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Combining grey relation analysis and entropy model for evaluating the operational performance: an empirical study

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Abstract Decision-making on operational performance evaluation is a complex multi-objective problem. Through the combination of grey relation analysis and information entropy, the evaluation results are more objective and reasonable. This paper would introduce entropy into the weighting calculation of the grey relational analysis method for improving the precision. The improved decision model was applied in four notebook computer original design manufacturer companies. The result presented the proposed method is practical and useful. Significantly, the proposed method provides more flexible and objective information in determine the weights vector of the criteria. Also the study result represented that the combined method had certain scientific and rationality. The evaluation model indicates that this method be more reasonable and easier to grasp than other methods. As a result, it is easier to popularize this evaluation method in enterprises.

Keywords Grey relational analysis · entropy · Multiple attribute decision-making · Performance evaluation

1 Introduction

The performance evaluation and optimal design of weapon systems are multiple criteria decision making problems. In order to compete in today's competitive environment, many organizations have recognized benchmarking as being of strategic important in the drive for better performance and commitment to achieving a competitive advantage. There are many studies have investigated the method about performance evaluation (Chalasani and Sounderpandian 2004; Wynn-Williams 2005; Gleich et al. 2008; Maiga and Jacobs 2004; Lai and Yang 2008). Some literatures identified the different key performance indicators, including tangible and intangible aspect (Mukherjee et al. 2002; Chin et al. 2001; Gupta and Selvaraju 2006; Himes 2007; Jones and Kaluarachchi 2008; Welch and Mann 2001;

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Wainwright et al. 2005; Robson and Prabhu 2001). It is essential for the application of performance measurement that a company's tangible and intangible targets are defined in a way that is more appropriate to the requirements and objects of this targets and that its strategy is more extensively operationalized, quantified and linked in a mutually supplementing way.

In order to improve the low evaluation precision that the grey relational analysis method has been, the entropy theory was integrated to establish a new model. According to the variation of the index value, the coefficients of weight in the model are obtained from the utility value reflecting the information entropy of data; the subjective influence could be avoided. In the process of multi-objective decision-making on performance evaluation, people often consider relative importance of each evaluation factors or objects. The most direct and simple method is to give each factors weights. This paper has used the entropy weight coefficient method, and carries on the analysis and the processing subjective data. That is, through analyzing the inherent links between factors, the relative importance between factors is marked and calculated to get the weight of factors. The new model was applied to the comprehensive evaluation on exploration potentiality of regional rainwater resource. The analysis result showed that introducing the entropy theory into grey relational analysis method is scientific the proposed model is reasonable and the evaluation precision of the grey relational analysis method has been improved.

Performance evaluation is the procedure to find the best alternative among a set of alternatives. In next section, an approach for performance evaluation is proposed. Firstly, Sect. 2 describes the conceptual mode of performance evaluation. The problem of determination of evaluation criteria weights will be solved in Sect. 3. Thirdly, based on these, Sect. 4 describes the steps of the proposed algorithm for performance evaluation.

2 Grey relation analysis

Grey relational analysis method, which is a basic method of grey system theory for system analysis, is based on qualitative analysis and quantitative analysis (Wang and Fang 2007; Wu and Yang 2008). Through the application of this method, it overcomes the defects that the traditional correlation analysis method is not fit for Nonlinear Model. The grey relational evaluation system calculated the correlation degree of each evaluation object to evaluation criterions for estimating its grade. The grey relational analysis method has been developed to a widely applied technique in evaluation gradually (Wang et al. 2007a; Li et al. 2007). Grey Relation Analysis is based on the concepts of Grey Space. Hence, in this subsection, we respectively introduce the basic concepts and the specific analysis method.

Let $p(X)$ be a theme characterized by a factor set X, and Q be an influence relation, $[p(X); Q]$ is a factor space (Kuo et al. 2008; Firouzabadi et al. 2008; Maniya and Bhatt 2011). The factor space $[p(X); Q]$ has the following properties (Wang et al. 2007c; Lin et al. 2009; Pal and Gauri 2010):

(1) Existence of key factors, for example, the key factors for a basketball player can be height and rebound.
(2) That the numbers of factors are limited and countable.
(3) Factor independence, so each factor must be independent.
(4) Factor expansibility, so for example, besides the height and rebound, weight can be added as another factor.

Suppose $x_i = (x_1(k), \ldots, x_i(k)) \in X$
$k = 1, 2, 3, \ldots, n \in N;\ i = 0, 1, 2, \ldots, m \in I$, X is a series.

This series is said to be comparable if, and only if, the following conditions are met (Wang et al. 2007c; Lin et al. 2009; Wei 2010; Pophali et al. 2011):

(1) Non-dimension: Factors must be processed to become non-dimensional, irrespective their units and scales.
(2) Scaling: The factor value $x_i = (x_1(k), \ldots, x_i(k))$ of the different series must be at the same level.
(3) Polarization: The factor value of $x_i = (x_1(k), \ldots, x_i(k))$ of the different series is described in the same direction.

If all the series in a factor space $[p(X); Q]$ are comparable, the factor space is a grey relational space which is denoted as $[p(X); \Gamma]$. X is a collection of data series and Γ is the grey relation map set and based on geometrical, has the following four axioms.

Four axiom of grey relational analysis (Wang et al. 2007b; Firouzabadi et al. 2008; Chen and Chou 2011; Kuo and Liang 2011)

(1) Normality:

$$0 \le \Gamma(x_i, x_j) \le 1 \quad \forall i, \forall j$$

$$\Gamma(x_i, x_j) = 1 \Leftrightarrow x_i \equiv x_j;\ \Gamma(x_i, x_j) = 0 \Leftrightarrow x_i \cap x_j \in \emptyset$$

(2) Symmetry:

$$\Gamma(x_i, x_j) = \Gamma(x_j, x_i) \quad \forall i, \forall j$$

(3) Entirety

$$\forall i, \forall j \in X = \{x_\sigma \mid \sigma = 0, 1, \ldots, n\}, \quad n \ge 2\ \Gamma(x_i, x_j) \overset{often}{\neq} \Gamma(x_j, x_i)$$

(4) Proximity:

$\Gamma(x_i(k), x_j(k))$ increases as $\Delta(k) = \left|x_i(k) - x_j(k)\right|$ decrease for $\forall k \in \{1, 2, \ldots, k\}$.

Step 1: Establish data series construction

From raw matrix, we can get reference array A_0 and compare array A_1. Reference array, A_0, is the set of ideal value for each factors. Then the compare array, A_1, is the performance value of each project (Kuo et al. 2008; Maniya and Bhatt 2011).

Step 2: Standardize the raw matrix R'

Under the principle of series comparability, to achieve the purpose of grey relational analysis, we must perform data processing. This processing is called generation of grey relation or standard processing. The expected goal for each factor is determined by Himes (2007) which based on the principles of data processing. They are described in the following (Himes 2007; Lin et al. 2009; Kuo and Liang 2011):

(a) If the expectancy is larger-the-better (e.g., the benefit), then it can be expressed by:

$$X_{ij}^* = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{1}$$

(b) If the expectancy is smaller-the-better (e.g., the cost and defects), then it can be expressed by:

$$X_{ij}^* = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{2}$$

(c) If the expectancy is nominal-the-best value, then it can be expressed by:

$$X_{ij}^{*} = \frac{\left|x_{ij} - x_{obj}\right|}{\max_i x_{ij} - x_{obj}} \tag{3}$$

where $\max_i x_{ij} \geq x_{ij} \geq \min_i x_{ij}$

Step 3: Construct the normalized matrix and generate the reference sequence (Himes 2007; Lin et al. 2009; Kuo and Liang 2011):

$$\text{Normalized matrix } R' = \begin{bmatrix} x_1'(1) & x_1'(2) & \cdots & x_1'(m) \\ x_2'(1) & x_2'(2) & \cdots & x_1'(m) \\ \vdots & \vdots & \ddots & \vdots \\ x_n'(1) & x_n'(2) & \cdots & x_n'(m) \end{bmatrix} \tag{4}$$

reference sequence $x_0' = x_0'(1), x_0'(2), \ldots, x_0'(m)$

The $x_0'(j)$ is the reference value in relation to the jth factor and is determined by the largest and normalized value of each factor could be defined as

Step 4: The next step is found out all difference $\Delta_{oi}(j)$ between the all normalize sequences and the reference sequence x_0' (Himes 2007; Lin et al. 2009; Wei 2010).

$$\Delta_{oi}(j) = \left|x_0'(j) - x_i'(j)\right| \tag{5}$$

$$\Delta = \begin{bmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \cdots & \Delta_{01}(m) \\ \Delta_{02}(1) & \Delta_{02}(2) & \cdots & \Delta_{02}(m) \\ \vdots & \vdots & \ddots & \vdots \\ \Delta_{0n}(1) & \Delta_{0n}(2) & \cdots & \Delta_{0n}(m) \end{bmatrix}$$

Step 5: Then the third step is base on Eq. to calculate the grey coefficient for each entity could be defined as (Himes 2007; Lin et al. 2009; Wei 2010; Pophali et al. 2011):

$$\gamma_{0i}(j) = \frac{\min_{i=1}^{n} \min_{j=1}^{m} \Delta_{0i}(j) + \zeta \times \max_{i=1}^{n} \max_{j=1}^{m} \Delta_{0i}(j)}{\Delta_{0i}(j) + \zeta \times \max_{i=1}^{n} \max_{j=1}^{m} \Delta_{0i}(j)} \tag{6}$$

where ζ is the distinguish coefficient. In the most situations, ζ takes the value of 0.5 because this value usually offers moderate distinguishing effects and good stability (Himes 2007; Lin et al. 2009).

Step 6: Finally we get the grey relational degree value. The grey relational degree is a weighted sum of the grey relational coefficients given by the following equation (Himes 2007; Pal and Gauri 2010; Kuo and Liang 2011):

$$\Gamma_{0i} = \sum_{j=1}^{m} (w(j) \times \gamma_{0i}(j)) \qquad \sum_{j=1}^{m} w(j) = 1 \tag{7}$$

This research use entropy to calculate the normalized weighing of criteria.

3 Entropy method

Entropy was originally thermodynamic conception and an uncertainty measurement of system state (Wang et al. 2007a; Oliveski et al. 2009; Kaluri and Basak 2011). Information represents ordered degree but entropy represents disordered degree of system in information theory (Chen and Qu 2006). The two is equal in value but opposite in sign. If the lower information entropy value of one objective, the higher variation of index value and quantity of message, the weighting should be higher (He and Ricci 2002; Afsan and Basu 2011; Jaber 2007). On the contrary, the higher information entropy value of one objective, the lower variation of index value and quantity of message, the weighting should be lower. So entropy could be calculated based on the variation of index value. The weighting of all indexes was calculated and then the objective conclusion of comprehensive evaluation was obtained (Li et al. 2007; Kumar et al. 2010). It measures the degree of uncertainty that exists in a system. The entropy weight is really certain and objective, though the index value is subjective. The way to combine subjective with objective method, overcame the shortage of the tradition subjective weight, lead into the entropy weight, made the evaluation result is more accurate and valid (Li et al. 2007; Kumar et al. 2010; Kumar and Taneja 2011). The concrete steps for deciding index weight based on entropy method are as followings.

The decision matrix A of multi-criteria problem with m alternatives and n index is shown as following equation (Li et al. 2007; Jaber 2007):

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

where $x_{ij}(i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n)$ is the performance value of the ith alternative to the jth factor.

Definition in the entropy technique

Step 1: The set projection of the factor: P_{ij}, it is a relative frequency (Li et al. 2007; Jaber 2007; Chang 2009):

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{8}$$

Step 2: Entropy: the output entropy of the jth factor according to the information theory is the following equation (Li et al. 2007; Jaber 2007; Chang 2009).

$$E_j = -k \sum_{i=1}^{m} P_{ij} \ln(P_{ij}) \quad j = 1, 2, \ldots, n \tag{9}$$

where k represents a constant: $k = \frac{1}{\ln m}$, which guarantees that $o \leq E_j \leq 1$.

Step 3: Calculate the weight of entropy (Vaz et al. 2004; Jaber 2007; Chang 2009)

The degree of diversification d_j of the information provided by the factor j can be defined as following equation

$$d_j = 1 - E_j \quad \forall j \tag{10}$$

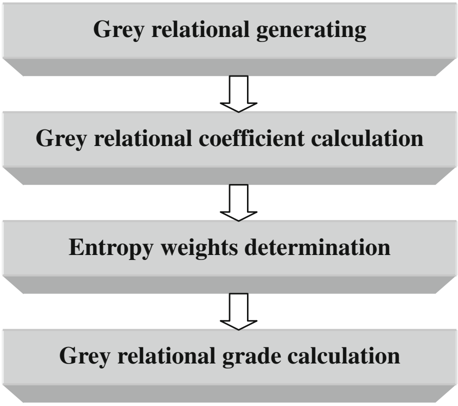

Fig. 1 Procedure of GRA and entropy models

Then the weight of entropy of jth factor could be defined as (He and Ricci 2002; Li et al. 2007; Wang et al. 2007a; Muñuzuri et al. 2010):

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad \forall j \tag{11}$$

There are many different research applied entropy method to calculate the weighting. Wen et al. (1988) based on the definition of entropy to derive the discrete type of entropy, and it calls grey entropy. Xiu and Pan (2007) put forward the entropy weight matter-element appraisal model for quantitative analysis to virtual enterprise risk. Tian et al. (2008) give a method of entropy weight coefficient that is applied to calculate the weight of factors and decrease subjective judgment on the effect of the weight coefficient. Huang (2008) proposes a combined entropy weight and TOPSIS method for information system selection. Liu (2008) applies grey relational analysis and entropy weights into fuzzy design theory, and solve the problem of three levels structure fuzzy comprehensive evaluation. Li et al. (2008) review the evaluation and entropy weight when it's necessary and give an approach about the multiple objective decision methods, and at the end, give a more accurate and credible engineering item choice.

4 Empirical illustrations

In this section, we propose our research framework and describe our variable measurement and sample selection. The calculation example has identified that the MADM with comprehensive entropy weight is valid to solve the problem of operational performance evaluation. The problem is how to evaluate the operating performance of these four notebook original design manufacturer (ODM) companies based on MADM with comprehensive entropy weight. The model reduces the subjective influence, enhances the evaluation results objectivity. It provides an effective method for performance evaluation. This research procedure of grey relational analysis and entropy models are shown in Fig. 1.

4.1 Research framework

This research tries to measure the performance of notebook computer ODM companies. The grey relational analysis decision making was introduced for solutions decision, and entropy weights were also used with grey relational analysis decision to choose the solutions.

Table 1 Qualitative measures for four notebook computer ODM companies

Company	Year	Total assets	Operating expenses	Number of employees	Net sales	Gross profit	EPS
Quanta	2009	377,403,656	7,387,446	64,719	280,859,508	12,329,614	1.89
Compal	2009	335,290,043	5,524,664	58,025	235,090,852	13,692,573	2.05
Wintron	2009	179,832,288	5,389,317	39,239	160,448,951	8,757,827	1.79
Inventec	2009	145,103,923	3,357,511	29,646	114,693,184	5,411,944	0.42

Source Taiwan Economic Journal (TEJ) database

4.2 Variable measurement and sample selection

Frontier models require the identification of inputs (resources) and outputs (transformation of resources). Several criteria can be used in their selection. The first of these, an empirical criterion, is availability. Secondly, the literature survey is a way of ensuring the validity of the research and thus represents another criterion to be taken into account. The samples of this research are four notebook computer ODM companies, which are Quanta Computer, Compal Computer, Wintron Computer and Inventec Computer. We use three input variables and three output variables. The evaluation variables are total assets, operating expenses and number of employees, net sales, gross profit and earning per share (EPS). The sources of data are from the Taiwan Economic Journal (TEJ) Database.

4.3 Grey relational analysis

Base on the data of Table 1, the grey relational analysis procedure is as follows:

4.3.1 Grey relational generating

First, we should construct the normalized matrix and generate the reference sequence. The main purpose of grey relational generating s transferring the original data into comparability sequences. Operating expenses is a smaller-the better attribute, and total asset, number of employees, net sales, gross profit and EPS are all larger-the-better attributes.

The grey relational process adopts Eq. (2) for the data of performance value of operating expenses, Eq. (1) for the data of performance value of total asset, number of employees, net sales, gross profit and EPS where X^*_{ij} is equal to 1. For example, in the case of the total assets attribute in 2009, the maximum value is 377,403,656 from Quanta Company and the minimum value is 145,103,923 from Inventec Company. Using Eq. (2) the results of grey relational generating of Inventec Company is equal to (145,103,923–145,103,923)/(377,403,656–145,103,923) = 0. The entire results of grey relational generating in 2009 are showing in Table 2.

4.3.2 Calculate the difference between the all normalize sequences and the reference sequence

The next step is found out all difference $\Delta_{oi}(j)$ between the all normalize sequences and the reference sequencex'_0. We can use Eq. (5) to get all value of the difference between the all normalize sequences and the reference sequence. The entire results are shown in Table 3.

Table 2 Results of grey relational generating for four ODM notebook companies

Companies	Total assets	Operating expenses	Number of employees	Net sales	Gross profit	EPS
Quanta	1.0000	0.0000	1.0000	1.0000	0.8354	0.9018
Compal	0.8187	0.4622	0.8091	0.7246	1.0000	1.0000
Wintron	0.1495	0.4958	0.2735	0.2754	0.4041	0.8405
Inventec	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000

Table 3 The difference between the all normalize sequences and the reference sequence

Companies	Total assets	Operating expenses	Number of employees	Net sales	Gross Profit	EPS
Quanta	0.0000	1.0000	0.0000	0.0000	0.1646	0.0982
Compal	0.1813	0.5378	0.1909	0.2754	0.0000	0.0000
Wintron	0.8505	0.5042	0.7265	0.7246	0.5959	0.1595
Inventec	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000

Table 4 Results of grey relational coefficient for four ODM notebook companies

Companies	Total assets	Operating expenses	Number of employees	Net sales	Gross profit	EPS
Quanta	1.000	0.333	1.000	1.000	0.752	0.836
Compal	0.734	0.482	0.724	0.645	1.000	1.000
Wintron	0.370	0.498	0.408	0.408	0.456	0.758
Inventec	0.333	1.000	0.333	0.333	0.333	0.333

4.3.3 Grey relational coefficient calculation

The grey relational coefficient can be calculated by Eq. (6). The entire results are shown in Table 4.

4.3.4 Determine the criteria weights using entropy method

This paper gives a method of entropy weight coefficient that is applied to calculate the weight of factors and decrease subjective judgment on the effect of the weight coefficient. The entropy method can greatly improve the performance in four notebook computer ODM companies by overcoming the shortcomings of conventional methods that only use either the subjective or the objective weights.

Based on the initial data in Table 1, the initial evaluation matrix A was obtained as follows:

$$A = \begin{bmatrix} 377{,}403{,}65 & 7{,}387{,}446 & 64{,}719 & 280{,}859{,}508 & 12{,}329{,}614 & 1.89 \\ 335{,}290{,}043 & 5{,}524{,}664 & 58{,}025 & 235{,}090{,}852 & 13{,}692{,}573 & 2.05 \\ 179{,}832{,}288 & 5{,}389{,}317 & 39{,}239 & 160{,}448{,}951 & 8{,}757{,}827 & 1.79 \\ 145{,}103{,}923 & 3{,}357{,}511 & 29{,}646 & 114{,}693{,}184 & 5{,}411{,}944 & 0.42 \end{bmatrix}$$

Table 5 The calculated entropy weight data

	Total assets	Operating expenses	Number of employees	Net sales	Gross profit	EPS
Entropy weight	0.192	0.093	0.115	0.141	0.144	0.315

Table 6 The results of grey relational analysis for four ODM notebook companies

Alternative companies	Grey relational grade	Ranking results of GRA
Quanta	0.8506	1
Compal	0.8187	2
Wintron	0.5262	3
Inventec	0.3954	4

Then the normalized index matrix was calculated by using Eq. (8) as following matrix P

$$P = \begin{bmatrix} 0.680 & 0.660 & 0.648 & 0.675 & 0.584 & 0.566 \\ 0.604 & 0.493 & 0.581 & 0.565 & 0.649 & 0.614 \\ 0.324 & 0.481 & 0.393 & 0.386 & 0.415 & 0.536 \\ 0.261 & 0.300 & 0.297 & 0.276 & 0.256 & 0.126 \end{bmatrix}$$

Then we calculate the weight of entropy by using Eq. (9) and Eq. (10) to. The entropy weight table just follows as Table 5.

4.3.5 Grey relational grade calculation

This research use entropy to calculate the normalized weighing of criteria. In this research, the value of $\Delta_{\max}$ is equal to 1 and the value of $\Delta_{\min}$ is equal to 0. Then the value of ζ is the distinguish coefficient. The value of ζ is equal to 0.5 because this value usually offers moderate distinguishing effects and good stability. Then by using Eq. (7), the grey relational grade can be calculated and is shown in Table 6.

5 Conclusion

The paper sets up the operational performance evaluation index system of notebook computer ODM companies, and determines the weight of indexes based on entropy weight. Based on entropy weight and grey relation analysis, the evaluation model provides the quantitative method for sorting the operational performance of notebook computer ODM enterprises.

The results showed that the grey relational analysis method based on coefficients of entropy is reasonable and the evaluation result is reliable. The method of grey relational grade analysis overcomes the defects that traditional related analysis method is not suitable for nonlinear model, which is the supplement and development to the related analysis method. The entropy method is more subjective. The result presented the proposed method is practical and useful. Significantly, the proposed method provides more flexible and objective information in determine the weights vector of the criteria. According to the above analysis of the multi-decision that basing on the entropy weight, we can see the entropy weight is really certain and objective, though the index value is subjective. The way to combine subjective with objective method, overcame the shortage of the tradition subjective weight, lead into the entropy weight, made the evaluation result is more accurate and valid.

From the results of GRA and entropy models, we know that industrial industrialist not only enhance their managerial skills but also increase and improve innovative performance and upgrade technology level.

Better manufacturing ability could predict resource capacities and competing resource requirements provides more accurate forecasts of production lead time. This ability comes from the acuity gained through improved communication, scanning, and analysis. Then greater responsiveness provides flexibility to react to schedule variations and changes. Competing in the marketplace on the basis of cost efficiency requires striving for low cost production. In order to keep manufacturing costs competitive, managers must address materials, labor, overhead, and other costs. Inventories have long been the focus of cost reduction in factories and are one of the justifications of the JIT system. Therefore, inventory and inventory-related items, such as improving vendor's quality, reducing waste of purchased materials, are considered as the indicators of the cost capability. Realizing low inventory level, decreasing labor cost, and reducing machine time are all positive factors of the cost efficiency construct.

Manufacturing capability is considered to be an important element in a firm's endeavor to improve firm performance. Manufacturing capability management strategies have reduced inventory and manufacturing cycle times, and more complete and on-time shipments of better quality products (Himes 2007). The enterprises should focus on reducing costs; they also pay much more attention to building agility and flexibility into their manufacturing processes, seeking better market differentiation. Cost reductions remain the focus of all enterprises and many still struggle with data collection and cultural issues (Wainwright et al. 2005). The manufacturing capability includes five aspects, such as reducing manufacturing cost, shrinking manufacturing cycle time, improving schedule compliance, satisfying demand for more complete and on-time shipments (Gleich et al. 2008; Welch and Mann 2001).

Innovation shows up in the quality and quantity of ideas and the efficiency and effectiveness of implementation of those ideas (Jones and Kaluarachchi 2008). The second face of R&D is called the absorptive capacity, and it is considered to be crucial particularly for assessing the effective contribution by spillovers from others. Defined as a set of knowledge and competencies, the firm's knowledge base remains a preliminary condition in the assimilation of spillovers from R&D efforts of environment. R&D activity does not only stimulate innovation, but it also enhances the firms' ability to assimilate outside knowledge.

Successfully managing human resource capability is important for the high tech industry. Human resource performance management is a huge priority for competitive organizations. That's where superior software solutions come in. By automating much of the human resource performance management process, and adding much-needed knowledge and information access to the equation, such solutions can help to make these HR initiatives a source of success. Valued human resource development not only improves professional skills and capabilities, but also solves the problem of measuring the effect of human resources on an organization. We think that HRM as an instrument designed to enhance the labor extraction process and thus improve firm performance.

The approach is computationally simple and its underlying concept is rational and comprehensible, thus facilitating its implementation in a computer-based system. An empirical study demonstrated the feasibility and practicability of the proposed method for real-world applications.

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