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CORPORATE FIRM-LEVEL KNOWLEDGE ACCUMULATION AND ENGINEERING MANPOWER OUTSOURCING

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Firm-level knowledge is a key resource providing a competitive advantage in innovation for enterprises. Outsourcing strategies reveal trends in strategic business administration. However, internal knowledge accumulation (KA) and engineering manpower outsourcing (EMO) produce opposing effects on firm-level knowledge. This study analyzes the relationship between KA and EMO among enterprises in Taiwan by means of expert interviews, an analytic hierarchy process (AHP), and a fuzzy logic inference system (FLIS). The results show that, compared to EMO, firm-level KA affords a greater degree of influence on the effectiveness of firm-level knowledge. Based on the literature and expert interviews, the three sub-variables of knowledge integration ability (KIA), knowledge absorption ability (KAA), and knowledge sharing ability (KSA) are extracted from the KA variable, and the three sub-variables of cost, resources, and strategy are extracted from the EMO variable.

Keywords: analytic hierarchy process (AHP), engineering manpower outsourcing, fuzzy logic inference system (FLIS), knowledge accumulation

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1. INTRODUCTION

In recent years, in order to empower economic growth and propel industrial production, the global economy has been gradually developing and aiming to mold knowledge accumulation and innovation. It is obvious that accumulating knowledge during the process of R&D and performing industrial mechanisms by making use of the services of technology, knowledge, and organization will be the bases of innovation and the core of future development in industry. From the perspectives of the innovation era and knowledge economy, not only is accumulating knowledge important but disseminating technologies is also the key to leveraging the R&D innovation abilities of industry. Garner declared on January 15, 2009, that “outsourcing will continue to grow in 2009 despite economic slowdown”, and Woodall et al. (2009) also indicated that the outsourcing of core management functions is a growing trend and is beginning to receive attention from enterprises. Just as predicted outsourcing, not only of non-core business but also of engineering functions, continues to become more popular. By engaging in engineering manpower outsourcing (EMO), an enterprise can avoid excessive investments in technology and manpower.

However, internal knowledge accumulation (KA) and EMO produce opposing effects on firm-level knowledge according to Gavious and Rabinowitz (2003). This *Harvard Business Review* paper addresses the concept that the outsourcing strategy employed by a firm reveals the trends of its strategic business administration. It also points out that, over the past 80 years, outsourcing has become one of the most important concepts in business management and operation. In Taiwan, photonics, semiconductors, and information technology (IT) are the major industries that require engineer outsourcing, mostly because the characteristics of these industries are capital-intensive and demand both a high quality and a large quantity of engineers. Since the photonics industry is currently at an early stage of development, the categories of its technical manpower are not only inclined to be diversified but also reflect an increasing need for technical manpower. Moreover, the combination of technical manpower needs and rapid industrial expansion results in a significant imbalance in supply and demand of technical manpower.

Finding ways of accumulating internal R&D knowledge while gaining technical manpower by outsourcing to engineers from outside firms is a problem that has obviously existed and been raised in recent years. Most of the high-tech enterprises in Taiwan currently utilize the traditional experience-based method to temporarily find a balance and optimization for this problem, but there is still no systematic and suitable solution for the imbalance in KA and technical manpower outsourcing. This study explores the incorporation of KA and EMO using a hierarchical research framework based on a literature review and expert interviews. This hierarchical framework defines the influential major variables and sub-variables of KA and EMO. The analytic hierarchy process (AHP) is used to calculate the weights for each variable and sub-variable. Since AHP can only evaluate the weights by making pair-wise comparisons among variables and sub-variables, it is essential to employ a fuzzy logic inference system (FLIS) to generate 3D fuzzy surfaces, in order to clearly analyze the growth-and-decline relationships among the variables and sub-variables. FLIS researchers often make use of the Delphi method to collect opinions from professionals and to generate a fuzzy logic gate for fuzzy rule-based calculations (e.g., Perng et al., 2005; Hsu and Chen, 2007). To simplify the interview processes, AHP weights are utilized in the formation of the fuzzy logic gate in this study.

2. LITERATURE REVIEW

2.1 Firm-Level Knowledge Accumulation (KA)

In the face of an uncertain and competitive environment, it is common for enterprises to implement resource sharing and risk partaking through cross-company collaborations. During long-term and intimate cooperation, an enterprise has the chance to acquire its partners' knowledge or build innovation based on inspiration from its partners. Knowledge is an invisible but valuable element that is difficult to materialize into the practical environment. In view of the rapid obsolescence and continual upgrading of knowledge, the core issue of managing knowledge focuses on ways to obtain valuable knowledge and accumulate enterprise-specific knowledge. A knowledge network can be achieved via close interactive communication and mutual cross-boundary coordination. By participating in the actual processes, learners can acquire experience and produce new knowledge.

Knowledge accumulation and the various adaptations of knowledge are critical issues in the field of knowledge management. The complexity of dynamic application domains and the uncertainty of future maintainability are the main problems of knowledge accumulation (Koh et al., 2005). Knowledge flows exist between tacit and explicit states, creating a symbiotic relationship between the two states (Polanyi, 1967). Most tacit knowledge is obtained by constructing knowledge networks and sending knowledgeable workers to explore situations or personal experiences. Firm-level knowledge can be stored in the memories of employees, and the combination of knowledge and activities within enterprises allows knowledge to become stored in the systematic routines of enterprises (Argot, 1999). Barry and Stephens (1998) argue that only by the accumulation and diffusion processes of knowledge can firm-level knowledge be created and gathered into a firm's core competitive forces. Morgan et al. (2003) also suggest that efficiency in adapting relevant knowledge is the key to understanding organizational performance. Based on the viewpoint of knowledge-based theory (KBT), knowledge comprised of different types at different levels of the organization is linked with business performance outcomes. Therefore, knowledge is considered to be the most strategically significant resource of a firm: the firm exists as social communities of knowledge, with knowledge forming the most strategically significant resource accounting for inter-firm performance variations (Grant, 1996; Kogut and Zander, 1992). Knowledge accumulation lies in the knowledge-absorbing ability of knowledge receivers and knowledge-receiving enterprises. Although firm-level knowledge is difficult to accumulate in a specific way, knowledge integration, absorption, and sharing are important abilities that enable enterprises to accumulate knowledge.

Kogut and Zander (1992) view knowledge integration as the ability to apply existing knowledge in an integrative way to acquire new knowledge, and Demsetz (1988) states that the integration and application of knowledge are the processes that need to be specialized in a company. Knowledge integration not only refers to the application of IT tools, such as databases, but also to communication and coordination between individuals as well as the common knowledge possessed by these individuals. In order to achieve knowledge integration, it is essential to have an effective and efficient method of capturing detailed working knowledge directly from the subject matter experts. In addition, enterprises should not only integrate internal knowledge resources to fully realize the value of knowledge, they should also integrate required knowledge from the plentiful external knowledge bases (Nonaka, 1994). Teece and Pisano (1994) indicate that, in order to achieve success in an environment of global competition, enterprises should not only immediately integrate related knowledge resources and quickly take on the innovated ability, but also efficiently systematize and structure their knowledge by combining various kinds of internal and external knowledge.

Cohen and Levinthal (1990) point out that an enterprise's ability to absorb and assimilate knowledge leads to self-reliance of innovation, rooted in an enterprise's communication interface of internal and external communication mechanisms. A smooth communication interface offers more opportunities for an enterprise to absorb knowledge. Atuahene-Gima (1992) indicates that knowledge absorption not only relates to a company's human assets, relative knowledge accumulation mechanism, enterprise culture, and knowledge distribution, but also relates to the knowledge which the company has accumulated from its R&D, manufacturing, and marketing, as well as its sensitivity to external technical knowledge. In order to digest, integrate, and internalize knowledge, it is essential for enterprises to seize possession of knowledge absorption. A firm's knowledge absorption is related to the attributes of its alliances and the concept of "dyadic level" (relative absorptive capacity), and foreign investors are significant actors in the framework of knowledge absorption (Torkkeli et al., 2009). Berghman et al. (2006) distinguish knowledge absorption by the marketing practices of knowledge recognition, knowledge assimilation, and knowledge transformation. The efficiency of knowledge absorption depends on the abilities to distinguish valued knowledge and transform diversified knowledge into knowledge with a "common language" that is easily absorbed and applied. In addition, absorption ability not only depends on the members of an enterprise, but also on the managerial attitude within the enterprise.

Sveiby (1997) purports that knowledge sharing is a kind of communication behavior used to help team members quickly master information, experiences, and skills, giving rise to thoughts and innovations. Davenport and Prusak (1998) argue that knowledge is a kind of special asset within enterprises and that knowledge sharing multiplies the effects of the accumulating assets of enterprises. Knowledge sharing is the activity of exchanging knowledge among people or organizations, and it provides enterprises with a solid basis for strategic differentiation. The sharing of knowledge constitutes a major challenge in the field of knowledge management because some employees tend to resist sharing their knowledge with the rest of the members in the organization (Bock and Kim, 2002; Ciborra and Patriota, 1998). The ideas and experiences of employees are regarded as human capital (Petrash, 1996). If employees are able to share their knowledge and experiences with others through sharing mechanisms, this kind of sharing interaction can not only promote the various capitals of enterprises and customers, but also contributes to the core values of enterprises. Knowledge sharing behavior also involves interaction between two different individuals, and is a kind of communication learning process in which one learns knowledge from others and absorbs and internalizes external knowledge (Hendriks, 1999). The processes of knowledge sharing face the obstacles of knowledge distortion and misunderstandings due to differences in time, space, social status, language, culture, personal mentality etc. Davenport and Prusak (1998) note that mutual trust is not only necessary for knowledge transaction but also essential for knowledge sharing, and that the collaborative abilities constructed by mutual trust positively influence the knowledge sharing of enterprises. Collaborative abilities can be viewed as a kind of learning-oriented culture within enterprises, and are the foundation for creating a sustainable competitive advantage and for the process of refining and renewing an enterprise's knowledge.

2.2 Engineering Manpower Outsourcing (EMO)

Outsourcing is a strategic business behavior that enterprises can adopt to make use of external resources to transfer specific internal tasks to external providers, so that the enterprises can focus their resources on their core business activities. Labbs (1993) describes outsourcing as an activity in which enterprises allow external service providers to take responsibility for certain necessary but non-core competencies by signing contracts with them to help maintain the internal operations of their enterprises. Quinn and Hilmer (1994) define outsourcing from the viewpoint of resource distribution as making an appropriate allocation of a company's technologies and resources to produce the biggest profit, for which the most practical method is to focus the company's resources on its core business and to outsource other non-core activities appropriately. Minoli (1995) states that, if an external organization can perform certain tasks for an enterprise more efficiently and cheaply, then these tasks should be handed over to the external organization. However, if the enterprise can perform the tasks better, then they should be handled by the enterprise. Arnold (2000) summarizes many scholars' opinions and indicates that outsourcing must be justified based on value-creating activities, strategic considerations, and the usage and distribution of resources. With limited resources and fast-changing markets and technology environments, if enterprises cannot provide core abilities themselves to satisfy business requirements and maintain competitive advantage in the market, then EMO is actually a cooperative strategy that enterprises should consider in order to continue to grow. This study discusses EMO competence by considering the three aspects of cost, resources, and strategy.

From the cost-based viewpoint, labor costs usually include salaries, year-end bonuses, health insurance premiums, personnel welfare expenses, and retirement pensions. To avoid enormous expenditures on personnel, many enterprises use a certain percentage of short-term contract workers as part of their internal personnel allocation. The enterprise usually takes care to ensure that the labor supply conforms to requirements and to pay the expenses associated with obtaining these workers. On the other hand, as the economic recession and changes in industrial structure continue to permeate the economy, many small and medium enterprises (SMEs) face the crisis of possibly ceasing operations. To reduce operating costs and fill work vacancies without employing regular workers, hiring contract labor has become a new trend for enterprises. In addition, when the internal personnel needs of an enterprise change, contract labor may be used to maintain management flexibility and to ensure that the core personnel are not affected by fluctuations in manpower demands. Enterprises often use short-term contract workers to adjust internal manpower levels so as to avoid the problem of overabundant or underused manpower when a temporary work requirement is finished. In response to varying requirements, the enterprise can adjust the current personnel allocation through appropriate additions or subtractions of manpower to make the core organization more flexible.

From the resource-based viewpoint, Collis (1991) divides resources into the three classes of core abilities, organizational abilities, and corporate heritage. Wernerfelt (1989) emphasizes that an enterprise uses its own resources to judge competitive advantage and disadvantage and the feasibility of outsourcing. In addition, Wu (1998) points out that there are three kinds of motives for EMO alliances: (1) the enhancement motive, to enhance the enterprise's present resources; (2) the complementary motive, to exchange resources among enterprises; and (3) the dependent motive, to find and share resources together. At the same time, Wu (1998) indicates that, when constructing its own core resources, the enterprise should take three strategic-resource characteristics into consideration: uniqueness, specialization, and ambiguity. Wu's theory is different from that of Barney's (1991), which suggests that whether a resource offers ongoing potential competitive advantage depends on its value, rarity, imperfect imitability, and non-substitutability.

From the strategy-based viewpoint, operations within enterprises are composed of series of activities, which usually include input, processing, and output activities. When an organization is confronted with the need to exchange resources and there is uncertainty in the external competitive environment, the organization will be inclined to obtain resources essential for its survival, to combine its own resources with important production elements in the external environment, and to obtain the desired resources through this combination. This explains the factors that influence an enterprise's outsourcing decisions. As for the enterprise's relationships, whether enterprises use a cooperative model of merging, marketing, or forming networks of alliances depends on the degree of mutual resource dependence. The factors within an enterprise that depend on other enterprises include resource importance, usage ability, and controlling ability. The precondition of resource dependence theory (RDT) is that, because the enterprise aims to reduce uncertainty and management dependence, it can try to establish formal or semiformal relationships with other enterprises with the intent of undertaking joint activities, including contracts, joint ventures, acquisitions, alliances, outsourcing, and so on (Ulrich and Barney, 1984).

3. RESEARCH METHOD

3.1 Expert Interviews

KA within enterprises lies in "knowledge integration ability (KIA)", "knowledge absorption ability (KAA)", and "knowledge sharing ability (KSA)". EMO within enterprises lies in the aspects of "cost", "resources", and "strategy". Figure 1 illustrates a hierarchical framework of an enterprise's KA and EMO developed in this study from the literature review and interviews with experts. Experts in related fields were interviewed regarding their enterprise's actual operation of knowledge management and human resources. All experts identified the importance of KA and EMO for an enterprise's future development. This study applies Expert Choice 2000 and MATLAB's fuzzy logic toolbox to calculate and analyze the priorities of the influential variables of both level 2 and level 3 variables.

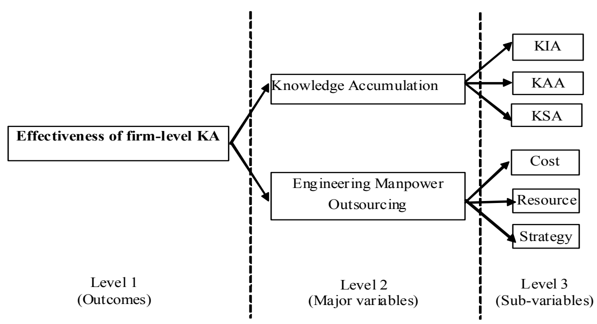


Figure 1. Hierarchical framework of KA and EMO

3.2 Analytic Hierarchy Process (AHP) Questionnaires

The AHP, developed by Saaty in 1971, is efficient for the measurement of multiple criteria decision-making. It employs pair-wise comparisons to determine weights and priorities with respect to various variables and sub-variables. The basic assumption is that decision makers are able to structure a complex problem in the form of a hierarchy where each variable or sub-variable can be identified and evaluated with respect to other related variables and sub-variables. The optimal decision at the highest level can be selected from pair-wise comparisons of sub-variables. Thus, the analytical aspects of the AHP stimulate the creation of new dimensions for the hierarchy. The AHP is a process that induces cognitive awareness, and it has been used for various decision-making problems with a multitude of quantitative and qualitative variables and sub-variables. Dolan et al. (1989) indicated that there are three fundamental elements of AHP: (1) structuring the problem, (2) pair-wise comparisons, and (3) weighting the decision variables. The nine steps of AHP implementation in this study are:

1. A system can be dissolved into many components.
2. In the hierarchy structure, each factor has a single level.
3. Factors at each level can be evaluated according to the previous level.
4. An absolute numerical scale can be transformed into a proportional scale.
5. After pair-wise comparison, use a positive reciprocal matrix.
6. The relationship of factors' priorities must have transitivity (If *A* is better than *B*, and *B* is better than *C*, then *A* must dominate *C*), and strength (IF *A* is two times better then *B*, *B* is two times better than *C*, then *A* must be four times better than *C*).
7. Transitivity is hard. Thus, factors that do satisfy transitivity can be acceptable. However, such factors must pass the test

of consistency ratio (CR<0.1), where CR=CI/RI, and CI=(λmax-n)/(n-1) and RI=random index, gained from the rank of RI (Satty, 1980, p. 21).

8. Through the weighting principle, factors gain an intensity of priority.
9. Regardless of the intensity of factors, all factors in the hierarchy are considered to relate to the overall assessment.

In this study, the AHP method takes experts as the objects of a questionnaire survey and selects participants who had been in charge or served in the industry for a number of years. 27 questionnaires were distributed and 22 completed questionnaires were received back. The completed questionnaires were from the following experts: 2 CEOs, 7 technical staff members, 4 group leaders and section supervisors, 6 deputy managers, and 3 senior advisors. The shortest term of seniority is 4.5 years and the longest is 25 years. The industrial distribution of the returned questionnaires covers machinery, hardware devices, semiconductors, electro-optical, manufacturing, technical services, and R&D institutes. Table 1 shows the interviewed experts' backgrounds.

Table 1. Interviewed experts' backgrounds

No	Expert's background	Professional title	Years of seniority
1	Management of administration	CEO	12
2	Management of administration	Vice CEO	8
3	R&D department	Senior engineer	7
4	R&D department	Senior engineer	6
5	Electro-optical technology	Senior engineer	8
6	Semi-conductor company	R&D engineer	6
7	Manufacturing department	Engineer	9
8	Manufacturing department	Engineer	4.5
9	Hardware device company	R&D engineer	5
10	R&D department	Director	7
11	R&D department	Vice director	15
12	R&D Institute	Director	18
13	Semi-conductor company	Department manager	7
14	HR department	Deputy manager	12
15	Sales and marketing	Deputy manager	12
16	Sales and marketing	Deputy manager	5
17	Electro-optical technology	Deputy manager	12
18	Foreign-business technology	Deputy manager	8
19	Manufacturing department	Deputy manager	12
20	HR department	Senior advisor	6
21	Sales and marketing	Senior advisor	7
22	R&D institute	Senior advisor	25

After obtaining the values for the weights from AHP, a fuzzy logic inference system (FLIS) was adapted to generate 3D fuzzy surfaces to analyze the growth-and-decline relationships between variables and sub-variables. Fuzzy inference is the core of fuzzy systems, and it has been applied to a wide variety of systems.

3.3 Fuzzy Logic Inference System (FLIS)

Inference system of Mamdani

Through inferences from a fuzzy rule base, the inference engine processes input sets and produces output sets. Two types of inference systems commonly used for fuzzy logic are the Mamdani type and the Sugeno type. Mamdani fuzzy inference is named after Professor Mamdani, of London University. In general, Mamdani fuzzy control rules follow Professor Mamdani's usage of "IF-THEN" terms. Sugeno fuzzy inference was introduced by Sugeno in 1985 (Sugeno, 1985). Mamdani and Sugeno inferences adapt the same algorithms; both involve fuzzifying the inputs and applying the fuzzy operator. The main difference between Mamdani and Sugeno is that the Mamdani output is generally considered continuous, and the Sugeno output is considered discrete. Owing to the discovery of successive variations in output, this study has adopted a Mamdani model to set up a FLIS. The Mamdani model has three segments: fuzzy set definitions of input criteria and output; fuzzy scales of membership functions; and IF-THEN rules. Different from the research approaches of Perng et al. (2005) and Hsu and Chen (2007), this study adapted the weights calculated from the AHP to construct IF-THEN rules. Figure 2 shows the fuzzy inference of Mamdani.

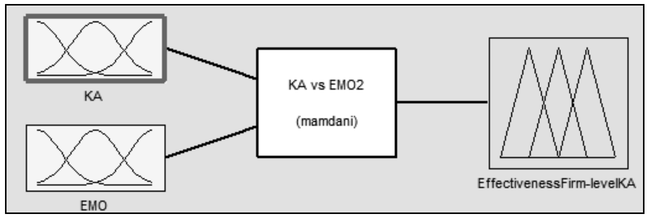


Figure 2. The fuzzy inference of the Mamdani model

Membership functions

A membership function is characterized by a fuzzy linguistic term given a support value, i.e. degree of membership. Membership values vary from 0 to 1, representing non- to full membership. Membership functions commonly used include triangular functions and bell-shaped functions (Yu and Skibniewski, 1999). The bell-shaped function has continuous output and smoothly generates less fuzzy square measures, reducing fuzziness. However, such a function requires greater computational effort. In order to reduce the complexity of FLIS computations, this study uses triangular functions as input and bell-shaped functions as output. The final membership functions of the major variables are shown in Figure 3.

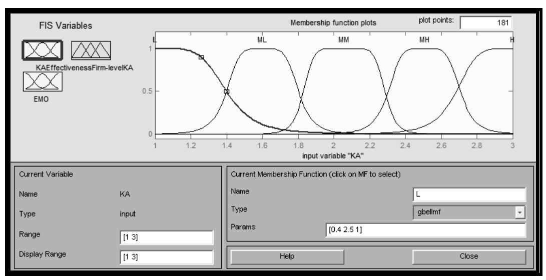


Figure 3. Construction of membership functions in MATLAB's fuzzy logic toolbox

Ragin (2000, p.158) emphasized that assigning fuzzy scores with a midpoint value that is the mean or median of the range of a dependent value "would be a serious mistake". Therefore, this study set three qualitative anchors, Moderate High, Moderate Middle, and Moderate Low, within the input and output criteria of Moderate. Each input criterion represents diverse influences on performance. Therefore, to determine the evaluation standard requires an individual fuzzy set for each criterion. Determinations of the maximum and minimum levels for the three criteria, KIA, KAA, and KSA (within KA) and cost, resources, and strategy (within EMO) are shown in Table 2. The evaluation of fuzzy scales is designed for easy interpretation. The *k* values for High, Moderate High, Moderate Middle, Moderate Low, and Low are assigned as 3.0, 2.5, 2.0, 1.5, and 1.0, respectively.

Table 2. Definitions of input criteria and output values

Input criteria				Output value		
Influential variable	Sub-variables	Linguistic terms	*k* values	Name	Linguistic terms	*k* values
KA	KIA KAA KSA	High	3	Effectiveness of firm-level knowledge	High	3
		Moderate High	2.5		Moderate High	2.5
		Moderate Middle	2		Moderate Middle	2
		Moderate Low	1.5		Moderate Low	1.5
		Low	1		Low	1
EMO	Cost Resources Strategy	High	3			
		Moderate High	2.5			
		Moderate Middle	2			
		Moderate Low	1.5			
		Low	1			

3.4 Construction of the fuzzy IF-THEN logic gate

According to Pan and Yun (1997), fuzzy logic gates are used to model the uncertainty of relationships between events. In this study, the weights (w) of the major variables and sub-variables were based on the AHP analysis of the experts' questionnaires. In order to construct the fuzzy logic gate and conduct the relevant analysis of the various variables, the author adopted the MATLAB fuzzy tool and AHP weights to distinguish the relevancies and degrees of influence between the variables and sub-variables. The IF-THEN rules are constructed in this section from the High, Moderate High, Moderate Middle, Moderate Low, and Low values of the input criteria, including major variables and sub-variables. Some IF-THEN rules relate sub-variables with a single major variable while other IF-THEN rules relate major variables. Each of the 6 sub-variables and 2 major variables can be assumed to be a rule input. First, the major feature IF-THEN rules are described, followed by rules relating sub-variables. All rules have a unique output defined for each possible set of inputs.

(1) Each rule relating major variables takes 2 inputs. There is one input for each major variable, namely KA and EMO, and each input can take one of 5 values (High, Moderate High, Moderate Middle, Moderate Low, and Low). Thus there are 5×5=25 possible input sequences because there are 25 combinations of values.

(2) The IF-THEN rules relating sub-variables within KA must accommodate every combination of the 3 sub-variables, namely KIA, KAA, and KSA. Because KA takes 3 sub-values, there are 5×5×5=125 rules.

(5) The IF-THEN rules relating sub-variables within EMO must accommodate every combination of the 3 sub-variables, namely cost, resources, and strategy. Because EMO takes 3 sub-values, there are 5×5×5=125 rules.

Table 3 shows the fuzzy scenarios of the IF-THEN rules relating the sub-variables of KA and EMO.

Table 3. Fuzzy scenarios relating the sub-variables of KA and EMO

Level 1	Level 2 (Major variable)	Scenarios	Total scenarios
KA	KIA KAA KSA	5×5×5=125	250
EMO	Cost Resource Strategy	5×5×5=125	

3.5 IF-THEN rules calculations for KA and EMO

The weights (*w*) of the major variables and sub-variables are based on the AHP analysis of the experts' questionnaires. In order to conduct the relevant analysis of the various variables, this study adopts the MATLAB fuzzy tool to distinguish the relevancies and degrees of influence between the various variables. For example, in scenario 6 in Table 4, KA is MH (Moderate High) and EMO is H (High). The calculation of the IF-THEN outcome is thus obtained as: 2.5*0.642 + 3*0.358= 2.679 (outcome value *P*). Table 5 shows the fuzzy range of outcome values *P* with respect to KIA, KAA, and KSA.

Table 4. IF-THEN rules calculations for KA and EMO

Scenario		KA (0.642)	EMO (0.358)	Outcome value (*P*)	Linguistic term
1	if	H	H	3	H
2	if	H	MH	2.821	H
3	if	H	MM	2.642	H
4	if	H	ML	2.463	MH
5	if	H	L	2.284	MH
6	if	MH	H	2.679	H
			……….		
20	if	ML	L	1.321	L
21	if	L	H	1.716	ML
22	if	L	MH	1.537	ML
23	if	L	MM	1.358	L
24	if	L	ML	1.179	L
25	if	L	L	1	L

Table 5. Fuzzy range of outcome values *P*

P range	Linguistic term	Abbr.
$2.6 < P \leqq 3$	High	H
$2.2 < P \leqq 2.6$	Moderate High	MH
$1.8 < P \leqq 2.2$	Moderate Middle	MM
$1.4 < P \leqq 1.8$	Moderate Low	ML
$1 \leqq P \leqq 1.4$	Low	L

4. RESULTS AND ANALYSIS

4.1 Analytic Hierarchy Process (AHP) Results and Analysis

The AHP questionnaire analyses calculated via Expert Choice 2000 and Excel are shown in Table 6. The results of this study show that both the consistency index (CI) and the consistency ratio (CR) values in the hierarchy comparison analysis are less than or equal to 0.1, conforming with the acceptable deviation scope suggested by Saaty (1980). From Table 6, it is obvious that KA is the most important variable (w=0.642) when considering the incorporation of KA and EMO in enterprises. KIA (w=0.558) is regarded as the most important KA sub-variable. It is also inferred that the ability circulating inside and outside of enterprises of quickly integrating resources in a systematic, structural, and interactive way is important for integrating knowledge in enterprises and, further, for accumulating firm-level knowledge. The second most important variable in this study is KSA (w=0.232), which shows that appropriate mechanisms for sharing knowledge are beneficial to firm-level KA within enterprises. According to the AHP results, although KAA has a relatively low weight value (w=0.21), it is almost equivalent to KSA based on the experts' opinions. In Table 6, it also shows that "cost" is the most important variable (w=0.476) when considering the engineering outsourcing in enterprises. The second most important variable is "resources" (w=0.291), which shows that appropriate mechanisms for "resources" are beneficial to the engineering outsourcing in Taiwan's enterprises. According to the AHP results, although "strategy" has a relatively low weight value (w=0.233), it is almost equivalent to "resources" based on the experts' opinions.

Table 6. AHP weights

Major variable	Sub-variables	w for major variable
KA (0.642)	KIA	0.558
	KAA	0.210
	KSA	0.232
EMO (0.358)	Cost	0.476
	Resource	0.291
	Strategy	0.233

4.2 Fuzzy Surfaces and Analysis

Fuzzy surfaces of KA vs. EMO

Based on the fuzzy surfaces of KA and EMO depicted in Figure 4, KA has a significant impact on the incorporation of KA and EMO since, when the value of EMO on the y-axis is fixed, the rising slope on the x-axis of KA is significant and it is relatively easy to reach the "High" degree of effectiveness of firm-level KA on the z-axis. Figure 4 also shows that, when the value of KA is located in the range of 2-1 ($1 \leqq P \leqq 2$), no matter how the values of EMO are increased the highest degree of effectiveness of firm-level KA can only reach the range of 1.5-1 ($1 \leqq P \leqq 1.5$). This demonstrates that KA has a significant impact on the effectiveness of firm-level knowledge.

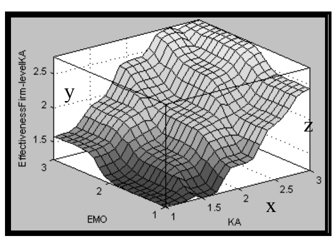
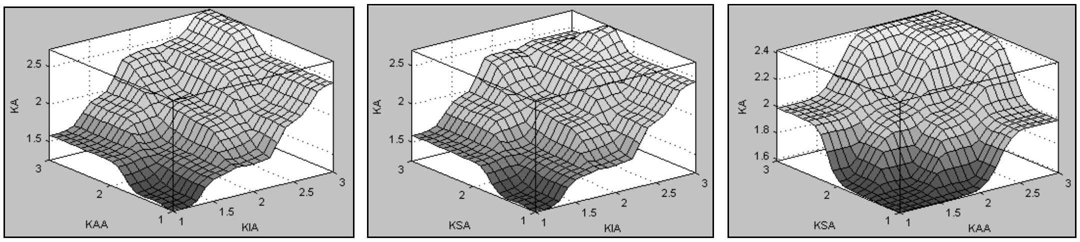


Figure 4. Fuzzy surfaces of KA and EMO

Fuzzy surfaces of KA

Figures 5 (a), (b), and (c) show the fuzzy surfaces of major variables KIA vs. KAA, KIA vs. KSA, and KAA vs. KSA. Figures 5 (a) and (b) indicate that KIA has a significant impact on KA since, as long as the degree of strength of KIA is close to 2.5 (i.e. $P \geqq 2.5$), the outcome of KA is mostly located in the High range. Figure 4 (c) shows that KSA and KAA have similar strengths of influence and also indicates that, without considering KIA, the outcome of KA is only located in the range of Moderate Middle (MM). Through the integrative discussion of KAA, it can be seen that the greatest influence on KAA lies in how many resources are invested in firm-level KA. Among the theories of studying KA, quite a few experts and researchers have pointed out that the importance of knowledge sharing contributes to the knowledge environment construction (Sveiby, 1997; Senge, 1997; Davenport and Prusak, 1998; Iwata et al., 2006). Therefore, an efficient knowledge creation mechanism is useful for improving the performance of knowledge creation, and thus KSA determines the effectiveness of knowledge creation.

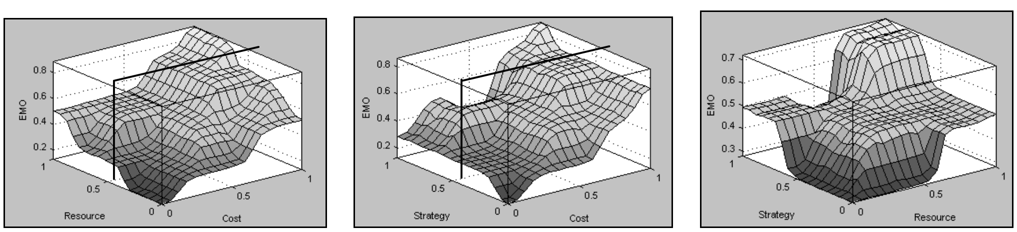


(a) (b) (c)

Figure 5. Fuzzy surfaces of KA

Fuzzy surfaces of EMO

Figures 6 (a), (b) and (c) show the fuzzy surfaces of sub-variables “cost” vs. “resources”, “cost” vs. “strategy” and “resources” vs. “strategy”. Figures 6 (a) and (b) indicate that, compared to the factors “resources” and “strategy”, the factor “cost” has a more significant impact on the EMO. In addition, when the degree of strength of “resources” reaches 0.5, the strength of EMO will be able to reach the “High” range if “cost” also reaches the “High” range. However, when the degree of strength of “strategy” reaches 0.9, the strength of EMO then will be able to reach the “High” range. This demonstrates that “cost vs. resource” is better than “cost vs. strategy”. Figure 6 (c) shows that “resources” and “strategy” have similar strengths of influence, and it also indicates that, without considering “cost”, the outcome of EMO is only located in the range of Moderate Middle (MM). Through the integrative discussion of the “resources” variables, it can be seen that the greatest influence on the “resources” is how many resources are able to be obtained.



(a) Cost vs. strategy (b) Cost vs. resources (c) Strategy vs. resources

Figure 6. Fuzzy surfaces of EMO

5. CONCLUSION

The high-tech industry is an important economic engine in Taiwan and is bound to develop constantly by innovating and initiating its own brands. An enterprise’s abilities in knowledge creation, acquisition, and accumulation are beneficial to its propensity to innovate. Due to the current strategy of enhancing firm-level knowledge, it is essential to acquire knowledge by means of internal R&D and external alliances within companies in Taiwan. This study adapts academic theories with the assistance of practical and empirical results from expert interviews to analyze the phenomena of building a balance between knowledge held inside and outside enterprises to obtain an optimal model for accumulating knowledge.

From research theories in the literature and practical interviews with a number of experts, this study identifies three elements that influence firm-level KA: knowledge integration ability (KIA), knowledge absorption ability (KAA), and knowledge sharing ability (KSA). It is inferred through the empirical results that the cultivation of KIA is the most beneficial to enterprise KA. KIA is the ability to integrate diversified kinds of knowledge, from both inside and outside enterprises. KIA achieves the alternation and transformation between internalization and externalization of enterprise knowledge through systematization, interaction and coordination, and socialization processes. This study also finds that

KSA is the catalyst that promotes the cultivation and transformation process underpinning an enterprise's ability to accumulate knowledge. Therefore, cultivating a climate conducive to knowledge sharing and learning together with adequate motivation and reward mechanisms and sharing platforms are important variables for promoting firm-level KA. Though KAA has a relatively low *w* value (*w*=0.210), the cultivation of this ability is also beneficial to the enterprise's KA to some extent. Since KIA is developed during the process of KA, in order to apply firm-level knowledge effectively, enterprises must enhance their KAA, build a culture of trust, and motivate enterprise members through KSA. KIA is thus an important ability that Taiwan's enterprises cannot neglect.

EMO involves contracting with another company or person to perform a particular function or service, and it is rapidly becoming a part of the worldwide business lexicon. However, because the specialized aspects of technical manpower not only require a diversity of skills but also impose an increasing need for technical workers, the combination of technical manpower needs and rapid industrial expansion has resulted in a significant imbalance between the supply of and demand for technical manpower. Therefore, EMO can play an important role in meeting the technical manpower needs of enterprises. To analyze the factors influencing EMO, this study, on the basis of theories proposed in the literature and practical interviews with a number of experts, classifies the factors influencing EMO into aspects of cost, resources, and strategy. It can be inferred from the empirical results presented here that cost is the most important variable influencing EMO and that, by combined consideration of costs and resources, a high degree of EMO utilization is more likely to be reached. The results also reveal that, for enterprises to achieve better results with EMO, combined consideration of the direct costs and talent resources within the enterprise is more important than combining cost and strategic considerations.

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6. REFERENCES

1. Arnold, U. (2000), "New dimensions of outsourcing: a combination of transaction cost economics and the core competencies concept," *European Journal of Purchasing and Supply Management*, 6, 23-29.
2. Argot, L. (1999), "Organizational learning: Creating, retaining and transferring knowledge," Boston, Kluwer Academic Publishers.
3. Atuahene-Gima, K. (1992), "Inward technology licensing as an alternative to international R&D in new product development: A conceptual framework," *Journal of Product Innovation Management*, 9, 156-167.
4. Barney J. B. (1991), "Firm resources and sustained competitive advantage," *Journal of Management*, 17, 99–120.
5. Barry, B.; Stephens, C.U. (1998), "Objections to an Objectivist Approach to Integrity," *Academy of Management Review*, 23 (1), 162-169.
6. Berghman, L.; Matthyssens, P.; Vandenbempt, K. (2006), "Building competences for new customer value creation: An exploratory study," *Industrial Marketing Management*, 35(8), 961-973.
7. Bock, G.W.; Kim, Y.G. (2002), "Breaking the myths of rewards", *Information Resources Management Journal,* 15 (2), 14-21.
8. Ciborra, C.U.; Patriota, G. (1998), "Groupware and teamwork in R&D: limits to learning and innovation," *R&D Management*, 28 (1), 1-10.
9. Cohen, W.M.; Levinthal, D. A. (1990), "Absorptive capacity; A new perspective on learning and innovation," Administrative Science Quarterly, 35, 128-152.
10. Collis, D. J., (1991), "A Resources-based Analysis of Global Competition: The Case of the Bearing Industry," *Strategic Management Journal*, 12, 46-68.
11. Davenport, T.H. and Prusak, L. (1998). Working knowledge: How organizations management what they know. Boston: Harvard Business School Press.
12. Demsetz, H. (1988), "The Theory of the Firm Revisited," *Journal of Law, Economics, and Organization*, 4(1), 141-161.
13. Dolan, J.G., Isselhardt, Jr. B.J., and Cappuccio, J.D. (1989), "The Analytic Hierarchy Process in Medical Decision Making: A Tutorial," *Medical Decision Making*, 9(1), 40-50.
14. Gavious A. and G. Rabinowitz. (2003), "Optimal knowledge outsourcing model," *Omega*, 31, 451-457.
15. Grant, R.M. (1996), "Toward a knowledge-based theory of the firm," *Strategic Management Journal*, 17, 109-122.
16. Hendriks, P. (1999), "Why share knowledge? The influence of ICT on motivationfor knowledge sharing," *Knowledge and Process Management*, 6 (2), 91-100.
17. Hsu, P.F. and Chen, B.Y. (2007), "Developing and Implementing a Selection Model for Bedding Chain Retail Store Franchisee Using Delphi and Fuzzy AHP," *Quality and Quantity*, 41(2), 275-290.

18. Iwata, S.; Kurokawa, S.; Fujisue, K. (2006), "An Analysis of Global R&D Activities of Japanese MNCs in the US From the Knowledge-Based View," *IEEE Transactions on Engineering Management*, 53 (3), 361-379.
19. Koh, H,; Ha, S.; Kim, T.; Lee, S. H. (2005),"A method of accumulation and adaptation of design knowledge," *The International Journal of Advanced Manufacturing Technology*, 26(9-10), 943-949.
20. Kogut, B.; Zander, U. (1992), "Knowledge of the firm, integration capabilities, and the replication of technology," *Organization Science*, 3, 383-397.
21. Labbs, J.J., (1993), "Successful Outsourcing Depends on Critical Factors," *Personal Journal*, 51-60.
22. Minoli, D. (1995), Analyzing Outsourcing: Reengineering Information and Communication Systems, New York: McGraw-Hill.
23. Morgan, N. A., Zou, S., Vorhies, D. W., Katsikeas, C. S., (2003), "Experiential and Informational Knowledge, Architectural Marketing Capabilities, and the Adaptive Performance of Export Ventures: A Cross-National Study," *Decision Science*, 34(2), 287-320.
24. Nonaka, I. (1994), "A dynamic theory of organizational knowledge creation," *Organization Science*, 5 (1), 14–37.
25. Pan, H.S. and Yun, W.Y. (1997), "Fault tree analysis with fuzzy gates," *Computers & Industrial Engineering*, 33(3-4), 569-572.
26. Perng, Y., Hsueh, S., and Yan, M. (2005), "Evaluation of Housing Construction Strategies in China Using Fuzzy-Logic System," *International Journal of Strategic Property Management*, 9, 215-232.
27. Petrash, G. (1996), "Dow's journal to a knowledge value management culture," *European Management Journal*, 14(4), 365-373.
28. Polanyi, M. (1967). The Tacit Dimension. New York: M.E. Sharp Inc.
29. Quinn, J. B. and Hilmer F. G. (1994), "Strategic Outsourcing," *Sloan Management Review*, 35(4), 43-55.
30. Ragin, C.C. (2000). Fuzzy-Set Social Science. Chicago: The University of Chicago Press.
31. Saaty, T.L. (1980). The analytic hierarchy process. New York, McGraw-Hill.
32. Senge, P.M. (1997), "Sharing knowledge," *Executive Excellence*, 14, 17-18.
33. Sugeno, M. (1985). Industrial Applications of Fuzzy Control. Elsevier Science Pub. Co.
34. Sveiby, N.E. (1997). The New Organization Wealth: Managing and Measuring Knowledge-Based Assets. San Francisco, betrett-koehler.
35. Teece, D. J. and Pisano, G. (l994), "The dynamic capabilities of firms: an introduction," *Industrial and Corporate Change*, 3, 537-556.
36. Torkkeli, M.T., D. Podmetina, A.M. Yla-Kojola, and J. Vaatanen, (2009), "Knowledge absorption in an emerging economy – the role of foreign investments and trade flows in Russia," *International Journal of Business Excellence*, 2(3/4), 269-284.
37. Ulrich, D. and Barney, J., (1984), "Perspectives in organizations: resource dependence, efficiency and population," *Academy of Management Review*, 9, 471–481.
38. Wernerfelt, B. (1989), "Firm Critical Resource to Corporate Strategy," *Journal of General Management*, 14, 4-12.
39. Woodall, J., Scott-Jackson, W., Newham, T., and Gurney, M. (2009), "Making the decision to outsource human resources," *International Journal of Human Resource Management*, 38(3), 236-252.
40. Wu, S.H. (1998). Nine Principles of Strategy. Taipei, Facial Culture Publisher.
41. Yu, W.D.; Skibniewski, M.J. (1999), "Quantitative constructability analysis with a neuro-fuzzy knowledge-based multi-criterion decision support system," *Automation in Construction*, 8, 553-565.

BIOGRAPHICAL SKETCH

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