International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-3 Issue-11, April 2014

A Proposed Model for Firm's Technological Capability Assessment under Uncertain Environment

Le Ngoc Son

***Abstract*—The recognition of technological level and capability has become one of the most important activities which not only help the firm appraise its strength and weakness, but also guide to plan the technological innovation strategic and enhance the competitive advantages. In this study, firm's technological capability is determined completely with four components (T – Technoware, H – Humanware, I – Inforware, O - Orgaware) and their criteria using Technology Atlas method, which was developed by Asian and Pacific Center for Technology Transfer. The contribution degrees toward technological capability of each component and criteria in specific industry are determined efficiently rely on fuzzy-AHP. Besides, aggregation of group judgment using a new technique with triangular intuition fuzzy number (IFN) representation makes the decisions more accuracy and efficiency. Our proposed model helps the firm's managers can easily evaluate their current technological capability keep track of their technological growth, compares with the industrial level and guides to the technological renovation strategy which is one factor to raise competitive advantage.**

***Index Terms*—technological capability assessment, group aggregation, analytic hierarchy process, intuitionistic fuzzy.**

I. INTRODUCTION

Technology has become an integral part of nearly every business and social endeavor [1]. The recognition of technological level and capability has become one of the most important activities which not only help the firm appraise its strength and weakness, but also guide to plan the technological innovation strategic and enhance the competitive advantages. Therefore, several authors have studied the impact of technology in term of business productivity [2], innovation [3] and technology transfer. Recently, many authors suggested new approach to solve this problem such as [4-13].

In this study, firm's technological capability is determined using Technology Atlas method. Technology Atlas method was developed by Asian and Pacific Center for Technology Transfer (APCTT [14,15]) to assess the technological capability of a firm or county, through evaluation of its capability in various components of technology. That is the reason why it is always mentioned firstly in articles which are related to technology or apply Technology Atlas [16-10]. In each industry, four components (T – Technoware, H – Humanware, I – Inforware, O - Orgaware) have different contribution degrees toward the technological capability.

Thus, we determine the weights of each component and its criteria, which is an important factor, with analytic hierarchy process (AHP) method under fuzzy environment to deal with imprecise and uncertain human comparisons judgments. In addition, aggregation of decision maker (DM) opinions using a new technique with triangular intuition fuzzy number (IFN) representation makes the decisions more accuracy and efficiency.

The remaining parts of this paper are structured as follows: Section 2 briefly reviews some basic definitions of fuzzy sets (FSs) and introduces about Technology Atlas method. In section 3, a new model is proposed to assess the technological capability of firm. An experimental example illustrates the proposed model in section 4. Finally, section 5 concludes the paper.

II. METHODOLOGY

A. Technology Atlas method

Technology has been defined in a variety of ways. According to Dosi [21], in the most general term, a technology can be seen as a human-constructed means for achieving a particular end, such as the movement of goods and people, the transmission of information or the cure of a disease. Christensen and Raynor [22] defined technology as the process that any company uses to convert inputs of labor, materials, capital, energy and information into outputs of greater value. Sharif [23] suggests that the streams of technology referred to by Prahalad and Hamel [24] fall into four major categories and that mastering these technological assets is essential for competitively positioning a company (Figure 1). These comprise the ''THIO Framework'' [1]: Technoware-T (object-embodied physical facilities), Humanware-H (person-embodied human talents), Inforware-I (record-embodied codified knowledge), Orgaware-O (organization-embodied operational schemes).

Based on Technology Atlas method, technological capability is determined by four components, those are T, H, I, O as mentioned above. The formula of Technology Contribution Coefficient (TCC) is used to measure technological capability:

$$TCC = T^{W_T}.H^{W_H}.I^{W_I}.O^{W_O} \qquad (1)$$

where W_T, W_H, W_I, W_O relate the role (important) of each component $W_T + W_H + W_I + W_O = 1$.

Manuscript received April, 2014.

MSc. Le Ngoc Son, School of Management and Economics, University of Electronic Science and Technology of China, Chengdu, 610054, China.

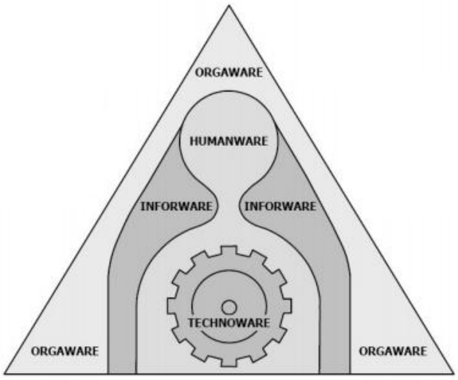

Fig. 1. Four technological components (Sharif, 1995)

B. Fuzzy sets (FSs)

As the complexity of the problem increases, impreciseness and vagueness in the data of the corresponding problem also increases [24]. Zadeh [25] proposed the idea of FSs to deal with these uncertainties. Since its original definition, several extensions have been proposed.

Definition 1 [25]

A triangular fuzzy number (TFN) $\tilde{A}$ can be defined by a triplet (*l*, *m*, *u*), where $l \le m \le u$, *l* and *u* stand for the lower and upper value of the support of $\tilde{A}$, respectively, and *m* is the mid-value of $\tilde{A}$. If *l*=*m*=*u*, it is a non-fuzzy number by convention (a crisp number). The graph of triangular fuzzy can be shown in Figure 2.

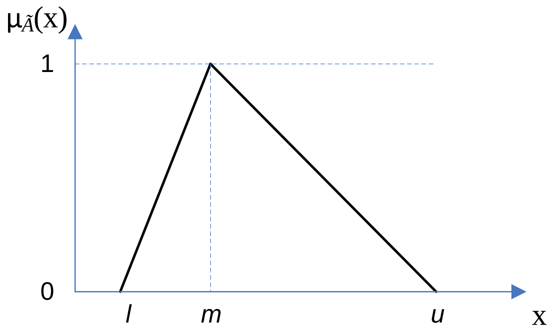

Fig.2. A triangular fuzzy number

The membership function $\mu_{\tilde{A}}$ (x) is defined as:

$$\mu_{\tilde{A}}(x)=\begin{cases}0, & x<l\\ \dfrac{x-l}{m-l}, & l\le x\le m\\ \dfrac{x-u}{m-u}, & m\le x\le u\\ 0, & x>u\end{cases} \qquad (2)$$

As a generalization of Zadeh's fuzzy set [25], Atanassov [26] proposed the IFS, which is characterized by a membership function and a non-membership function. IFS has been proven to be a very suitable tool to describe the imprecise or uncertain decision information.

Definition 2 [27]

A triangular intuitionistic fuzzy number (IFN) $\tilde{A}$ is represented as:

$\tilde{A}$=<[(a'$_1$,b'$_1$,c'$_1$); $\mu_{\tilde{A}}$], [(a$_1$,b$_1$,c$_1$); $\nu_{\tilde{A}}$]>. (3)

The membership functions $\mu_{\tilde{A}}$ is used to derive the lower bounds of membership μ_L for IFN $\tilde{A}$, where the upper bound of membership μ_U is derived by taking the compliment of non-membership functions $\nu_{\tilde{A}}$, respectively. A triangular IFN is shown in Figure 3.

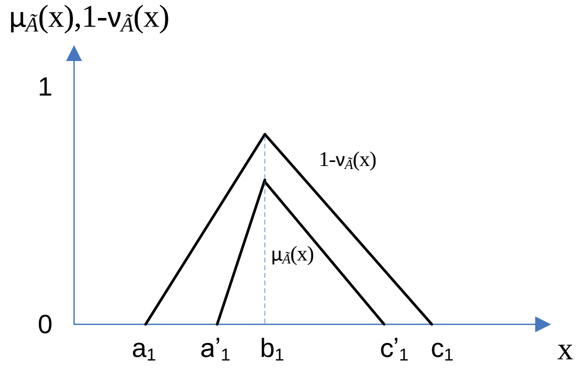

Fig.3. A triangular IFS Ã

C. Representation of group aggregation with triangular IFNs

In this research, the triangular IFNs are generated based on the mean (or average value) and the deviation among group. In order to do the representation, each parameter in TFNs, which is the result of aggregation operator, should accompany with its deviation value ∂.

$$\tilde{c}_j = \tilde{f}(\tilde{c}_j^{(i)}) = (<a_1;\partial_1>,<a_2;\partial_2>,<a_3;\partial_3>), \qquad (4)$$

$$\tilde{c}'_j = <[(a_1,a_2,a_3);\mu],\ [(a_1-\Delta_L,a_2,a_3+\Delta_U);\nu]>, \qquad (5)$$

where $\tilde{c}_j$ is a TFN and $\tilde{c}'_j$ is a triangular IFN with $1\le j\le k$, $\tilde{f}$ is the fuzzy aggregation operator used in previous step,

$$\Delta_L = \lambda\ min(a_1\text{-}minimum\_of\_range,\ \partial_1), \qquad (6)$$

$$\Delta_U = \lambda\ min(maximum\_of\_range\text{-}a_3,\ \partial_3), \qquad (7)$$

$$\mu = 1 - \nu - \pi, \qquad (8)$$

$$\nu = 0, \qquad (9)$$

$$\pi = \lambda\, \partial_2/(a_2+ \lambda\, \partial_2/2). \qquad (10)$$

$\tilde{c}'_j$ is a TFN of the universe of discourse X, which represent an imprecise value from *minimum_of_range* to *maximum_of_range.*

With this formula, the generated triangular IFN contain the divergence in group judgment. It reflects truthfully and objectively the group judgment after aggregating.

III. THE PROPOSED MODEL

In this study, we use Technology Atlas method to define the current technological state of the firms under uncertain environment with group judgment. Technological capability relates to four components (T, H, I, O) and their criteria. A group of decision makers give their opinion using linguistic terms, which are computed and represent by intuitionistic fuzzy sets. After that, the extend IF-AHP method are applied to assess the firm's technological. The process of proposed model includes following steps:

Step 1: Define and describe the criteria

The first step of the process is gathering relevant information and defining the assessment criteria (attributes). According to Technology Atlas method, technology consists of four components (T, H, I, O) and its criteria as in the first and the second layer of hierarchy structure in Figure 4.

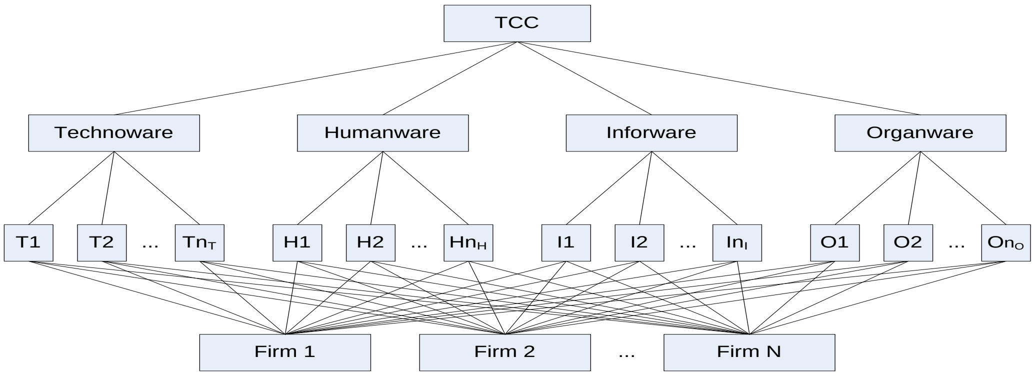

Fig. 4. The hierarchy structure

Step 2: Identify the appropriate linguistic variable.

In this step, we must define the appropriate linguistic variables for the importance weight of components and criteria. This paper suggests linguistic terms which can be expressed in positive TFNs, as in Table 1.

Table 1. Definitions of linguistic terms for the evaluation

	Linguistic terms	FS values
JE	Just Equal	(1,1,1)
EI	Equally important	(1,1,2)
WMI	Weakly more important	(2,3,4)
SMI	Strongly more important	(4,5,6)
VSMI	Very strongly more important	(6,7,8)
AMI	Absolutely more important	(8,9,10)

Step 3: Determine the important weight of components and criteria.

A group of decision makers give their opinions in pairwise comparison matrices with linguistic variables. They should have experience and good knowledge in main industry that the firm belongs to.
In this step, it is checked for the consistency. The most widely used consistency index is the consistency ratio (CR) (Saaty, 1991)

$$CR = \frac{CI}{RI} < 0.1 \qquad (11)$$

where $CI = \frac{\lambda_{\max} - n}{n-1}$, is the consistency index, *RI* is the average random index based on matrix size shown in Table 2, λ_{max} is the maximum eigenvalue of matrix A, and n is the order of matrix A.

Table 2. The average random index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

According to rule of thumb, the comparison matrix is consistent only if the value of *CR* is less than 0.1.

Step 4: Aggregate experts' opinion.

Since the evaluation of decision makers are based on triangular FN, the aggregation operator with geometric mean under fuzzy environment can generate the triangular IFN by using Eq.4 to Eq.10. The conversion to intuitionistic fuzzy environment helps to improve the efficiency and the accuracy of this model.

Step 5: Calculate the important weight vector.

Figure 4 is the hierarchy structure of AHP method. The concept of IFS is applied to AHP, called IF-AHP (Sadiq and Tesfamariam, 2009). It is applied appropriately to calculate the important weight vector in this study.

Step 6: Measure the technological component contribution and the technological contribution coefficient.

The firm's manager evaluates the criterion rating and calculates the contributions of each component:

$$C = \sum C_i W_{C_i} \qquad (12)$$

where:
C_i: is the score of the ith criteria of that component;
W_{C_i} : is the weight of the ith criteria of that component;
C: is the contribution of that component.
After calculating the values of each component T, H, I, O, they are combined their role by using a function that Technology Atlas and N. Sharif used to define the technology contribution coefficient (Eq. 1).

Step 7: Present and analysis the result using THIO graph and importance-performance chart.

Besides TCC value which indicates the current technological state of firms, other information can be presented in visual forms. The THIO graph indicates the split between existing condition and optimal condition of share of technological component in a firm. The importance-performance chart helps to recognize and analysis the current technological advantages of a firm easily. The correlation between importance and performance expresses the strength, the weakness and the readiness of a firm for each technological component.

IV. EXPERIMENTAL EXAMPLE

This part presents an experimental example that is technological capability assessment of a firm with group judgment using triangular IFNs representation. The result is based on the data of a firm in Aquatic Product Processing Industry, located in Dong Thap province, Vietnam (2013).
A group of technological experts (three members) use the linguistic terms in Table 1 to give their opinion for evaluation (as in Table 3). The λ_{max} values of three matrices are 4.002, 4.046 and 4.020 respectively.

Hence, they are consistency because the consistency ratio values less than 0.1 (CR= 0.001, 0.017, 0.007).

Table 3. Group judgment

DM		T	H	I	O
DM1	**T**	JE	WMI	SMI	EI
DM1		JE	EI	SMI	WMI
DM3		JE	WMI	VSMI	1/EI
DM1	**H**		JE	WMI	1/WMI
DM1			JE	EI	EI
DM3			JE	WMI	1/EI
DM1	**I**			JE	1/SMI
DM1				JE	1/EI
DM3				JE	1/SMI
DM1	**O**				JE
DM1					JE
DM3					JE

Table 4. Aggregation results with triangular IFNs

		Lower bound			Upper bound			μ	ν
T	T	1.00	1.00	2.00	1.00	1.00	2.00	1.00	0.00
H	T	0.28	0.38	0.63	1.00	0.38	0.92	0.83	0.00
I	T	0.14	0.18	0.26	1.00	0.18	0.36	0.88	0.00
O	T	0.44	0.69	1.14	1.00	0.69	2.47	0.12	0.00
T	H	1.59	2.62	3.63	1.01	2.62	4.21	0.85	0.00
H	H	1.00	1.00	2.00	1.00	1.00	2.00	1.00	0.00
I	H	0.28	0.38	0.63	1.00	0.38	0.92	0.83	0.00
O	H	0.87	1.44	2.29	1.00	1.44	3.82	0.42	0.00
T	I	3.78	5.59	7.32	2.05	5.59	7.90	0.86	0.00
H	I	1.59	2.62	3.63	1.01	2.62	4.21	0.85	0.00
I	I	1.00	1.00	2.00	1.00	1.00	2.00	1.00	0.00
O	I	2.08	3.68	5.28	1.00	3.68	7.59	0.69	0.00
T	O	0.87	1.44	2.29	1.00	1.44	3.82	0.42	0.00
H	O	0.44	0.69	1.14	1.00	0.69	2.47	0.12	0.00
I	O	0.19	0.27	0.48	1.00	0.27	0.87	0.57	0.00
O	O	1.00	1.00	2.00	1.00	1.00	2.00	1.00	0.00

Table 5. Important weight of components

Component	Weight	Stdev	Normalization
T	0.420	0.108	0.376
H	0.245	0.081	0.219
I	0.109	0.030	0.098
O	0.344	0.117	0.308

Table 4 is the aggregation results presented with triangular IFNs. With this matrix, the consistency test is also satisfy with λ_{max}= 4.005 and CR=0.002.

Using extend triangular IF-AHP to process the next steps, the result is showed in Table 5. With the similar way for criteria of each technological component, the global weights are showed in Table 6.

Next step, the contribution of technological components (T, H, I, O) are calculated from the scores of criteria given by the firm's manager, which is presented in Table 6.

Table 6. Important weight of criteria and technological score

	Weight	Score
T	**0.38**	**47.56**
T1	0.09	100.00
T2	0.14	100.00
T3	0.19	100.00
T4	0.19	96.66
T5	0.20	10.00
T6	0.10	10.00
T7	0.09	60.00
H	**0.22**	**41.14**
H1	0.21	93.85
H2	0.26	100.00
H3	0.15	100.00
H4	0.25	10.00
H5	0.13	10.00
I	**0.10**	**84.44**
I1	0.26	58.00
I2	0.30	100.00
I3	0.19	86.50
I4	0.25	100.00
O	**0.31**	**56.30**
O1	0.21	100.00
O2	0.24	30.00
O3	0.24	80.00
O4	0.19	50.00
O5	0.12	43.33

Next step, the contribution of technological component (T, H, I, O) are calculated from the scores of criteria given by the firm's manager, which is presented in Table 6.

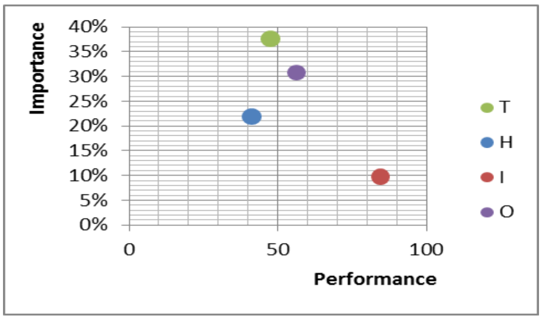

Figure 5. THIO graph

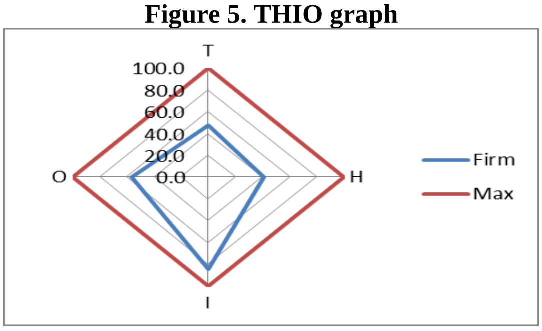

Figure 6. Important-Performance chart

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Finally, the result TCC of this firm is 51.32/100. The THIO graph (Figure 5) shows the contributions of each component in this firm. The important-performance chart (Figure 6) helps to indicate visually that the most important component in this industry is Technoware, but this is the weakness of this firm while it is strong at Inforware, the least important one.

Using this proposed method, the important weights of the components and criteria are determined efficiently rely on IF-AHP. They are very important in case of using to assess the technological capability of various firms in the same industry. This approach also provides a way for the firm's managers to self-assess and re-assess their technological status after doing a technological investment.

V. CONCLUSION

This study applies a new technique to firm's technological assessment. The proposed model combined MCDM method and group decision making under fuzzy environment. The fuzzy theory improves in giving the opinion to deal with imprecise and uncertain human comparison judgments. Besides, group aggregation judgment is represented with triangular IFN helps reflect truthfully and objectively the group judgment after aggregating.

This paper stated a specific process of firm's technological assessment based on the Technology Atlas method, in which technology is determined completely by four technological components (T, H, I, O). The contribution degrees toward technological capability of each component and the important weight of its criteria in specific industry are determined efficiently rely on fuzzy-AHP and group expert's opinion aggregation method. By this way, the firm's managers can easily to evaluate their current technological capability by themselves. This is also the approach for technological assessment at the industrial and national level. This information helps them keep track of their technological growth, compares with the industrial level and guides to the technological renovation strategy which is one factor to raise competitive advantage.

REFERENCES

1. Smith, R., & Sharif, N. (2007). Understanding and acquiring technology assets for global competition. Technovation, 27(11), 643-649.
2. Syverson, C. (2010). What determines productivity? (No. w15712). National Bureau of Economic Research.
3. Cooper, R. G., & Edgett, S. J. (2010). Developing a product innovation and technology strategy for your business. Research-Technology Management, 53(3), 33-40.
4. Lall, S. (1992). Technological capabilities and industrialization. World development, 20(2), 165-186.
5. Udo, G. J., & Edoho, F. M. (2000). Information technology transfer to African nations: An economic development mandate. The Journal of Technology Transfer, 25(3), 329-342.
6. Archibugi, D., & Coco, A. (2004). A new indicator of technological capabilities for developed and developing countries (ArCo). World Development, 32(4), 629-654.
7. Archibugi, D., & Coco, A. (2005). Measuring technological capabilities at the country level: A survey and a menu for choice. Research policy, 34(2), 175-194.
8. Ortega, M. J. R. (2010). Competitive strategies and firm performance: Technological capabilities' moderating roles. Journal of Business Research, 63(12), 1273-1281.
9. Archibugi, D., Denni, M., & Filippetti, A. (2009). The technological capabilities of nations: The state of the art of synthetic indicators. Technological Forecasting and Social Change, 76(7), 917-931.
10. Zhen-qin, W., & Wei-cai, W. (2011, September). The measurement of regional technological capability in China: An empirical study. In Management Science and Engineering (ICMSE), 2011 International Conference on (pp. 630-636). IEEE.
11. Filippetti, A., & Peyrache, A. (2011). The patterns of technological capabilities of countries: A dual approach using composite indicators and data envelopment analysis. World Development, 39(7), 1108-1121.
12. Lamin, A., & Dunlap, D. (2011). Complex technological capabilities in emerging economy firms: The role of organizational relationships. Journal of International Management, 17(3), 211-228.
13. Molina-Domene, M. A., & Pietrobelli, C. (2012). Drivers of technological capabilities in developing countries: An econometric analysis of Argentina, Brazil and Chile. Structural Change and Economic Dynamics, 23(4), 504-515.
14. ESCAP, A. Pacific Centre for Transfer of Technology (Technology Atlas Project)(1989). Framework for Technology-Based Development.
15. ESCAP, A. (1994). Extension of the Technology Atlas. United Nations, New York, USA.
16. Alizadeh, Y. (2012, June). Firm-level technological capability assessment; a literature review. In Technology Management Conference (ITMC), 2012 IEEE International (pp. 398-404). IEEE.
17. Akbari, M. R., & Yunusi, M. (2012). A methodology to evaluate both internal and external environments of applied-scientific educational system used in strategic planning. Scientific Research and Essays, 7(17), 1746-1760.
18. Jayasena, T. D. S. A., Wickramasinghe, V., & Dasanayaka, S. W. S. B. (2013, December). TECHNOLOGY TRANSFER: THE ROLE OF CULTURE IN TRANSFERRING TECHNOLOGY. In Proceedings of International Conference on Business Management (Vol. 2).
19. Giang, N. H., Van Binh, T., & Viet, P. M. (2006, October). Distributed Data Model for Assessment and Management of Enterprises and Economic Sectors' Technology Capabilities. In Communications and Electronics, 2006. ICCE'06. First International Conference on (pp. 387-391). IEEE.
20. Nezhad, S. G. G., Rostamzadeh, R., & Sofian, S. (2010). The Influence of (beta) Technology Intensity and Evaluating TCC Using AHP Model in Iran Tractor Manufacturing Company (ITMCO). International Review of Business Research Papers, 6(6), 286-298.
21. Dosi, G., & Grazzi, M. (2010). On the nature of technologies: knowledge, procedures, artifacts and production inputs. Cambridge Journal of Economics, 34(1), 173-184.
22. Christensen, C. M., & Raynor, M. E. (2003). The innovator's solution: Creating and sustaining successful growth. Harvard Business School Press.
23. Sharif, N. (1999). Strategic role of technological self-reliance in development management. Technological forecasting and social change, 62(3), 219-238.
24. Devi, K. (2011). Extension of VIKOR method in intuitionistic fuzzy environment for robot selection. Expert Systems with Applications, 38(11), 14163-14168.
25. Zadeh, L. A. (1965). Fuzzy sets. *Information and control*, *8*(3), 338-353.
26. Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy sets and Systems*, *20*(1), 87-96.
27. Sadiq, R., & Tesfamariam, S. (2009). Environmental decision-making under uncertainty using intuitionistic fuzzy analytic hierarchy process (IF-AHP). Stochastic Environmental Research and Risk Assessment, 23(1), 75-91.

AUTHORS PROFILE

MSc. Le Ngoc Son is with School of Management and Economics, University of Electronic Science and Technology of China (UESTC), Chengdu, China. Le's from Ho Chi Minh city, Vietnam. He got Masters' degree of computer science at Ho Chi Minh City University of Technology, Vietnam. Le is a lecturer in IT department of Industrial University of HCM city (IUH). Recently, he is researching in information management and data mining. His current research interests are MCDM and CBR. Now he is a PhD. candidate in UESTC. Son has published some papers in new combination of AHP and CBR, and proposed a model for firm's technological capability assessment under fuzzy environment.