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A Study on the Application of Fuzzy Analytic Hierarchy Process to Construct an R and D Management Effectiveness Evaluation Index for Taiwan's High-Tech Industry

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Abstract: The high-tech industry is one of the most important links in Taiwan's economic development. Research and Development (R and D) technology and management is the key to sustainable enterprises. However, the involvement of many difficult quantification factors and the fuzzy character of human subjective judgment on the R and D management content and process makes R and D management effectiveness evaluation more difficult. This study adopted the Fuzzy Analytic Hierarchy Process (FAHP) from the Fuzzy Theory to develop a set of systematized evaluation indices for R and D management effectiveness. This method is designed to assist enterprises in conducting R and D management effectiveness evaluations to achieve the goal increasing enterprise competitiveness. According to the outcome of this study, the researchers found the importance and weight of these major aspects for Taiwan's high-tech industry's R and D management effectiveness is shown as follows: R and D and Innovation (0.346), R and D Process (0.269), Customer (0.209) and R and D Personnel (0.184). Moreover, among the effectiveness evaluations on implementing the R and D management in certain industries, R and D and Innovation and R and D Process are determined as the important item that revealed how Taiwan's high-tech industries are particular about achieving R and D management through the completed R and D and innovation process.

Key words: R and D management, fuzzy theory, fuzzy analytic hierarchy process

INTRODUCTION

In Taiwan the high-tech industry has a shorter product lifecycle, higher investment amount, faster market change and higher rate of product elimination and replacement. In addition, under the globalization trend Taiwan's high-tech industry has gradually used Information Technology (IT) to shorten the process, reduce costs, increase flexibility and increase the product quality or service level to enhance enterprise competitiveness and achieve sustainable operation. Thus, to achieve the above mentioned goals, enterprises actively engage in R and D management to integrate their internal and external resources to improve operation performance (Liu *et al*., 2004, 2005; Tien *et al*., 2007). For corporate organizations, performance evaluations are absolutely important. Through performance evaluation results, corporate organizations can access the efficiency and efficacy of their resource operations as criterion for decision-making when setting up operational strategic goals. Kaplan and Norton (1996) argued that an effectiveness evaluation is one of the critical functions of management control. Without effectiveness measurements, the operation and practice performance of corporate activities cannot be controlled. This study adopted a questionnaire survey, data collection and analysis to conduct a probing discussion on the effectiveness of R and D management for Taiwan's high-tech industry. An evaluation index of R and D management effectiveness is constructed. This study also adopted the Fuzzy Analytic Hierarchy Process from the Fuzzy Theory to develop a set of systematized evaluation indices for R and D management effectiveness. This method is designed to assist enterprises in conducting R and D management effectiveness evaluations to achieve the goal increasing enterprise competitiveness. The main purposes of this study are as follows: Through enpterise R and D management activities the effectiveness R and D management is evaluated. The R and D management effectiveness is sorted out to construct an evaluation framework for R and D management and Fuzzy theory is used to construct a systemized evaluation model for R and D management effectiveness as a reference to assist enterprises in evaluating R and D management activities. The followings are mainly to explore domestic and foreign scholars

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review of related literatures of this research and briefly reorganize the data as the theoretical base when this research observes Taiwan's high-tech industry.

Definitions and characteristics of high-tech industry: Bleicher and Paul (1983) pointed out that the high-tech industry is a capital-/technology-intensive industry that is particularly about professional knowledge, research and development and the incubation of technology talents. Gould and Keeble (1984) thought the high-tech industry should be evaluated using 3 indices: the ratio of R and D expenses to the productivity, the speed of technology innovation and the ratio of R and D personnel. Shanklin and Ryans (1984) believed that enterprises should possess a powerful foundation in scientific technology. This new technology is able to promptly replace the existing technology and the follow-up application of new technology is capable of constructing or changing the market demand. This is called High Technology. The studies of Chiu (2002) indicated that the characteristics of the high-tech industry included: capital intensity, high technology level, short product lifecycle, etc. By integrating and organizing the above documents and literature, this study segmented Taiwan's high-tech industries into 6 major industries: Integrated Circuit (IC) Industry; Computer and its Peripheral Industry; Communication Industry; Optoelectronics Industry; Precision Machinery Industry and Biotechnology Industry.

R and D management: In 1991 the Arthur D. Little Corporation, a US-based enterprise, organized and indicated that the R and D Management could be divided into 3 eras from 1959 up to now: First Generation R and D Management (1950-1960): Target lacked a strategic framework; Second Generation R and D Management (1970~1980): Possessed partial strategic framework and would be considered cooperating with enterprise's overall development strategy for projects and third Generation R and D Management (after 1980): Possessed integrated strategic framework. Brown and Svenson (1988) regarded the activities of R and D management as a whole system that included investment, process and output to discuss the productivity of R and D management. Milletts (1990) researches pointed out that in order to respond to customer demands, regular upward and downward communications channel will upgrade R and D management capability. Ellis and Curtis (1995) indicated that R and D management might be influenced by customer satisfaction. Clausing (1994) pointed out the contents of R and D Management included whether the product fully responded to customer demand, design feasibility, successful integration and influenced strategy. McDonough (1993) indicated that external technology might save more time than internally developed technology. DeMott (1990) researches pointed out, in order to acquire a competitive advantage, enterprises should approach a strategic alliance with other corporations for sharing facilities and exchanging information to enhance their R and D Management capability. Mabert *et al.* (1992) found in their researches that if the R and D teams felt the competitive threat from their competitors and such situation might help them to shorten the R and D time. As well as in the studies of Gordon and Anne (2001) that found, when improving the R and D performance of certain projects teams, the leaders of such teams should know and understand the mental condition and the character trait for their team members. Through the literature review process, there were 5 aspects for evaluating R and D management for Taiwan's high-tech industry described as follows:

- **Degree of customer participation in early stage of new product R and D:** The researches of Karagozoglu and Brown (1993) pointed out that customer participation in developing new products is able to provide R and D departments with effective solutions to customer demands. Kamath and Liker (1994) found that if enterprises allowed their suppliers to participate in the new product development process it would help enterprises shorten their R and D time.
- **Degree of cooperation between R and D projects and external technology:** Karagozoglu (1993) pointed out that if enterprises used external technology, they could shorten R and D time and reduce costs.
- **Degree of cooperation between R and D projects and external capital:** Chakrabarti (1991) pointed out that the high-tech industry is categorized as one of the most capital-intensive industries with a significant positive correlation between R and D investment growth and business growth rates. In addition, conducting R and D activities by acquiring external capital would reduce costs.
- **Interdepartmental degree of R and D projects:** Youssef (1994) indicated that early participation and design in manufacturing, the adjustment and evaluation between design and manufacturing might be substantially reduced. Cusumano and Nobeoka (1992) pointed out that if the multi-function teams were adopted in developing new products, better manufacturing and design performance and increased quality would result.

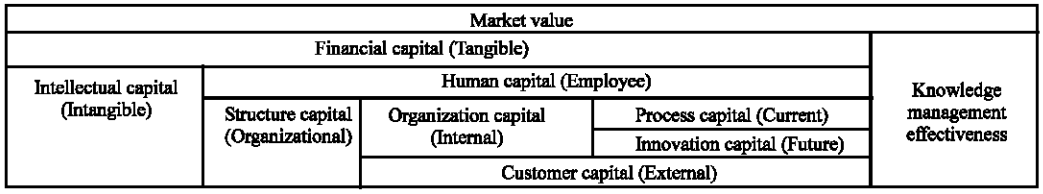

Fig. 1: Value chain of business market for scandia AFS

- **Investing top-level management participation in R and D projects:** Rosenau (1998) pointed out that the participation of top-level managers in R and D activities would be helpful to the supply and support of resources. The researches of Brown and Eisenhardt (1995) showed that the support of the top-level managers would be helpful in improving the new product development capability and R and D speed.

R and D management effectiveness: Effectiveness indicated that the degree of achieving the expected output target after resources were invested in a system is quantifiable and comparable. This study referred to the researches of Edvinsson and Malone (1997) which was aimed at the business market value chain for Scandia AFS, as shown in Fig. 1 and described as follows:

- **Innovation Capital (In C):** It evaluates the emphases, investing, forecasting, responding, innovating and regulation capabilities for enterprises facing future customer, product, market, strategic alliance, infrastructure and employee development trends.
- **Process Capital (PC):** It evaluates whether enterprises possess the culture, strategy, system, tool and capability to create an effective process for project implementation.
- **Customer capital:** It evaluates whether enterprises can effectively increase their customer base and maintain good relationships with them to construct a loyal, steady, high-satisfied and sustainable customer base.
- **Human capital:** It evaluates whether enterprises possess a group of employees equipped with high R and D capability, R and D experience, R and D originality and R and D motivation and whether enterprises positively encouraged and invested in the educational training and development for their employees.

Analytic Hierarchy Process (AHP): The AHP is a set of decision-making methods (Saaty, 1980; Lin *et al.*, 2007). Originally, the purpose of AHP is to solve the Transportation Respondent Project for the Ministry of National Defense of Egypt. The hierarchical structure was used to resolve the complicated problem from the high hierarchy to low hierarchy, as well as structure the hierarchy. Millet and Harkear (1990) pointed out that when adopting the AHP method, if the number of hierarchies increased, the number of comparisons between two required factors will show exponential growth. In addition, the researches of Belton and Gear (1985) indicated that it will only use the comparative rate to evaluate the importance of viewpoint between factors for the experts.

Fuzzy theory: The Fuzzy theory was proposed by Zadeh (1965) which defined as: make U the entire universe of discourse; each object in the Universe of Discourse is called an Element which is represented as u. Each fuzzy subset A of U indicates that with any $x \in U$, it appointed a real number $u_a(x) \in [0,1]$ which is called as the degree x under A. The researches of Dubois and Prade (1980) pointed out that the fuzzy number is standard and is the fuzzy set of the convex set. Zimmerman (1991) indicated that the sectional set is the method of converting the fuzzy set into the crisp set. The definition of the α-cut of the fuzzy number $\tilde{M}$ is shown as follows:

$$\tilde{M}^{a} = [(b-a)\alpha + a, c-(c-b)\alpha]$$

where, $0 \le \alpha \le 1$. In addition, the researches of Chen (2000) pointed out, assumed the $\tilde{M}_1 = (a_1, b_1, c_1)$ and $\tilde{M}_2 = (a_2, b_2, c_2)$ are the triangular fuzzy numbers, respectively and then the calculation of distance $(\tilde{M}_1, \tilde{M}_2)$ between them is shown as follows:

$$d(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3}[(a_1-a_2)^2 + (b_1-b_2)^2 + (c_1-c_2)^2]}$$

Fuzzy AHP: Laarhoven and Pedrycz (1983) evolved Saaty's Traditional AHP and developed into the Fuzzy Analytic Hierarchy Process (FAHP). Buckly (1985) was based on the inaccurate problems in Traditional AHP to lead the Fuzzy Set Theory in the Traditional AHP and converted the concept of consistence into the Fuzzy

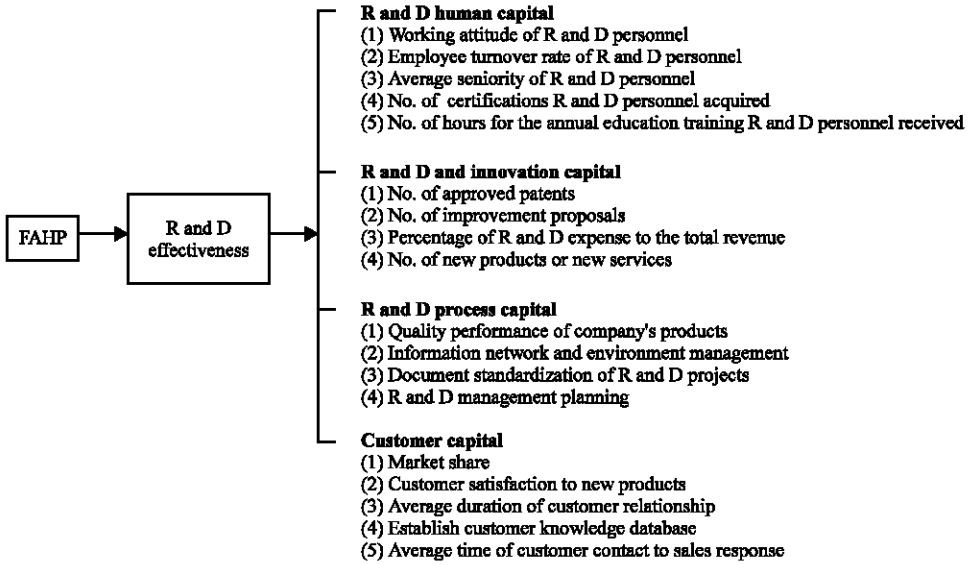

Fig. 2: Research framework

Matrix. With aiming at the AHP that is only able to apply to the confirmed condition, Mon *et al.* (1994) proposed the Fuzzy AHP Decision-Making Model with the basis of the Entropy Weight Method. This study is adopted the AHP, Fuzzy Theory, Fuzzy AHP methods to probe into the evaluation index of R and D management effectiveness for Taiwan's high-tech industries.

RESEARCH DESIGN AND CONSTRUCTION OF EVALUATION INDEX OF R AND D MANAGEMENT EFFECTIVENESS

This study refers to the research by Edvinsson and Malone (1997) as the business market framework for the Scandia AFS. The research framework content has undergone 3 expert screening processes and organized into the evaluation index for this study. This includes 4 major evaluations of R and D and Innovation Capital (In C); R and D Process Capital (PC); R and D human capital and customer capital, as shown in Fig. 2. After completing the construction of the hierarchical structure for this study, further to design the questionnaire with using the Analytic Hierarchy Process to acquire the relative weights of hierarchy and index in order to establish the construction of the R and D management effectiveness index for Taiwan's high-tech industry.

This study is aimed at the evaluation of the relative weights for the hierarchical structure to conduct a pair comparison between each hierarchical factor and calculate the fuzzy weights for the Fuzzy AHP as the evaluation index. Interviews were conducted with the related personnel responsible for carrying out R and D management in each enterprise. This included enterprises person in charge, managers, senior R and D engineers, R and D heads and heads of each level, then generalized and organized the information and data that acquired and collected from these interviews into the contents of the R and D Management Effectiveness Evaluation Index Questionnaire. The 1,000 questionnaires in total have been distributed, the number of returned ones is 850 and the number of valid questionnaires is 800.

Table 1: Priority table of Fuzzy and relative weights of the evaluation index for the first hierarchical evaluation aspect

Aspect	Fuzzy weight	Relative weight	Priority
R and D personnel	0.116, 0.176, 0.258)	0.184	4
R and D process	(0.212, 0.262, 0.325)	0.269	2
R and D and innovation	(0.313, 0.355, 0.387)	0.346	1
Customer	(0.217, 0.215, 0.229)	0.209	3

λ(MAX) = 4.18; CI: Consistency index = 0.07; CR: Consistency ratio = 0.07

ANALYSIS OF THE RESEARCH FINDINGS

Evaluation result and analysis of the first hierarchical evaluation aspects: The first hierarchy of this study is divided into: R and D personnel; R and D and innovation; R and D process and customer. In addition, from the calculated results, the researchers obtained the priority of the first hierarchical evaluation index as shown in Table 1.

The relative weights for R and D and Innovation and R and D Process are relatively higher with 0.346 and 0.296, respectively, which showed the crucial position of R and D and Innovation in implementing the R and D management evaluation model. The number of new products or new services, number of improvement proposals, ratio of the R and D personnel to overall

employees, information Network and environment Management, document standardization of R and D projects, R and D management planning, etc had a crucial impact on constructing the completed R and D management model for Taiwan's high-tech industry.

Evaluation result and analysis of the second hierarchical evaluation aspects: In the second hierarchical evaluation criteria of this study each evaluation aspect is subdivided into 4 evaluation criteria. The related second hierarchical evaluation criteria corresponds to the evaluation results from the first hierarchical evaluation aspect, the classification and evaluation results are described as follows:

Aspect of R and D personnel

- **Contents of the evaluation indices:** Working attitude of R and D personnel; Employee turnover rate of R and D personnel; Average seniority of R and D personnel; Number of certifications R and D personnel acquired and Number of hours for the annual education training R and D personnel received.
- **Evaluation results:** After the calculation, the priority of the evaluation index for the second hierarchical aspect of R and D personnel is obtained as shown in Table 2.
- **Evaluation results analysis:** R and D personnel shows that personnel quality is the most important property of company, the relative weights of the working attitude of R and D personnel and the average number of certifications R and D personnel acquired are higher with 0.267 and 0.215, respectively which indicated that the working attitude of R and D personnel and the average number of certifications R and D personnel acquired have already become the crucial factors in the aspect of R and D personnel.

Aspect of R and D and innovation

- **Contents of the evaluation indices:** Number of Approved Patents; Number of Improvement Proposals; Percentage of R and D Expense to the Total Revenue and Number of New Products or New Services.
- **Evaluation results:** After the calculation, the priority of the evaluation index for the second hierarchical aspect of R and D and Innovation is obtained as shown in Table 3.
- **Evaluation results analysis:** Within the continuous development in new technology and the fast accessibility of information, the R and D and Innovation of new products or new services are taking the crucial part for enterprises that wish to occupy a competitive position. In addition, in terms of R and D and innovation, the relative weights for the number of new products or new services and the number of improvement proposals were higher with 0.274 and 0.212, respectively. This indicated that enterprises need many R and D new product resources converted from internal and external market R and D knowledge.

R and D process

- **Contents of the evaluation indices:** Quality performance of company's products; information network and environment management; document standardization of R and D projects and (4) R and D management planning.
- **Evaluation results:** After the calculation, the priority of the evaluation index for the second hierarchical aspect of R and D Process is obtained as shown in Table 4.
- **Analysis of the evaluation results:** When constructing the R and D management model, the acquisition of data depends on the integrity of the R and D management model. In this aspect, the relative weights of the information network and environment management and the document standardization of R and D projects are higher with 0.276 and 0.274, respectively, which indicated that the construction of R and D management model needs the completed information network and the document standardization of R and D projects.

Customer

- **Contents of the evaluation indices:** Market share; customer satisfaction to new products; average duration of customer relationship; establish customer knowledge database and average time of customer contact to sales response.
- **Evaluation results:** After the calculation, the priority of the evaluation index for the second hierarchical aspect of Customer is obtained as shown in Table 5.
- **The evaluation results analysis:** R and D management is a systemized management with using enterprises' business intelligence, within the indices, the relative weights of the customer satisfaction to new product and the establish customer knowledge database are higher with 0.310 and 0.227, respectively. This indicated that in R and D management the degree of customer satisfaction with a new product is able to upgrade R and D management's enterprise value. In terms of these indices of the Establish customer knowledge Database, average duration of customer relationship etc., the R and d management can be regarded as the related information and knowledge to customer and company's operation.

Table 2: Priority table of fuzzy and relative weights of the evaluation index for the aspect of R and D personnel

Aspect	Fuzzy weight	Relative weight	Priority
Working attitude of R and D personnel	(0.171, 0.258, 0.373)	0.267	1
Employee turnover rate of R and D personnel	(0.121, 0.176, 0.246)	0.179	4
Average seniority of R and D personnel	(0.156, 0.198, 0.239)	0.192	3
No. of certifications R and D personnel acquired	(0.194, 0.221, 0.251)	0.215	2
No. of hours for the annual education training R and D personnel received	(0.144, 0.148, 0.156)	0.142	5

λ(MAX) = 5.18; CI: Consistency index = 0.05; CR: Consistency ratio = 0.05

Table 3: Priority table of fuzzy and relative weights of the evaluation index for the aspect of R and D and innovation

Aspect	Fuzzy weight	Relative weight	Priority
No. of approved patents	(0.078, 0.112, 0.158)	0.116	4
No. of improvement proposals	(0.167, 0.208, 0.265)	0.212	2
Percentage of R and D expense to the total revenue	(0.158, 0.188, 0.230)	0.190	3
No. of new products or new services	(0.256, 0.280, 0.297)	0.274	1

λ(MAX) = 5.24; CI: Consistency index = 0.07; CR: Consistency ratio = 0.07

Table 4: Priority table of fuzzy and relative weights of the evaluation index or the aspect of R and D process

Aspect	Fuzzy wight	Relative wight	Priority
Quality performance of company's products	(0.076, 0.122, 0.184)	0.130	4
Information network and environment management	(0.181, 0.274, 0.372)	0.276	1
Document standardization of R and D projects	(0.224, 0.280, 0.323)	0.274	2
R and D management planning	(0.187, 0.221, 0.249)	0.216	3

λ(MAX) = 5.21; CI: Consistency index = 0.06; CR: Consistency ratio = 0.06

Table 5: Priority table of fuzzy and relative weights of the evaluation index for the aspect of customer

Aspect	Fuzzy wight	Relative wight	Priority
Market share	(0.058, 0.089, 0.142)	0.096	5
Customer satisfaction to new products	(0.208, 0.304, 0.417)	0.310	1
Average duration of customer relationship	(0.157, 0.210, 0.271)	0.211	3
Establish customer knowledge database	(0.196, 0.233, 0.266)	0.227	2
Average time of customer contact to sales response	(0.165, 0.168, 0.169)	0.161	4

λ(MAX) = 5.25; CI: Consistency index = 0.07; CR Consistency ratio = 0.07

Table 6: Comprehensive relative weight priority for each hierarchical aspect and index

Target	Evaluation index of R and D management effectiveness for Taiwan's high-tech industry		
Aspect	Index	Relative weight	Comprehensive priority
R and D personnel	Working attitude of R and D personnel	0.049	8
	Turn over rate of R and D personnel	0.033	15
	Average seniority of R and D personnel	0.035	13
	No. of certifications R and D personnel acquired	0.040	12
	No. of hours for the annual education training R and D personnel received	0.027	18
R and D and innovation	No. of approved patents	0.031	16
	No. of improvement proposals	0.094	2
	Percentage of R and D expense to the total revenue	0.050	7
	No. of new products or new services	0.095	1
R and D process	Quality performance of company's products	0.044	11
	Information network and environment management	0.072	3
	Document standardization of R and D projects	0.065	4
	R and D management planning	0.056	5
Customer	Market share	0.029	17
	Customer satisfaction to new products	0.055	6
	Average duration of customer relationship	0.045	10
	Establish customer knowledge database	0.048	9
	Average time of customer contact to sales response	0.034	14

Comprehensive relative weight of each evaluation index for the second hierarchy

Priority of comprehensive relative weight: According to the relative weights of the second hierarchical index and the first hierarchical aspect, the relative weights of each aspect to the entire values that obtained after calculating are sorted as shown in Table 6.

Analysis of the evaluation results: Within evaluating the effectiveness of carrying out the R and D management in enterprises, R and D and innovation and R and D process are the most important indices, among which, the new product or new service are the most important sub indices in terms of R and D and innovation. This indicated that the innovation and R and D of new product is an

important index of evaluating the R and D management effectiveness for Taiwan's high-tech industry. In addition, as for the R and D process, the information network and environmental management, document standardization of R and D Projects and R and D management planning are occupied the top 3 positions of all indices, which showed how the Taiwan's high-tech industry, through the integrated information network to practically implement the process of standardization ad further to achieve the goal of R and D management.

CONCLUSIONS

Through the collection and arrangement of related documents and literature, this study is adopted Taiwan's high-tech industry as the research object to conduct an in-depth discussion on the connotation, aspect and evaluation index of R and d management effectiveness for Taiwan's high-tech industry to develop a proper evaluation model to evaluate R and D management effectiveness for Taiwan's high-tech industry. In this study we found that the importance priority of the major aspects of R and D management effectiveness for Taiwan's high-tech industry is as following: R and D and innovation (0.346), R and D process (0.269), Customer (0.209) and R and D personnel (0.184). In terms of evaluating the effectiveness of carrying out R and D management, R and D and innovation and R and D process are the most important indices and as for the R and D and Innovation, the Number of new products or services and the number of improvement proposals are the most important indices which showed the innovation and R and D of new products are the crucial indices of evaluating the R and D management effectiveness for Taiwan's high-tech industry. In terms of the R and D process, the information network and environmental management, document standardization of R and D projects and r and d management planning occupied the top 3 positions of all indices. This showed how Taiwan's high-tech industry through the integrated information network to practically implement the process of standardization ad further to achieve the goal of R and D management. This study is only used Taiwan's high-tech industry as the evaluation of constructing the R and D management effectiveness index without considering the interaction between each hierarchical aspect and index, as a result, the outcome of the simplified model may produce some evaluation errors. In the future researchers may categorize a large number of indices from related document and literature, then through the factor analysis to construct the hierarchical structure of evaluating the R and D management effectiveness for Taiwan's high-tech industry.

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