Determinants of Technological Innovation Capabilities: Using Fuzzy-DEMATEL and ANP

Chien-Ke Huang[1], Chi-Hui Wu[2,3,*], Jing Li[1,4] and Chih-Ling Hsieh[5]
[1]*Ph.D. Program in Management, Da-Yeh University, University Rd., Changhua, Taiwan*
[2]*Department of Management and Information, National Open University, Zhong Zheng Rd., New Taipei, Taiwan*
[3]*Department of Information Management, Da-Yeh University, University Rd., Changhua, Taiwan*
[4]*Music and Film College, Tainjin Normal University, Binshui West Rd., Tianjin, China*
[5]*Professional Development in Education, Da-Yeh University, University Rd., Changhua, Taiwan*

Keywords: Technological Innovation Capabilities, Fuzzy DEMATEL, ANP.

Abstract: This paper applies Fuzzy-DEMATEL and ANP to analyse the decisive determinants of technological innovation capabilities (TICs) and the weight relation in high-tech and traditional manufacturing industries. Technological innovation capabilities comprise various features that are complex and interrelated. Thus, the purpose of this paper is to clarify the causal relationship of the various features to precisely provide the enterprises with some determinants to maximize the effectiveness of resource utilization. In terms of dimension, the research shows that the innovation management capability is the decisive factor of technological innovation capabilities for high-tech industry and traditional manufacturing industry, which affects the other five dimensions. However, in terms of criteria, learning capabilities are decisive determinants. Therefore, in the face of competitive environment with continuous shortening of the product life cycle and rapidly changing customer demands, overall, in order to enhance innovation capabilities, enterprises must focus on the improvement of innovation management capabilities. In regard to the detail factors, the enterprises must enhance the learning capabilities to recognize, absorb and make use of knowledge from the internal organization in order to strengthen the knowledge management capability, the innovative decision-making capability and technology of the enterprise itself.

1 INTRODUCTION

Innovation is the key factor and source of the competitiveness of an enterprise (Hult, Hurley, & Knight, 2004). Also it is the motive power for economic growth (Schumpeter, 1942). Especially, the application of technological innovation is the major source of economic growth (Kuznets, 1973) and the innovation capability also affects the performances of an enterprise (Jayani Rajapathirana & Yan, 2018). Therefore, in the face of changing circumstances, the enterprise needs constant technological innovations in order to maintain competitive advantages (Wang, Lu, & Chen, 2008).

Because the traditional technology indexes are no longer sufficient to reflect the environmental and development conditions of the knowledge economy, the relevant technology measurement indexes and research methods have been constantly adjusted and developed since the 1990s. Technological innovation capabilities are defined as the ability of enterprises to create new value for their customers by introducing new products and services, developing new technologies, and exploring new skills and capabilities (Huang, 2011). Because the technological innovation capability is a complex, multidimensional and uncertain concept (Ince, Imamoglu, & Turkcan, 2016), many researchers have developed different methods of measurement to assess the technological innovation capabilities of an enterprise (Shafia, Shavvalpour, Hosseini, & Hosseini, 2016). However, there is no consistent conclusion due to various indexes for measuring technological innovation capabilities, so it is difficult to evaluate from a single point of view (Burgelman, Christensen, & Wheelwright, 2004). Therefore, the

*Corresponding author. Tel.: +886-938-567-834

Huang, C., Wu, C., Li, J. and Hsieh, C.
Determinants of Technological Innovation Capabilities: Using Fuzzy-DEMATEL and ANP.
DOI: 10.5220/0009412101060114
In *Proceedings of the 2nd International Conference on Finance, Economics, Management and IT Business (FEMIB 2020)*, pages 106-114
ISBN: 978-989-758-422-0

measurement of technology innovation requires a variety of quantitative and qualitative criteria (Wang et al, 2008). Besides, the assessment of the enterprise's technological innovation capabilities is considered subjective and inaccurate, this subjectivity and inaccuracy increase the complexity of the assessment. In general, evaluators judge it subjectively by means of past experience, professional knowledge and information.

However, many decision-making issues, such as technological innovation capabilities, the characteristics of their internal complexities cannot be expressed in a hierarchical manner (Sumrit & Anuntavoranich, 2013a). This is because it interacts with each other at the upper and lower levels, and the elements at the lower level also have interdependence between the elements at the top. (Saaty, 1996).

According to the research results about the literatures of the capabilities of technological innovation, studying the technological innovation capabilities of different industries, the factors that affect technological innovation capabilities, the degree of correlation between each factor, and the results of causality are different. For example, some scholars' research objects are the traditional industries and the research results show that the technology development capability and the innovation management capability are crucial factors to an enterprise's capabilities of the technological innovation (Kumar, Kaviani, Hafezalkotob, & Zavadskas, 2017). Other scholars' research objects are the high-tech industries and the research results show that collective learning capability and innovation management capability are crucial factors to an enterprise's capabilities of the technological innovation (Ravari, Mehrabanfar, Banaitis, & Banaitiene, 2016).

The purpose of the research is to find out and compare the decisive factors of the capabilities of technological innovation between the traditional and high-tech industries in order to upgrade the capabilities of the technological innovation of industries and to maintain the reference of the competitive advantage. Therefore, the research objects of this research are the traditional and high-tech industries and to obtain the indexes of technology innovations by fuzzy Delphi method's questionnaire and build the structures on the capabilities of the technological innovation. Additionally, it analyses the relations of the cause and effect that affect the structures and criteria of the capabilities of the technological innovation and to ascertain the decisive factors. Finally it applies ANP to analyse the weight of the priority on the criteria of the capabilities of the technological innovation in order to provide enterprise operators with the reference of the strategy planning.

2 LITERATURE REVIEW

Facing the incessant change around the global environment, technological innovation capabilities are the important and unique strategies to upgrade the enterprise's competition advantages (Shafia et al., 2016). Technological innovation capabilities and information technology capabilities would affect the business performance (Yuan, Shin, He, & Kim, 2016; Bergeron, Croteau, Raymond & Uwizeyemungu, 2017) and innovation performance of an enterprise (Mir, Casadesus, & Petnji, 2016).

Adler and Shenhar (1990) first bring up the concepts about Technological Innovation Capabilities (TICs), TICs are an enterprise's special assets including the crucial fields of the technology, manufacture, process, knowledge, experience and organization (Türker, 2012). Burgelman et al.(2004) defines technological innovation capabilities as a set of complete strategies that the organization promotes the technological innovation. According to Adler and Shenhar's (1990) researches, technological innovation capabilities are classified to 4 kinds including (1) the capability to satisfy the needs of market through developing new products (2) the capability to manufacture these products with suitable technologies (3) the capability to satisfy future's needs by developing and introducing new products and technologies (4) the capability to respond to abrupt development of technologies and the unpredictability conditions that the rivals bring about. Therefore, technological innovation capabilities are defined as: an organization upgrades technological innovation capabilities by providing new products and services, adopting new technologies, innovating new skills and capabilities or abilities of creating new clients' claims on value (Huang, 2011).

The scholars researching technological innovation capabilities have different viewpoints to the indexes of measuring technological innovation capabilities. Christensen (1995) brings up the asset approach to measure the indexes of technological innovation capabilities. Chiesa, Coughlan, and Voss (1996), Burgelman et al. (2004), Turker (2012) and Ravari et al. (2016) measure the technological innovation capabilities by the process approach. Romijn and Albaladejo (2002) bring up the output-based approach to measure the indexes of technological innovation capabilities. Yam, Guan,

Pun, and Tang (2004), Guan, Yam, Mok, and Ma (2006) and Wang et al. (2008) bring up the functional approach to measure the indexes of technological innovation capabilities Besides, Sumrit, Anuntavoranich (2013b) and Kumar et al. (2017) measure the technological innovation capabilities by the comprehensive perspective approach.

As for Resource Based View(Wernerfelt, 1984; Grant, 1991), the technological innovation capabilities are enterprises' unique assets(Guan & Ma, 2003; Guan et al., 2006), it comprises of many different fields including resource allocation capability, resource exploiting capability, organizational capability, innovation planning capability and project cross functional team integration capability. As for the perspective from core competence (Prahalad & Hamel, 1990), the technological innovation capabilities are meant to integrate the management procedures for every department of an enterprise into unique competence including market capability, manufacturing capability and R&D capability. As for the viewpoint from Dynamic Capability (Teece, Pisano, & Shuen, 1997) and Knowledge Based View (Kogut & Zander, 1992; Grant, 1996), the technological innovation capabilities are viewed as the learning process (Cohen & Levinthal, 1989; Hitt, Ireland, & Lee, 2000) in order to enhance the enterprises' necessities of the knowledge and skills including learning capability, absorptive capability, knowledge management, innovative organization culture, network linkage capability and technology acquisition capability; And there is no way to measure the technological innovation capabilities by a single perspective (Chiesa et al., 1996; Burgelman et al., 2004; Guan & Ma, 2003; Guan et al., 2006). Additionally, different scholars have different viewpoints on the levels and frameworks of the technological innovation capabilities. Some scholars adopt the single-level index (Yam et al., 2004; Guan et al., 2006; Kumar et al., 2017), others adopt two-level dimension and index (Christensen, 1995; Chiesa et al., 1996; Romijn & Albaladejo, 2002; Sumrit & Anuntavoranich, 2013b). Because the technological innovation capabilities are complex and multi-dimension concepts, this research adopts two-level dimension and index to integrate what mentioned above by scholars and to coordinate and conclude six dimensions and twenty criteria.

3 RESEARCH METHODOLOGY AND MODEL DEVELOPMENT

3.1 Research Framework

The research is divided into three phases to analyse and collect information in order to construct dimensions and criteria; First of all, the first phase is to retrospect relevant literatures as a foundation, archiving the past scholars' perspectives, inducing technological innovation capabilities of affecting enterprises. It has six dimensions and twenty criteria and adopts Fuzzy Delphi method to make the group decisions to scholars and experts of the technological innovation in order to solve ambiguous problems and obtain consensuses. So it depends heavily upon the knowledge and experiences from scholars and experts and converge the dimensions and criteria to consistency and reliable structures for sieving out comparatively important and higher criterion items in order to compile questionnaires through the feedback of experts and scholars' opinions.

The second phase is the DEMATEL questionnaire. The main researching objects are Taiwan's high-tech and traditional manufacturing industries. The practical experts of technological innovation in high-tech and traditional manufacturing industries use Fuzzy DEMATEL to construct relation matrixes between dimensions and criteria, illustrating the graphs of the causal relationship, making path analysis about the cause- and -effect relevant affection . Furthermore, it finds out the decisive factors of technological innovation capabilities and to construct the causal relationship of the decisive factors in technological innovation capabilities.

The third phase is the ANP questionnaire. The main researching objects are Taiwan's technology and traditional manufacturing industries. The practical experts of the technological innovation in technology and traditional manufacturing industries analyse ANP to find out the comparative weight and relevancy of every dimension for the technological innovation capabilities in order to bring out conclusions and concrete suggestions on the important factors that affect technological innovation capabilities.

3.2 Calculating Steps on Fuzzy Delphi Method

This research uses fuzzy Delphi method to sieve out the comparatively important items of the dimension on the technological innovation capabilities. The

steps of fuzzy Delphi method are as follows (Liang, Lee, & Huang, 2010):

Step 1: Collect the decision-making group's opinions; Step 2: Set up triangle fuzzy numbers; Step 3: Defuzzification; Step 4: Sieve out the assessment criterion.

3.3 Contents and Objects of Questionnaire Design

It compiles six dimensions including innovation management capability (A), collective learning capability (B), innovation sourcing capability (C), technology development capability (D), robustness product & process design capability (E), technology commercialization capability (F) and to sieve out six dimensions and twenty criteria by fuzzy Delphi method. We issue questionnaires to twenty scholars and practical experts of the innovation research, high-tech and traditional industry. They judge whether to maintain dimensions according to their knowledge and experiences. The threshold value in this research is 60% which means that if over 60% of the scholars and experts agree to maintain on dimensions of the certain items, they are kept. This research sorts out 6 dimensions and twenty criteria. The criterion of the minimum threshold value is 60.3% of the product structure design and engineering capability. The criterion of the maximum threshold value is 87.9% of the learning capability. Every item has over 60% experts and scholars' agreements which mean that all criteria are kept. Finally, twenty criteria and operating definitions in this research are as follows: Strategic management capability (A_1), Organization capability (A_2), Resource allocation capability (A_3), Risk management capability (A_4), Innovation decision capability (A_5), Resource exploiting capability (A_6), Learning capability (B_1), Absorptive capability (B_2), Knowledge management capability (B_3), Innovative organization culture (B_4), Network linkage capability (C_1), Technology acquisition capability (C_2), Investment capability (C_3), R&D capability (D_1), Project cross functional team integration capability (D_2), Technology change management capability (D_3), Product structural design and engineering capability (E_1), Process design and engineering capability (E_2), Manufacturing capabilities (F_1), Market capability (F_2).

3.4 Fuzzy DEMATEL Computing and Steps

Li (1999), Lin and Wu's (2008) classifications are references of the linguistic scale and triangular fuzzy numbers in the fuzzy DEMATEL part. The linguistic scale is divided into 5 kinds. In order to facilitate the subjects to consider and fill up, it provides concretely 4 to 0 points in the questionnaire.

Fuzzy DEMATEL is the method that combines the fuzzy linguistic variations with DEMATEL and the steps of formulas and computing are as follows (Wu, Liao, Tseng, & Chiu, 2015):

Step 1: Define the evaluation criteria and determine the fuzzy linguistic scale; Step 2: Establish the directed-relation matrix; Step 3: Establish and analyse the structural model; Step 4: Establish the total-relation matrix; Step 5: Conduct defuzzification; Step 6: Centrality and relation; Step 7: The result analysis.

3.5 ANP Computing and Steps

ANP is the method used in Multi-Criteria Decision-Making, MCDM. It deduces the comparative priority of the criterion through experts' judgement or practical measurement. The judgement shows the comparative affection relations (Saaty, 2006). The applications of ANP are divided into five steps as follows:

Step 1: Establish the pairwise comparisons matrix; Step 2: Compute the eigenvalue of the pairwise comparisons matrix and the eigenvector; Step 3: Consistency test; Step 4: Calculate limit supermatrix formation; Step 5: Choose the optimum criterion.

4 RESEARCH THE RESULT ANALYSES AND DISCUSS

4.1 The Results of Fuzzy DEMATEL

4.1.1 The Analysis Results of Every Dimension

Step 1: Define the Evaluation Criteria and Determine the Fuzzy Linguistic Scale

The assessment dimensions are as follows: A, B, C, D, E, and F.

Step 2: Establish the Direct Relative Matrix

It is able to obtain experts' opinions after experts compare dimensions in pair. And it integrates every expert's opinions by numbers in order to decrease affections from extreme values; afterward, it is able to obtain the fuzzy, direct and relevant matrixes.

Step 3: Establish and Analyze the Structure Model

It converts linear scales into normalization formulas by transforming the criterion scale into the

comparable scale. It calculates the maximum value *r*, 4.612. It obtains the fuzzy, direct and relevant matrixes of the normalization by transforming all values in the fuzzy, direct and relevant matrixes.

Step 4: Establish the Fuzzy, Total, Direct and Relevant Matrixes

After it obtains the fuzzy, direct and relevant matrixes of the normalization, it obtains the fuzzy, total and relevant matrixes.

Step 5: Defuzzification

It proceeds to have defuzzification on the fuzzy, direct and relevant matrixes in order to obtain the total and relevant matrixes.

Step 6: Centrality and Relation

It is able to calculate the row values (*d*), column values (*r*), the sum of the rows and columns (*d*+*r*) and the difference of the rows and columns (*d*-*r*). The compilings show in Table 1. As for centrality (*d*+*r*), the affection importance of 2 dimensions about D and E is the biggest; and as for relation (*d*-*r*), the pluses on 2 dimensions about A and B represent causal dimensions; meanwhile, A is the strongest. Otherwise, the minuses on 4 dimensions about C, D, E and F represent effect dimensions; meanwhile, F is the strongest. It obtains the causal relationship after combining analyses of centrality and relation; meanwhile, B is the strongest factor; D is the most affected factor. And F is classified as the independent dimension because centrality and relation are low; it shows in Table 1. B is the main decisive dimension that if enterprises consider only and upgrade technological innovation capabilities.

Table 1: Row and column values among dimensions.

	d(row value)	*r*(column value)	*d*+*r* (centrality)	*d*-*r* (relation)	Quadrant	Causal relationship
A	41.661	39.543	81.204	2.118	2nd quad	affecting criteria
B	41.573	41.225	82.798	0.348	1st quad	Core criteria
C	41.343	41.440	82.783	-0.097	4th quad	Criteria affected
D	41.548	41.656	83.204	-0.108	4th quad	Criteria affected
E	41.328	41.578	82.906	-0.250	4th quad	Criteria affected
F	39.661	41.671	81.332	-2.010	3rd quad	Independent
Average			82.371	0		

Step 7: The Result Analysis

After obtaining *d*+*r* (centrality) and *d*-*r* (relation), it illustrates the causal relationship diagram as Figure 1 according to values. The arithmetic mean of centrality (*d*+*r*) is 82.371 which is settled as the threshold value; dimensions of technological innovation capabilities are located on different quadrants. The quadrant locations of the causal relationship diagram in Figure 1 show as follows: one dimension located on the first quadrant of technological innovation capabilities represents B; it belongs to the dimension of high centrality and high relation. This dimension not only affects the dimension on quadrant 4 but also is the core dimension of technological innovation capabilities; meanwhile it is classified as the core dimension of technological innovation capabilities. One dimension located on the second quadrant of technological innovation capabilities represents the A; it belongs to the dimension of low centrality but high relation. This dimension can affect the dimension on quadrant 4; meanwhile it is classified as the important dimension of technological innovation capabilities. One dimension located on the third quadrant of technological innovation capabilities represents F; it belongs to the dimension of low centrality and low relation. Because the dimension on the quadrant does not affect any dimension of technological innovation capabilities; meanwhile it is classified the less important dimension of technological innovation capabilities. Three dimensions located on the fourth quadrant of technological innovation capabilities represent C, D and E; they belong to the dimension of high centrality but low relation. These 3 dimensions can upgrade and enhance their capabilities by dimensions on quadrant 1 and 2.

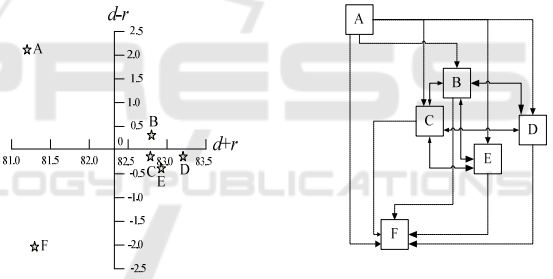

Figure 1: Cause and effect diagram among dimensions.

4.1.2 The Results of Every Criterion Analysis

The research will analyses the criterion of every dimension in order to understand the complex relevance of technological innovation capabilities in enterprises.

Step 1: Define the assessment criteria and design the fuzzy linguistic scale.

The assessment criteria: A_1, A_2, A_3, A_4, A_5, A_6, B_1, B_2, B_3, B_4, C_1, C_2, C_3, D_1, D_2, D_3, E_1, E_2, F_1 and F_2.

Step 2 to 7:

The analysis step 2 to 7 of every criterion calculates according to analysis step 2 to 7 of every above-mentioned dimension 4.1.1. The row values (*d*), the column values(*r*), the sum of the row and

column (*d*+*r*) and the difference of the row and column (*d*-*r*) are compiled in Table 2.

Table 2: Row and column values among criteria.

	d (row value)	*r*(column value)	*d*+*r* (centrality)	*d*-*r* (relation)	Quadrant	Causal relationship
A_1	57.629	57.526	115.155	0.103	1st quad	Core criteria
A_2	57.727	55.948	113.675	1.779	2nd quad	Affecting criteria
A_3	57.505	56.736	114.241	0.769	2nd quad	Affecting criteria
A_4	57.401	56.682	114.083	0.719	2nd quad	Affecting criteria
A_5	57.835	57.436	115.271	0.399	1st quad	Core criteria
A_6	56.734	56.823	113.557	-0.089	3rd quad	Independent
B_1	57.547	56.668	114.215	0.879	2nd quad	Affecting criteria
B_2	57.491	56.597	114.088	0.894	2nd quad	Affecting criteria
B_3	57.495	57.385	114.880	0.110	1st quad	Core criteria
B_4	56.830	56.650	113.480	0.180	2nd quad	Affecting criteria
C_1	55.369	57.375	112.744	-2.006	3rd quad	Independent
C_2	57.637	57.626	115.263	0.011	1st quad	Core criteria
C_3	57.417	56.680	114.097	0.737	2nd quad	Affecting criteria
D_1	57.548	57.755	115.303	-0.207	4th quad	Criteria affected
D_2	56.031	57.647	113.678	-1.616	3rd quad	Independent
D_3	57.606	57.571	115.177	0.035	1st quad	Core criteria
E_1	56.711	57.706	114.417	-0.995	4th quad	Criteria affected
E_2	57.513	57.678	115.191	-0.165	4th quad	Criteria affected
F_1	56.561	57.654	114.215	-1.093	3rd quad	Independent
F_2	57.261	57.703	114.964	-0.441	4th quad	Criteria affected
Average			114.385	0		

It shows on the quadrant locations in Table 2 that the 5 criteria located on the first quadrant of technological innovation capabilities represent individually A_1, A_5, B_3, C_2, and D_3; they belong to the criterion of high centrality and high relation. The criteria on this quadrant of technological innovation capabilities occupy comparatively important positions compared to the criteria on other quadrants of technological innovation capabilities. 7 criteria located on the second quadrant of technological innovation capabilities represents individually A_2, A_3, A_4, B_1, B_2 and C_3; they belong to the criterion of low centrality but high relation. These 7 criteria can affect the criteria on the fourth quadrant; meanwhile they are classified as important criteria of technological innovation capabilities. 4 criteria located on the third quadrant of technological innovation capabilities represents individually A_6, C_1, D_2 and F_1; they belong to the criterion of low centrality and low relation. Because the criteria on this quadrant do not affect any criterion of technological innovation capabilities; meanwhile they are classified as the less important criteria of technological innovation capabilities. 4 criteria located on the fourth quadrant of technological innovation capabilities represents individually D_1, E_1, E_2 and F_2; they belong to the criterion of high centrality but low relation. These 4 criteria can upgrade and strengthen their abilities by the criteria on quadrant 1 and 2. If the criteria of technological innovation capabilities on quadrant 1 upgrade, they will improve the criteria of technological innovation capabilities on quadrant 4. The enterprises should engage in the criteria about A_1, A_5, B_3, C_2 and D_3 under the conditions of limited resources and to classify them as the first priority of upgrading technological innovation capabilities. Additionally, the criteria of technological innovation capabilities on quadrant 2 upgrade, they will also improve the criteria of technological innovation capabilities on quadrant 4; so they are classified as the second priority of upgrading technological innovation capabilities.

4.2 The Results of the ANP

4.2.1 Develop the Network Structure Model

This part will probe priorities of the factors for technological innovation capabilities. So it constructs the weights of every dimension and criterion by the network procedure analyzing method. It analyzes the structure model of ANP by means of 6 main dimensions and 20 criteria of technological innovation capabilities and inputs Super Decisions software to establish the structure, calculating analyses.

4.2.2 Establishment of the Pairwise Comparison Matrix in the ANP Model and the Consistency Test

It obtains the pairwise comparison matrix values through calculating of geometric mean by the results of 30 filling-up effective questionnaires and proceeds to have consistency tests. The CI values of every pairwise comparison matrix among 0.00545 to 0.02298 are all less than 0.1 in this research; meanwhile, the CI values also less than 0.1 represent passing the consistency test.

4.2.3 Pairwise Comparison of ANP Dependency

Finally, the data from the ANP questionnaire, obtain from the practitioners, were analysed and are presented in Table 3.

4.2.4 The Results of the Analysis

As for the parts of the analysis results of dimensions, innovation management capability has the highest among the weights of dimensions. Innovation management capability can affect the factors about learning capability of the whole, innovation sourcing capability, technology development capability, robustness product & process design capability and technology commercialization capability. And

innovation management capability is the most important factor that enterprises develop technological innovation capabilities. Consequently, enterprises should engage in the innovation management capability including the factors about strategic management capability, organization capability, resource allocation capability, risk management capability, innovation decision capability and resource exploiting capability in order to upgrade their technological innovation capabilities.

Table 3: The weights of evaluation items for ANP method.

Dimensions	Criteria	Weights	Total weights	Rank
A	A_1	0.207	0.037	15
	A_2	0.151	0.027	19
	A_3	0.156	0.028	18
	A_4	0.162	0.029	17
	A_5	0.173	0.031	16
	A_6	0.151	0.027	19
B	B_1	0.242	0.039	13
	B_2	0.236	0.038	14
	B_3	0.273	0.044	10
	B_4	0.248	0.040	12
C	C_1	0.338	0.051	9
	C_2	0.384	0.058	6
	C_3	0.278	0.042	11
D	D_1	0.394	0.069	5
	D_2	0.303	0.053	7
	D_3	0.303	0.053	7
E	E_1	0.500	0.086	2
	E_2	0.500	0.086	2
F	F_1	0.549	0.089	1
	F_2	0.451	0.073	4

It also means that for the sake of improving innovation management capability, enterprises should be able to have abilities on discerning their advantages and disadvantages from the interiority and opportunities and threats from the external environment, being able to make plans according to enterprises' visions and missions, ensuring the organization operation mechanism and the coordinating capability, cultivating technological innovation culture of the organization, obtaining the capital, technology and allocating the capital suitably during technological innovation process, assessing and enduring the risk of technological innovation, organizing creative ideas of the high research and development from the interiority, cooperating and sharing the knowledge of the research and development with other strategy alliance enterprises or researching centers, being able to forecast and assess the future trend of technological innovation, having abilities to modulate and expand the technology, human and the capital resource for upgrading enterprises' innovation management capabilities.

As for the parts of the analysis results of dimensions, the top 3 important capabilities at the last priorities of the criterion assessment are manufacturing capability, product structural design and engineering capability and process design and engineering capability individually. It means that enterprises more emphasize the products that are transformed from the results of the research and development, designing the product structure, establishing the modularization of the product, supporting the manufacture design and devising the design process of the assembling activity.

5 CONCLUSIONS

The purpose of this research is to try finding out relations between dimensions and criteria that affect the technical innovation capabilities and the reciprocal affections; ranking the following important weight of every dimension. As for the results from Fuzzy-DEMATEL, there exist the relevant affections indeed among dimensions and criteria. It also obtains more precise weight measurement base through the results of ANP analysis. In the future, it will be a good reference according to the conclusion of the research and provides the following researchers who intend to research the issues on the technical innovations with new thinking directions. The results in this research show that there exist the relevant affections between dimensions and criteria. The degrees of the reciprocal affections of the technical innovation capabilities at every dimension or criterion are different.

So far as the dimensions are concerned, the capabilities on the technology commercialization respondent to other 5 dimensions have less manifest affections at the critical dimensions of the technological innovation capabilities. The reason is that the capabilities on the technological commercialization are affected easily by other factors; learning capabilities of the whole have most affections to other factors. Furthermore, innovation management capabilities are the key and important factor for success. It shows according to the results and relations of criteria that the enterprises will upgrade collective learning and innovation management capabilities of the whole if they can enhance the innovation decision, strategy management, knowledge management capabilities. Consequently, the interiority of the enterprise's organization should have ideas on high innovations of research and development and to cooperate with other strategy alliance enterprises or researching centers, being able to share the knowledge of research and

development, forecasting and assessing the future trends of the technology innovations, discerning the advantages and disadvantages in the interiority, making plans according to the enterprise's prospects and missions ,having capabilities to accumulate and manage crucial knowledge resources and then absorbing to use in order to upgrade learning and innovation management capabilities of the whole enterprise. However, the six dimensions affect undoubtedly the enterprise's decisive factors on technological innovation capabilities according to their strength. This research probes the reciprocal affections and degrees under the criteria of every dimension thoroughly. In practice, the enterprises can choose dimensions they want to enhance and then choose the suitable and manifest criteria that upgrade this dimension according to results of the research in order to increase and enhance enterprises' technology innovation capabilities, competition advantage and core competences.

So far as the criteria are concerned, the criteria about the organization, absorptive and learning capabilities are important factors that affect other criteria at the decisive criteria of technological innovation capabilities. It means that the enterprises should upgrade their collective learning capabilities of the whole incessantly in complex environments that change strongly in order to deal with the severe competitions and enhance to affect other dimensions of technological innovation capabilities for maintaining their competition advantages. Therefore, the enterprises should have abilities to discern, absorb and apply new values of the exterior information to enterprises' products and services. And they have abilities to discern, absorb and apply knowledge from the interiority of the system to accumulate and manage crucial knowledge resources. Finally, the enterprises can ensure operation mechanisms and coordinate capabilities in the interiority of the system, cultivating to innovative organization culture and heading to upgrade the criteria of technological innovation capabilities. From viewpoints of the most strong and bigger affections, the enterprises should improve the criteria of technological innovation capabilities by means of the core criteria of innovation decision, technology acquisition and technology change management capabilities under the conditions of limited sources. It means that the enterprises should have abilities to accumulate and manage crucial knowledge resources, then absorbing, using them. The enterprises can ensure operation mechanisms and coordinate capabilities, having abilities to discern, absorb and apply new values of the exterior information to enterprises' products and services, cultivating the technological innovation culture of the organization, organizing ideas on high innovations of research and development in the interiority of the organization, cooperating with other strategy alliance enterprises or researching centers, sharing the knowledge of research and development, forecasting and assessing the future trends of the technological innovations to upgrade their technological innovation capabilities.

REFERENCES

Adler, P.S., & Shenhar, A., 1990. Adapting Your Technological Base: The Organizational Challenge, *Sloan Management Review, 32*(1), 25-37.

Bergeron, F., Croteau, A.M., Raymond, L., & Uwizeyemungu, S., 2017. Path to IT Performance: A Configurational Analysis of IT Capabilities. *In Proceedings of the 19th International Conference on Enterprise Information Systems (ICEIS 2017), 3*, 294-305.

Burgelman, R.A, Christensen, C.M., & Wheelwright, S.C., 2004. Strategic Management of Technology and Innovation. New York: McGraw-Hill.

Chiesa, V., Coughlan, P., & Voss, C.A., 1996. Development of a technical innovation audit. *Journal of Product Innovation Management, 13*(2), 105-136.

Christensen, J.F., 1995. Asset profiles for technological innovation. *Research Policy, 24*(5), 727-745.

Cohen, W.M., & Levinthal, D.A., 1989. Innovation and learning: The two faces of R&D. *The Economic Journal, 99*(397), 569-596.

Grant, R.M., 1991. The resource-based theory of competitive advantage: Implications for Strategy Formulation. *California Management Review, 33*(3), 114-135.

Grant, R.M., 1996. Toward a knowledge-based theory of the firm. *Strategic Management Journal, 17*(S2), 109-122.

Guan, J.C, & Ma, N., 2003. Innovation capability and export performance of Chinese firms. *Technovation, 23*(9), 737-747.

Guan, J.C., Yam, R.C.M., Mok, C.K., & Ma, N., 2006. A study of the relationship between competitiveness and technological innovation capability based on DEA models. *European Journal of Operational Research, 170*(3), 971-986.

Hitt, M.A., Ireland, R.D., & Lee, H.U., 2000. Technological learning, knowledge management, firm growth and performance: An introductory essay. *Journal of Engineering and Technology Management, 17*(3-4), 231-246.

Huang, H. C., 2011. Technological innovation capability creation potential of open innovation: A cross-level analysis in the biotechnology industry. *Technology Analysis and Strategic Management, 23*(1), 49-63.

Hult, G.T.M., Hurley, R.F., & Knight, G.A., 2004. Innovativeness: Its antecedents and impact on business performance. *Industrial Marketing Management, 33*(5), 429-438.

Ince, H., Imamoglu, S.Z., & Turkcan, H., 2016. The Effect of Technological Innovation Capabilities and Absorptive Capacity on Firm Innovativeness: A Conceptual Framework. *Procedia - Social and Behavioral Sciences, 235*, 764-770.

Jayani Rajapathirana, P.R., & Yan, H., 2018. Relationship between innovation capability, innovation type, and firm performance. *Journal of Innovation & Knowledge, 3*(1), 44-55.

Kogut, B. and Zander, U., 1992. Knowledge of the firm, Combinative capabilities, and the replication of technology. *Organization Science, 3*(3), 383-397.

Kumar, A., Kaviani, M.A., Hafezalkotob, A., & Zavadskas, E.K., 2017. Evaluating innovation capabilities of real estate firms: a combined fuzzy Delphi and DEMATEL approach. *International Journal of Strategic Property Management, 21*(4), 401-416.

Kuznets, S., 1973. Modern Economic Growth: Findings and Reflections. *American Economic Review, 63*(3), 247-258.

Li, R., 1999. Fuzzy method in group decision making. *Computers & Mathematics with Applications, 38*(1), 91-101.

Liang, L.W., Lee, T.T., & Huang B.Y., 2010. Investigation of merging and acquisition of Taiwanese banks-application of the fuzzy delphi method. *Taiwan Banking & Finance Quarterly, 11*(4), 31-65.

Lin, C.J., & Wu, W.W., 2008. A causal analytical method for group decision-making under fuzzy environment. *Expert Systems with Applications, 34*(1), 205-213.

Mir, M., Casadesus, M., & Petnji, L.H., 2016. The impact of standardized innovation management systems on innovation capability and business performance: An empirical study. *Journal of Engineering and Technology Management, 41*, 26-44.

Prahalad, C.K., & Hamel, G., 1990. The core competence of the corporation. *Harvard Business Review, 68*(3), 79-91.

Ravari, S.S.M, Mehrabanfar, E., Banaitis, A. and Banaitienė, N., 2016. Framework for assessing technological innovation capability in research and technology organizations. *Journal of Business Economics and Management, 17*(6), 825-847.

Romijn, H., & Albaladejo, M., 2002. Determinants of innovation capability in small electronics and software firms in Southern England. *Research Policy, 31*(7), 1053-1067.

Saaty, T.L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*. Pittsburgh, PA: RWS Publication.

Saaty, T.L., 2006. Rank from comparisions and from ratings in the analytic network hierarchy/processes. *European Journal of Operational Research, 168*(2), 557-570.

Schumpeter, J., 1942. *Capitalism, Socialism and Democracy*. New York: Harper and Brothers.

Shafia, M. A., Shavvalpour, S., Hosseini, M., & Hosseini, R., 2016. Mediating effect of technological innovation capabilities between dynamic capabilities and competitiveness of research and technology organizations. *Technology Analysis and Strategic Management, 28*(7), 811-826.

Sumrit, D., & Anuntavoranich, P., 2013a. An Analytic Network Process Modeling to Assess Technological Innovation Capabilities: Case Study for Thai Automotive Parts Firms. *American Transactions on Engineering & Applied Sciences, 2*(3), 189-212.

Sumrit, D., & Anuntavoranich, P., 2013b. Using DEMATEL method to analyze the causal relations on technological innovation capability evaluation factors in Thai technology-based firms. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 4*(2), 81-103.

Teece, D.J., Pisano, G. and Shuen, A., 1997. Dynamic Capability and Strategic Management. *Strategic Management Journal, 18*(7), 509-533.

Turker, M.V., 2012. A model proposal oriented to measure technological innovation capabilities of business firms–a research on automotive industry. *Procedia - Social and Behavioral Sciences, 41*, 147-159.

Wang, C.H., Lu, I.Y., & Chen, C.B., 2008. Evaluating firm technological innovation capability under uncertainty. *Technovation, 28*(6), 349-363.

Wernerfelt, B., 1984. A resource-based view of the firm. *Strategic Management Journal, 5*(2), 171-180.

Wu, K.J., Liao, C.J., Tseng, M.L., & Chiu, A.S.F., 2015. Exploring decisive factors in green supply chain practices under uncertainty. *International Journal Production Economics, 159*, 147-157.

Yam, R.C.M., Guan, J.C., Pun, K.F., & Tang, E.P.Y., 2004. An audit of technological innovation capabilities in Chinese firms: Some empirical findings in Beijing, China. *Research Policy, 33*(8), 1123-1140.

Yuan, X., Shin, S., He, X., & Kim, S.Y., 2016. Innovation capability, marketing capability and firm performance: A two-nation study of China and Korea. *Asia Business & Management, 15*(1), 32-56.