Assessing Innovation Capability of Small and Medium-sized Enterprises Based on Analytic Hierarchy Process

Rui Mu[1, a], Shengquan Xiao[1, b] Yufeng Zhang[2, c, *]

[1]*School of Aerospace Engineering, Xiamen University, Xiamen 361102, China*
[2]*College of Physical Science and Technology, Xiamen University, Xiamen 361005, China*
[a]*murui@xmu.edu.cn*, [b]*878024358@qq.com*, [c]*yufengzhang@xmu.edu.cn*
** Corresponding author*

Keywords: innovation capability; Analytic Hierarchy Process; small and medium-sized enterprises

Abstract: In an increasing competing market, it is critical for small and medium-sized enterprises to transform into innovation-driven operation to secure a sustainable long-term development of their business. To carry out such transformation, it is necessary to objectively assess the innovation capability and understand the limiting factors. An evaluation model based on analytic hierarchy process is proposed, and tested with survey data of 10 manufacturing companies in Xiamen. The results show good consistency between the proposed model and other qualitative assessment, which sheds more light on the innovation process of enterprises, and would benefit both theoretical study and management of enterprises.

1. Introduction

In recent years, the competitiveness of China has risen steadily, however, the main driven factors are still not innovation-based[1]. Since small and medium-sized enterprises (SMEs) account for 97.5% of enterprises in China, contribute about 63% to gross revenue, and own at least 65% domestic patents, they possess an important role in economic development, as well as boosting the competitiveness and innovation of a country[2, 3]. However, SMEs also face a dramatically changing economic environment, and encounter ever demanding needs of local and global market. In order to overcome all these hurdles, it is critical for the SMEs to accurately assess their own innovation capability and understand the limiting factors, therefore, discover their potential and design appropriate strategy to assure sustainable development.

Currently, there are some research on this topic. Vincent Boly et al. evaluated the innovation processes in French firms using multi-criteria approach[4]. Gino Marchet et al. assessed the efficiency and innovation in the third party logistics industry in Italy using Data Envelopment

Analysis[5]. Chaogai Xue et al. analyzed the innovation capacity of information system in university and enterprises based on system dynamics model[6]. However, most of the research either focus on specific sector of the market, or without differentiation the size of enterprises. Since SMEs and large enterprises possess quite different characteristics, it is important to address the innovation capability of SMEs, specifically. The analytic hierarchy process (AHP) has shown great potential in decision-making for complex problems with multiple conflicting and subjective criteria.

Hence, in this paper, a model based on AHP is proposed to quantitatively assess the innovation capability of SMEs.

2. The AHP Model

Based on survey of manufacturing companies in Xiamen and literatures review, a judgment hierarchical modal is established, with evaluation of innovation capability as objective (O). Four factors as direct influential parameters for the objective are identified as: human capital (A1), financial investment (A2), research and development (R&D) capability (A3), and market performance (A4). These factors cover both the input and output of innovation activities of an enterprise, and are consistent with other research[4]. Furthermore, overall ten criteria are carefully picked to provide quantitative gauge of the four factors. For factor A1, personnel in R&D department (C1) and other technicians (e.g. engineers in manufacturing, customer service) (C2) are chosen as indicators, because these personnel directly involve in innovation activities. Financial investment in R&D (C3), technical renovation (C4), and other relevant investment (e.g., training, consulting) (C5) are selected as markers for factor A2. Since only technological results in new products development process are patented, to avoid underestimation of innovation capability, both new products (C6) and patents (C7) are set as indicators for factor A3. In order to measure the sustainability of innovation activities in an enterprise (i.e., how efficient an enterprise benefits from its innovation activities), sale of new products (C8), profit rate (C9), and export of new products (C10) are designated as indicators for factor A4. The detailed hierarchical structure is shown in Table 1, where the numbers in parenthesis represent weight of each factor and criteria, explained in the following paragraphs.

Table 1 The judgement hierarchy to assess innovation capability of SMEs

O: innovation capability	A1: human capital (0.251)	C1: personnel in R&D department (0.188)
		C2: other technicians (0.063)
	A2: financial investment (0.356)	C3: financial investment in R&D (0.192)
		C4: technical renovation (0.106)
		C5: other relevant investment (0.058)
	A3: R&D capability (0.295)	C6: new products (0.196)
		C7: patents (0.098)
	A4: market performance (0.098)	C8: sale of new products (0.016)
		C9: profit rate (0.053)
		C10: export of new products (0.029)

In order to quantitatively assess the innovation capability, the priority of each factor and criteria is determined using the standard pairwise comparison of AHP process[7]. To simplify the process and reduce interference between multiple elements, the quantitative process is carried out level by level. At each level of the hierarchy structure, pairwise comparison is performed for each element, which reflects the relative importance or influence of the two elements using the Saaty nine-level scale[7]. The rating forms a comparison matrix, which the principal diagonal contains entries of 1, as indication that each element is equally important as itself. Then, priority vector can be derived using linear algorism to yield a local weight (i.e., weight of current level). After repeating this process for all levels, a global priority vector for each criteria is calculated by multiplying the local weights with the weight of the level above it.

Here, the process for factor level is shown as an example. First, the comparison matrix, as shown in Table 2, is developed based on the pairwise comparison performed by the research team and data collected from the survey of the companies. Then, the eigenvectors and eigenvalues of the matrix is calculated. The normalized eigenvector, V(v_{A1}, v_{A2}, v_{A3}, v_{A4}), corresponding to the largest eigenvalue, represents the local priority vector (i.e., relative weight of the four factors), which is listed in both Table 2 and 1 in parenthesis after the corresponding factors. Since it is unavoidable to introduce certain degree of inconsistence in this process, it is important to check the consistency of each evaluation. First, consistency index (CI) [7]is derived

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

where λ_{max} is the largest eigenvalue of the matrix, n is the order of the matrix.

Table 2 The comparison matrix of factors and local priority vector

	A1	A2	A3	A4	V
A1	1	1/2	1	3	0.251
A2	2	1	1	3	0.356
A3	1	1	1	3	0.295
A4	1/3	1/3	1/3	1	0.098
λ_{max}	4.061	CI	0.020	CR	0.022

Then, the consistency ratio (CR)[8] is calculated

$$CR = \frac{CI}{RI} \tag{2}$$

where RI is average CI values gathered from a random simulation of Saaty pair-wise comparison, and changes with the order of the matrix. For example, when n=4, R=0.90[8]. If CR is larger than 0.1, it suggests that the results are untrustworthy because they are too close to randomness, and the whole process need to be redone. For current example, the CR equals to 0.022, which is way smaller than the threshold value of 0.1. Hence, the values can be used without worry of consistency. The other comparison matrixes (at criteria level) are processed according to the same procedures, and the results (not shown) are used to derive a global priority vector, shown in parenthesis after each criteria in Table 1.

Based on the current model, the innovation investment (including both human capital and financial investment) accounts for 60% of total weight in gauging the innovation capability, while the output (such as number of new products, and profits) taking about 40%. This suggests that the innovation capability relies on both input and output, but with slightly emphasis on the former sector. Such distribution of weight takes the hysteresis effect in the innovation process into account, since any initiative of innovation does take time to get any results. A closer inspection of the weight in input sector (A1: 0.251 and A2: 0.356) indicates that financial investment contributes more to the innovation capability than human capital. Even though the innovation can only be accomplished by human, all the innovation activities require heavy financial support, not only for purchasing sophisticated apparatus for R&D as well as renovation of instruments in production line, but also for hiring qualified researchers and engineers, providing necessary training for employees. On the other hand, the weight of output sector (A3: 0.295 and A4: 0.098) suggests that there is a gap between patenting, commercializing, and profiting of innovation activities either because the SMEs are not yet operating fully in innovation driven or at the early stage of transforming their operation mode. This suggests the lagging of financial gain from innovation is the dominant limiting factor in the innovation process for SMEs. Actually, similar phenomenon has been found in the overall competitiveness and innovation of China, which ranks 1st in Patents/GDP but only 14 in High- & medium-high-tech manufactures[9].

3. Case Study

The data was collected from 10 manufacturing (M1, M2, … , M10) SMEs in Xiamen and processed using the model to test its reliability. In order to comparing the different criteria, the collected data is pretreated to obtain dimensionless value. The number of personnel in R&D department is divided by total number of employee in the enterprise as value of C1, and similar ratio (i.e., number of technicians exclude the R&D department divided by number of employee) is used for C2. The financial investments (C3, C4, and C5) are ratio of corresponding budget over incomes of the enterprise. The C6 is ratio of marketing new products over products under development, while, C7 is proportion of successfully granted patents to the overall applied patents. The sale of new products over total sale is used as C8, and the ratio of exported new product over total sale of new products is set for C10. The results, in which the scores are normalized to maximum value for easier comparison, are shown in Table 3. It is clear that the ranking shows good consistency with other qualitative results, such as the innovative title granted at different level.

Table 3 Ranking the innovation capability of 10 manufacturing companies in Xiamen

Ranking	Name of the enterprise	Normalized Score	Note
1	M1	1.00	National innovative enterprise
2	M10	0.84	
3	M5	0.80	
4	M2	0.80	Provincial innovative enterprise
5	M9	0.77	Municipal innovative enterprise
6	M8	0.73	
7	M4	0.60	
8	M3	0.57	
9	M7	0.33	
10	M6	0.25	Municipal innovative seed enterprise

Note: the score is normalized to the maximum (i.e., the score of company rank 1st place is 1).

4. Conclusion

A quantitative model is proposed based on AHP to comprehensively and objectively assess the innovation capability of SMEs. It is found that the market performance is the major limiting factors in the innovation process. The SMEs can benefit greatly by addressing the lag between patenting and marketing the results of innovation activities. The model is tested using data of manufacturing companies in Xiamen, and yields a good agreement with other qualitative assessment. Hence, the proposed model provide a reliable method to study the innovation activities of SMEs for related community, as well as an important tools for management of SMEs to plan their strategy for sustainable and innovation driven operation.

Acknowledgments

This work was financially supported by Soft Science Research Program of Fujian Province (2017R0098), and the Fundamental Research Funds for Central Universities of China

(20720160013).

References

[1] K. Schwab, The global competitiveness report (2017-2018), World Economic Forum, Geneva, 2017
[2] GE, Global innovation barometer report, GE, Boston, 2018.
[3] OECD, Enhancing the contributions of SMEs in a global and digitalised economy, OECD, Paris, 2017.
[4] V. Boly, L. Morel, N. G. Assielou, et al., Evaluating innovative processes in french firms: Methodological proposition for firm innovation capacity evaluation, Research Policy 43 (2014) 608-622.
[5] G. Marchet, M. Melacini, C. Sassi, et al., Assessing efficiency and innovation in the 3PL industry: An empirical analysis, International Journal of Logistics-Research and Applications, 20 (2017) 53-72.
[6] C. Xue, Y. Xu, Influence factor analysis of enterprise it innovation capacity based on system dynamics, Procedia Engineering, 174(2017) 232-239.
[7] T. L. Saaty, A scaling method for priorities in hierarchical structures, Journal of Mathematical Psychology, 15 (1977) 234-281.
[8] R. W. Saaty, The analytic hierarchy process—what it is and how it is used, Mathematical Modelling, 9 (1987) 161-176.
[9] S. Dutta, B. Lanvin, S. Wunsch-Vincent, The global innovation index 2017: Innovation feeding the world, Cornell University, INSEAD, and WIPO, Geneva, 2017.