})	Equipment type (g_{251})	Repair period (g_{252})	Stopping influence (g_{253})	Customer service (g_{261})	Sales mode (g_{262})	Quality safety (g_{263})
Dynamic	Very complicated	compositive changes	Production line	Very frequent	Great impact	Very high	Market-oriented	Extremely higher
Multi-level	Complicated	Chemical changes	Equipment group	Frequent	Influential	Higher	Agents	Very higher
Two-level	Common	Physical changes	Production cell	Irregular	General impact	High	Branches	Higher
Fixed	Assembly relation	Structure changes	Machining center	Regular	Less affected	Ggeneral	Fixed customer	High
Single	Fixed	Assembly	Single equipment	Common	Little affected	Low	order-oriented	General

$$
\begin{aligned}
g'_2(k) &= g_2(k)/1/25p\sum_{k=1}^{p}\sum g_{2mn}(k) \\
&= \left(\frac{x_{211}(k)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}, \frac{x_{212}(k)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}, \ldots, \frac{x_{2mn}(k)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}\right) \\
g'_2(l) &= g_2(l)/1/25p\sum_{k=1}^{p}\sum g_{2mn}(k) \\
&= \left(\frac{x_{211}(l)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}, \frac{x_{212}(l)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}, \ldots, \frac{x_{2mn}(l)}{1/25p\sum_{k=1}^{p}\sum g_{2mn}(k)}\right)
\end{aligned}
\tag{15}
$$

Then, we call ρ_{kl} denoted in Eq. (16) is the grey comprehensive degree of correlation:

$$\rho_{kl} = \theta\varepsilon_{kl} + (1-\theta)r_{kl}, \quad \text{here} \quad \theta \in [0,1] \tag{16}$$

The above definition of the grey comprehensive evaluation for production characteristics provides a clear indication of the closeness between the evaluation sequences. In practical applications, we can usually take $\theta = 0.5$. If we are more concerned about the absolute correlation, the value of θ can be larger. If we are more concerned about the relative correlation, the value of θ can be smaller.

3.3. Informatization system functional requirements evaluation

3.3.1. Functional indexes composition

In the process of enterprise informatization, the system functional requirements of the enterprise and their application are the most important factors that reflect the level of enterprise informatization, and are the core content of the enterprise informatization evaluation (Chen & Lin, 2008). Based on the above analysis of the production management characteristic of the enterprise, we know that different enterprises have different functional requirements for the information system in the management of the business processes and the production processes. To determine where the focus should be in the implementation of the system, the enterprises must find out what the differences are between the requirements of the business management and the existing software when implementing the enterprise informatization. So, we select 16 functional indicators that directly affect the implementation of the software (such as, ERP, MIS, and SCM), through the grey clustering assessment method, to fulfill the evaluation targets of the system functional requirements. The scores of the functional indicators obey the standard of the ten-mark system, and the weighting values are obtained based on expert experiences (in practice, it can also be set up according to business needs). The evaluation indexes system of the enterprise information system's functional requirements is shown as Table 3.

3.3.2. Evaluation method of the system's functional requirements

Evaluation of system functional requirements based on Grey assessment technology includes five elements: assessment objects (evaluated enterprises), assessment indicators, assessment samples (indicator values) and evaluation grey classes. Its purpose is to obtain the clustering coefficient matrix of the assessment objects by processing the values of the evaluation indicators with the whitening function, then to make a semi-qualitative and semi-quantitative evaluation and a description of the status of the whole functional requirements of the evaluated enterprise in a certain period of time, to form comparable concepts and categories for the combined effect and the overall level of the system.

Definition 3. Evaluation elements of the information system functional requirements are defined as follows:

Assessment objects: $i, i \in I = \{1,2,\ldots,n\}$,
Assessment indicators: $j, j \in J = \{1,2,\ldots,16\}$,
Assessment samples: x_j, sample value of the object i for indicator j, and correspondence with the evaluation index,
Assessment grey classes: $k, k \in \{1,2,3\}$, corresponding to the weaker, general and strong classes respectively.

When taking the ith object into the kth grey class, depending on the value of the ith object for the jth indicator, we call it grey clustering. If we correspondingly classify the values of n objects for the indicator j into three grey classes, we call it the sub-class of the indicator j. The whitening weight function of the indicator j for the sub-class k is then denoted as $f_j^k(x)$.

Based on the indicators' grey classes given in Table 3, if we adopt the triangle whitening weight function to evaluate the objects, we can calculate the whitening weight function value about the grey k for one of the sample values x_j of the indicator j:

$$f_j^k(x) = \begin{cases} 0, & x \notin \left[x_j^{k-1}, x_j^{k+2}\right] \\ \frac{x - x_j^{k-1}}{\lambda_j^k - x_j^{k-1}}, & x \notin \left[x_j^{k-1}, \lambda_j^k\right] \\ \frac{x_j^{k+2} - x}{x_j^{k+2} - \lambda_j^k}, & x \notin \left[\lambda_j^k, x_j^{k+2}\right] \end{cases} \tag{17}$$

The formulation of the above triangle whitening weight function is shown in Fig. 2. Where, x_j^0 and x_j^5 are the extension items of the function, the extended values are $x_j^0 = 0.5$, $x_j^5 = 12$, and $x_j^1, x_j^2, x_j^3, x_j^4$ are taken as the threshold of the three grey classes: "weak type", "general type", "strong type", that is $x_j^1 = 1$, $x_j^2 = 4$, $x_j^3 = 7, x_j^4 = 10$. If λ_j^k is the mean value of x_j^k and x_j^{k+1}, then we obtain $\lambda_j^1 = 2.5,\ \lambda_j^2 = 5.5,\ \lambda_j^3 = 8.5$.

Assuming λ_j^k is the critical value of indicator j for sub-class k, then:

(1) The weights of the indicator j for sub-class $k$is given by:

$$\eta_j^k = \lambda_j^k \Big/ \sum_{j=1}^{m} \lambda_j^k \tag{18}$$

(2) The variable weight Grey clustering coefficient of the object i belonging to the grey class k is given by:

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_j)\lambda_j^k \tag{19}$$

(3) The clustering coefficient vector of the object i is given by:

$$\begin{aligned} \sigma_i &= \left(\sigma_i^1, \sigma_i^2, \ldots, \sigma_i^s\right) \\ &= \left(\sum_{j=1}^{m} f_j^1(x_j)\lambda_j^1, \sum_{j=1}^{m} f_j^2(x_j)\lambda_j^2, \ldots, \sum_{j=1}^{m} f_j^s(x_j)\lambda_j^s\right) \end{aligned} \tag{20}$$

(4) The clustering coefficient matrix is given by:

$$\sum = \left(\sigma_i^k\right) = \begin{bmatrix} \sigma_1^1 & \sigma_1^2 & \cdots & \sigma_1^s \\ \sigma_2^1 & \sigma_2^2 & \cdots & \sigma_2^s \\ \cdots & \cdots & \cdots & \cdots \\ \sigma_n^1 & \sigma_n^2 & \cdots & \sigma_n^s \end{bmatrix} \tag{21}$$

Assuming $\sigma_i^{k^*} = \max\limits_{1 \leqslant k \leqslant s}\{\sigma_i^k\}$, we say object i belongs to grey class k^*. Moreover, we can also identify the sub-elements that influence the information functional requirements according to the sub-index value of the whitening weight function.

4. Case study

To identify the validity of the proposed methods, we designed a questionnaire based on the evaluation index system proposed in this paper, and conducted an investigation on a number of companies in southwest China by on-the-spot surveys, letters, e-mail and other means. The survey respondents focused mainly on the enterprises' president/CEO, vice president in charge of information technology or the chief information officer. The selection of the sample enterprises conformed to the standard of medium-sized and small enterprises formulated in the "Chinese Economic and Commercial SME [2003] num.143" that is jointly issued by the Chinese Economy and Trade Committee, Development Planning Commission, Ministry of Finance and National Bureau of Statistics. This means the number of employees in the company was no more than 2000, or the sales of the company no more than 300 million each year. The industries are focused mainly on the process enterprises, including pharmaceutical, food production and chemical enterprises, and also include some discrete manufacturing enterprises. The evaluation of the informatization level for this region is as follows.

4.1. Analysis of the informatization influencing factors

Based on the assumed investigation data, we select 10 typical enterprises as the sample enterprises. The statistics data of the second-level indicators are shown in Table 4. These data acquired by the processing of the data for the third-level indicators are based on the calculation methods described in Section 2.3, and are then round-off. $E'1$ and $E'2$ denote discrete manufacturing enterprises, and the others are process enterprises. The value of the informatization level is achieved by calculating the mean of the other seven indicators.

Based on the evaluation method presented in Section 3.1, let the value of the enterprise informatization level $g_{10}(k)$, $k = 1,2,\ldots,10$ be a reference sequence, and the second-level indexes $g_{1i}(k)$, $i = 1,2,\ldots,7;\ k = 1,2,\ldots,10$ be comparative sequences. First, the non-dimensional sequence should be calculated using normalization processing for the indicator values of each sequence. Then, by calculating the absolute difference of the indicator value $\Delta_{0i}(k) = \left|g'_{10}(k) - g'_{1i}(k)\right|$, we can get:

$$\Delta_{min} \approx 0.001578, \quad \Delta_{\max} \approx 0.15830 \tag{22}$$

Let the distinguish coefficient $\rho = 0.5$, then we can get:

$$r(g_{10}(k), g_{1i}(k)) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(k) + \rho\Delta_{\max}} = \frac{0.001578 + 0.5 \times 0.15830}{\Delta_{0i}(k) + 0.5 \times 0.15830} \tag{23}$$

Thus we can calculate the correlation coefficient matrix as follows:

$$\sum_{i=1}^{7}\sum_{k=1}^{10} r(g_{10}(k), g_{1i}(k)) = \begin{bmatrix} 0.5552 & 0.7560 & 0.7223 & 0.6494 & 0.7186 & 0.5278 & 0.7002 & 1.0000 & 0.9474 & 0.8194 \\ 0.7062 & 0.9609 & 0.8419 & 0.4607 & 0.9331 & 0.9674 & 0.7966 & 0.9364 & 0.8663 & 0.7545 \\ 0.9958 & 0.7598 & 0.4275 & 0.4942 & 0.6821 & 0.6239 & 0.6313 & 0.7090 & 0.4246 & 0.4238 \\ 0.5287 & 0.8629 & 0.8286 & 0.9743 & 0.6451 & 0.9856 & 0.6538 & 0.6319 & 0.6835 & 0.6854 \\ 0.4976 & 0.5737 & 0.5801 & 0.8736 & 0.4767 & 0.8226 & 0.6460 & 0.4743 & 0.8875 & 0.6614 \\ 0.5316 & 0.9671 & 0.8946 & 0.9843 & 0.7956 & 0.9659 & 0.6436 & 0.8209 & 0.6845 & 0.6806 \\ 0.4514 & 0.9061 & 0.4597 & 0.3975 & 0.5184 & 0.9600 & 0.8917 & 0.5585 & 0.3423 & 0.3400 \end{bmatrix} \tag{24}$$

Table 3
Evaluation indexes of system functional requirement.

Functional indexes	Code	Weight	Assessment grey categories		
			Weak type (Urgently need resolve)	General type (general fitting)	Strong type (satisfy requirement)
supplier management(g_{311})	X_1	5			
human resource management (g_{312})	X_2	5			
customer management (g_{313})	X_3	6			
user management (g_{314})	X_4	4			
marketing forecating (g_{315})	X_5	7			
inventory management (g_{321})	X_6	8			
purchasing management (g_{322})	X_7	5			
production planning (g_{323})	X_8	7	$1 \leqslant x_i^3 < 4$	$4 \leqslant x_i^2 < 7$	$7 \leqslant x_i^1 < 10$
BOM management (g_{324})	X_9	7			
equipment maintenance (g_{325})	X_{10}	7			
financial management (g_{326})	X_{11}	5			
sales management (g_{327})	X_{12}	7			
material management (g_{328})	X_{13}	8			
product tracking (g_{331})	X_{14}	8			
manufacturing process (g_{332})	X_{15}	7			
quality control (g_{333})	X_{16}	8			

Let $\omega_1 = \omega_2 = \cdots = \omega_{10} = 1/10$, then the degree of correlation of the g_{1i} and g_{10} can be calculated as follows:

$$r(g_{10}, g_{11}) = \frac{1}{10}\sum_{k=1}^{10} r(g_{10}(k), g_{11}(k)) \approx 0.740$$
$$r(g_{10}, g_{12}) \approx 0.822; \quad r(g_{10}, g_{13}) \approx 0.617; \quad r(g_{10}, g_{14}) \approx 0.748$$
$$r(g_{10}, g_{15}) \approx 0.649; \quad r(g_{10}, g_{16}) \approx 0.797; \quad r(g_{10}, g_{17}) \approx 0.583 \tag{25}$$

From the above correlation analysis, the order of the degree of correlation is as follows:

$$r(g_{10}, g_{12}) > r(g_{10}, g_{16}) > r(g_{10}, g_{14}) > r(g_{10}, g_{11}) > r(g_{10}, g_{15}) > r(g_{10}, g_{13}) > r(g_{10}, g_{17}) \tag{26}$$

For the above seven comparison factors, to facilitate the comparison we classify the indicators, enterprise scale level (G_{11}), attention from leader (G_{12}) and institutional standards construction (G_{16}), as the dominant factors, and the others as the direct factors. As far as the dominant factors are concerned, it is easy to see that the indicator G_{12} ranks as number one, followed by the indicator G_{16} and the indicator G_{11}. These evaluation results are in line with practice in Chinese informatization development. From past practical experience, success or not in enterprise informatization in China depends mainly on the attention and intervention from the leaders of the enterprise. As is well known, if the level of the institutional standards construction is very high in an enterprise, the level of its modernization and informatization is also high. At the same time, the informatization level of bigger enterprises is generally better than of smaller enterprises. In addition, the ranking of the direct influencing factors match the proportion of investment for informatization, the ownership of existing software, the infrastructural facilities level and the informatization programming level. It is obvious that the level of investment in informatization will directly influence the development of the enterprise. The software systems the enterprise owns are also one of the important factors. Moreover, we can also select the 3rd level indicators as the comparison sequence to analyze the influence on the informatization level of the enterprise.

4.2. Degree of correlation analysis for production management

By analyzing the research information obtained through the investigation, and based on the characteristic indicators and values range mentioned in Table 2, we select six typical enterprises ($E'1, E'2, E3, E4, E5, E6$) as the sample enterprises, and the production management characteristic sequences of the selected six enterprises are as follows:

$$\begin{aligned}
g_2(1) &= (g_{211}(1), g_{212}(1), \ldots, g_{263}(1)) \\
&= (2,5,4,5,2,3,3,4,1,3,2,2,3,4,1,1,3,2,3,2,2,3,4,2,3) \\
g_2(2) &= (g_{211}(2), g_{212}(2), \ldots, g_{263}(2)) \\
&= (2,4,5,5,3,3,3,5,2,3,1,3,3,3,1,1,3,2,3,3,2,4,5,1,3) \\
g_2(3) &= (g_{211}(3), g_{212}(3), \ldots, g_{263}(3)) \\
&= (4,4,2,5,4,4,4,4,4,5,3,4,5,5,5,5,4,3,5,5,4,5,2,4,5) \\
g_2(4) &= (g_{211}(4), g_{212}(4), \ldots, g_{263}(4)) \\
&= (4,4,3,4,5,4,5,4,3,4,4,4,4,5,5,4,4,3,5,5,5,5,2,3,5) \\
g_2(5) &= (g_{211}(5), g_{212}(5), \ldots, g_{263}(5)) \\
&= (4,3,2,3,4,4,4,3,3,5,3,4,5,5,5,5,4,3,5,4,3,4,1,4,4) \\
g_2(6) &= (g_{211}(6), g_{212}(6), \ldots, g_{263}(6)) \\
&= (4,4,3,2,5,3,4,3,3,4,4,5,5,5,5,4,4,3,5,5,4,5,1,3,5)
\end{aligned} \tag{27}$$

According to the evaluation method of the production characteristics presented in Section 3.2.2, we will mainly discuss the differences in the production characteristics between the six enterprises. The absolute and relative degrees of correlation are calculated as follows:

(1) Absolute degrees of correlation among sequences:
Use the mean value operator D to deal with the above characteristic indicator sequence values, and by calculating the mean value, we get the following values:

$$|s_1| = \left|\sum_{n=1/m=1}^{4} g^0_{2mn}(1) + \sum_{m=2}^{4}\sum_{n=1}^{5} g^0_{2mn}(1) + \sum_{m=5}^{6}\sum_{n=1}^{3} g^0_{2mn}(1)\right| \approx 42$$
$$|s_2| \approx 39; \quad |s_3| \approx 9; \quad |s_4| \approx 11; \quad |s_5| \approx 16; \quad |s_6| \approx 13 \tag{28}$$

and:

$$\begin{aligned}
&|s_2 - s_1| = 3; \quad |s_3 - s_1| = 33; \quad |s_4 - s_1| = 31; \\
&|s_5 - s_1| = 26; \quad |s_6 - s_1| = 29 \\
&|s_3 - s_2| = 30; \quad |s_4 - s_2| = 28; \quad |s_5 - s_2| = 23; \\
&|s_6 - s_2| = 26 \\
&|s_4 - s_3| = 2; \quad |s_5 - s_3| = 7; \quad |s_6 - s_3| = 4 \\
&|s_5 - s_4| = 5; \quad |s_6 - s_4| = 2 \\
&|s_6 - s_5| = 3
\end{aligned} \tag{29}$$

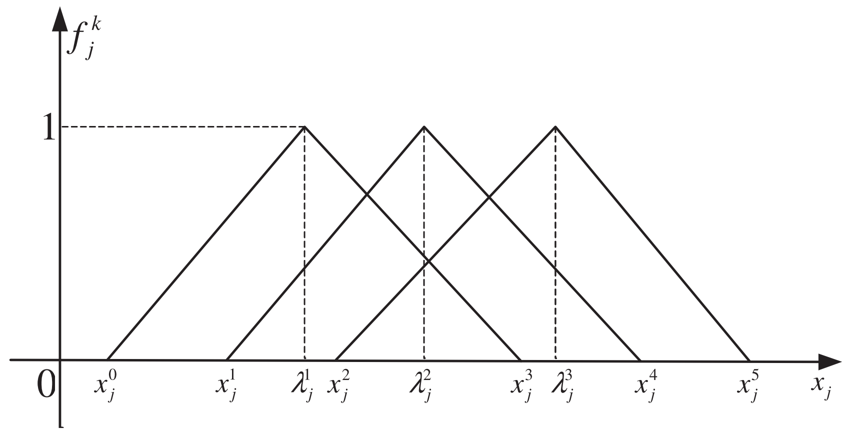

Fig. 2. Extension values based on the triangle whitening weight function.

Table 4
The second-level indicators data of the enterprise informatization.

Evaluation elements	$E1$	$E2$	$E3$	$E4$	$E5$	$E6$	$E7$	$E8$	$E'1$	$E'2$
Informatization level ($g_{10}(k)$)	51.6	46.7	53.4	47.7	42.0	54.3	37.1	55.2	80.0	84.3
Enterprise scale level ($g_{11}(k)$)	55	45	55	50	40	50	35	55	80	85
Attention from leader ($g_{12}(k)$)	53	46	52	42	42	54	38	55	80	85
Infrastructural facilities level ($g_{13}(k)$)	48	42	44	40	37	53	32	53	80	84
Proportion of informatization investment ($g_{14}(k)$)	48	48	55	48	45	55	40	53	83	83
Ownership of existing software ($g_{15}(k)$)	45	48	48	45	45	53	38	48	76	83
Institutional standards construction ($g_{16}(k)$)	44	43	50	44	40	50	32	52	76	80
Informatization programming level ($g_{17}(k)$)	68	55	70	65	45	65	45	70	85	90

Therefore, the absolute degrees of correlation between sequences are as follows:

$$\begin{aligned}
&\varepsilon_{21}=\frac{1+|s_1|+|s_2|}{1+|s_1|+|s_2|+|s_2-s_1|}=\frac{82}{85}\approx 0.965\\
&\varepsilon_{31}\approx 0.612;\quad \varepsilon_{41}\approx 0.635;\quad \varepsilon_{51}\approx 0.694;\quad \varepsilon_{61}\approx 0.658\\
&\varepsilon_{32}\approx 0.620;\quad \varepsilon_{42}\approx 0.646;\quad \varepsilon_{52}\approx 0.709;\quad \varepsilon_{62}\approx 0.671\\
&\varepsilon_{43}\approx 0.913;\quad \varepsilon_{53}\approx 0.788;\quad \varepsilon_{63}\approx 0.851\\
&\varepsilon_{54}=0.848;\quad \varepsilon_{64}\approx 0.926;\quad \varepsilon_{65}\approx 0.909
\end{aligned} \tag{30}$$

(2) Relative degrees of correlation:
In the same way, we can calculate the relative degrees of correlation between the sequences as follows:

$$\begin{aligned}
&r_{21}\approx 0.972;\ r_{31}\approx 0.801;\ r_{41}\approx 0.808;\ r_{51}\approx 0.829;\ r_{61}\approx 0.816\\
&r_{32}\approx 0.819;\ r_{42}\approx 0.827;\ r_{52}\approx 0.848;\ r_{62}\approx 0.835;\ r_{43}\approx 0.988\\
&r_{53}\approx 0.958;\ r_{63}\approx 0.976;\ r_{54}\approx 0.970;\ r_{64}\approx 0.988;\ r_{65}\approx 0.981
\end{aligned} \tag{31}$$

(3) Comprehensive degrees of correlation:
Let $\theta = 0.5$, the comprehensive degrees of correlation between the sequences are as follows:

$$\begin{aligned}
&\rho_{21}=\theta\varepsilon_{21}+(1-\theta)r_{21}=0.969\\
&\rho_{31}=0.707;\ \rho_{41}=0.722;\ \rho_{51}=0.762;\ \rho_{61}=0.737;\ \rho_{32}=0.7208\\
&\rho_{42}=0.720;\ \rho_{52}=0.779;\ \rho_{62}=0.753;\ \rho_{43}=0.951;\ \rho_{53}=0.873\\
&\rho_{63}=0.914;\ \rho_{54}=0.909;\ \rho_{64}=0.957;\ \rho_{65}=0.945
\end{aligned} \tag{32}$$

Based on the analysis of the results, it is not hard to see that the discrete manufacturing enterprise $E'1$ and $E'2$, and the process enterprises $E3$–$E6$, have a very high clustering. The comprehensive degrees of correlation for them are more than 0.9. However, we can also see that the comprehensive degrees of correlation between the discrete and process enterprise are just about 0.7. As far as the production management characteristics are concerned, we can conclude that the discrete enterprise and the process enterprise are of the same type but that the characteristics are quite different (If the comprehensive degree of correlation between two objects is less than 0.5, we regard them as not belonging to the same category). These evaluation results also tell us that we should correspondingly consider the production management characteristics during the implementation of the discrete and process enterprises' informatization, to select the required software or redesign and reconfigure the existing software.

4.3. System functional requirement assessment

Based on the evaluation indexes system for the enterprise information system functional requirements, we selected two discrete enterprises and six process enterprises as the research objects in the acquired investigation data, and invited some experts of the investigated enterprises to study the questionnaires and score the 16 system functional indicators proposed in Section 3.3.1. The evaluation values of the enterprises for business functional satisfaction are shown in Table 5.

Depending on the purpose, to evaluate the degree of functional satisfaction for the two types of enterprises in this investigated region, we picked the mean values of the discrete enterprises and the process enterprises shown in the Table 5 to carry out the assessment. The mean values of the two types of enterprises are illustrated in Table 6.

According to the assessment grey categories defined in Table 3, we adopted the triangle whitening weight function to assess the system functional requirement satisfaction. Therefore, the sub-index values of the whitening weight function for the three grey classes "weak type", "general type" and "strong type" can be calculated by the assessment method defined in Section 3.3.2 and shown in Table 7.

Table 5
Evaluation values of the business functional satisfaction.

Code	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
$E'1$	8	8	8	9	9	8	9	7	9	8	9	7	8	9	7	8
$E'2$	9	8	9	9	9	7	8	8	8	7	9	8	9	9	6	7
$E1$	8	8	8	9	4	3	8	2	3	6	9	5	2	2	3	5
$E2$	9	9	7	8	5	2	9	3	2	7	8	6	3	1	2	6
$E3$	8	8	9	10	6	3	8	3	3	5	9	6	3	3	1	7
$E4$	7	7	8	9	5	4	7	3	2	5	9	7	3	2	2	5
$E5$	7	9	8	8	7	2	9	3	3	6	9	5	4	2	3	6
$E6$	9	9	9	9	6	4	8	2	2	5	8	6	2	2	2	8

Table 6
Mean values of the business functional satisfaction.

Code	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
E'_{mean}	8.5	8	8.5	9	9	7.5	8.5	7.5	8.5	7.5	9	7.5	8.5	9	6.5	7.5
E_{mean}	8	8.33	8.17	8.83	5.5	3	8.17	2.67	2.5	5.67	8.67	5.83	2.83	2	2.17	6.17

Table 7
Sub-index values of whitening weight function.

Code	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
$f_j'^1(x)$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.111	0
$f_j'^2(x)$	0.333	0.444	0.333	0.022	0.022	0.556	0.333	0.556	0.333	0.556	0.022	0.556	0.333	0.022	0.778	0.556
$f_j'^3(x)$	1	0.889	1	0.667	0.667	0.778	1	0.778	1	0.778	0.667	0.778	1	0.667	0.556	0.778
$f_j^1(x)$	0	0	0	0	0.333	0.889	0	0.962	1	0.296	0	0.26	0.927	0.75	0.835	0.184
$f_j^2(x)$	0.444	0.371	0.407	0.26	1	0.444	0.407	0.371	0.333	0.962	0.296	0.927	0.408	0.222	0.26	0.851
$f_j^3(x)$	0.889	0.962	0.927	0.704	0.333	0	0.927	0	0	0.371	0.74	0.407	0	0	0	0.482

Furthermore, we can respectively calculate the variable weights grey clustering coefficients of the system functional requirement satisfaction that belong to the grey class $k(k = 1,2,3)$ for the discrete and process enterprises as follows:

$$\sigma'^1_{HN} = \sum_{j=1}^{16} f_j'^1(x_j)\cdot\eta_j = 0.777, \quad \sigma'^2_{HN} = 39.089, \quad \sigma'^3_{HN} = 84.131$$
$$\sigma^1_{HN} = \sum_{j=1}^{16} f_j^1(x_j)\cdot\eta_j = 47.802, \quad \sigma'^2_{HN} = 53.443, \quad \sigma'^3_{HN} = 37.601 \tag{33}$$

Therefore, we reach the following conclusions:

(1) According to $\max_{1\leqslant k\leqslant 3}\{\sigma'^k_{HN}\} = 84.131 = \sigma'^3_{HN}$, we can see that, for the chosen discrete enterprises in this region, the system functional requirement satisfaction for the existing information software belong to the "strong type" of the grey categories. That is to say, the existing information software and its function can satisfy the requirements of these enterprises very well. There is no need to redesign or reconstruct the systems during the process of the enterprise informatization.

(2) According to $\max_{1\leqslant k\leqslant 3}\{\sigma^k_{HN}\} = 53.443 = \sigma^2_{HN}$, we can see that, for the chosen process enterprises in this region, the system functional requirement satisfaction for the existing information software belong to the "general type" of the grey categories. At the same time, we can also see from the sub-index values of whitening weight function shown in Table 7 that the main functional indicators that influence the assessment results are X_6, X_8, X_9, X_{13}, X_{14}, and X_{15}. In other words, the system functions including inventory management, production planning, BOM management, material requirements, product tracking and manufacturing process are poor at meeting the requirements of the enterprises for business process management.

5. Discussion and conclusions

To establish a scientific, practical and workable evaluation index system and evaluation method is particularly important for the successful implementation of enterprise informatization. Through effective evaluation, it can reduce the risks in the implementation of information technology, decrease errors and waste, speed up the pace of informatization adoption. Nowadays, acquiring an appropriate management information system has been seen as the promised way for Chinese enterprises to gain a competitive advantage in the world. More and more companies are relying on efficient information evaluation to decide which favorable system modules and management methods should be selected for ensuring good system implementation.

In this paper, based on the design principles of project critical ratio, factor analysis and reliability analysis, we constructed a comprehensive evaluation index system which included 3 top indicator sets, 16 second-level indicators and 80 third-level indicators. The three top indicator sets are the current status of enterprise informatization, the production management characteristics and the system functional requirements, and they are used to progressively evaluate the level and status of the enterprise's informatization, which production management mode it belongs to and its functional requirements when selecting the information system. In particular, according to the different evaluation targets of the three top indicator sets, we propose to adopt different methods of dealing with the obtained indicator data to more precisely reflect the real informatization level. Second, according to the specific characteristics of the three evaluation objectives presented, we propose to correspondingly adopt the grey relative correlation analysis method, comprehensive correlation analysis method and grey clustering assessment technology to evaluate the influencing factors of the enterprise's informatization, the production management characteristics of the enterprise and the functional requirements of the enterprise information system. The method of constructing the evaluation model and performing the evaluation process are also described in detail. In addition, to identify the validity of the presented methods, we designed a questionnaire and conducted an investigation on a number of companies consisting mainly of pharmaceutical, food production and chemical enterprises in southwest China.

The evaluation results illustrate that the overall level of information technology in southwest China is not very high. The need to encourage the adoption of enterprise informatization in the process industries is more urgent than in the discrete manufacturing companies in this region. Case studies show that the evaluation results are properly in accordance with the current status of enterprise informatization in this region, which showed that the economic development level is relatively backward, most of the medium-sized and small process enterprises are private enterprises, and the managers of the companies lack an understanding of information technology. Therefore, following the results of the case study, we can conclude that the proposed evaluation index system and evaluation method are reliable, practical, and able to better reflect the level of enterprise information and demand characteristics, and can also be used to direct the selection and implementation of the enterprise information management system.

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