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A Hybrid Multi-Criteria Decision Model for Technological Innovation Capability Assessment: Research on Thai Automotive Parts Firms

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Abstract

The efficient appraisal of technological innovation capabilities (TICs) of enterprises is an important factor to enhance competitiveness. This study aims to evaluate and rank TICs evaluation criteria in order to provide a practical insight of systematic analysis by gathering the qualified experts' opinions combined with three methods of multi-criteria decision making approach. Firstly, Fuzzy Delphi method is used to screen TICs evaluation criteria from the recent published researches. Secondly, the Analytic Hierarchy Process is utilized to compute the relative important weights. Lastly, the VIKOR method is used to rank the enterprises based on TICs evaluation criteria. An empirical study is applied for Thai automotive parts firms to illustrate the proposed methods. This study found that the interaction between criteria is essential and influences TICs; furthermore, this ranking development of TICs assessment is also one of key management tools to simply facilitate and offer a new mindset for managements of other related industries.

Keywords: technological innovation capability, fuzzy delphi method, Analytic Hierarchy Process (AHP), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method

1. Introduction

The upcoming establishment of Asean Economic Community (AEC) in 2015 is to regionalize ASEAN countries as a whole. As stated in the AEC blueprint, there are four characteristics that are inter-related and mutually strengthen; "1) a single market and production base, 2) a highly competitive economic region, 3) a region of equitable economic development and 4) a region fully integrated into the global economy." These elements changing will create the free flow of skilled labor, goods & services, investment, and capital. Given this, the economic competitions will be more severe and uncontrollable. Thus, the enhancement of firms' core competencies will be an important strategy to achieve and maximized benefits from AEC. Thai automotive parts industry plays an important role in substantial benefits contribution to the country; therefore, it is inevitably facing more intensified competitions from both regional and global economy. Burgelman et al. [1] described Technological Innovation Capabilities (TICs) are as a whole set of a firm's characteristics that facilitate the firms' technological innovation strategies. The developments of capabilities are also rather important and closely related to their sustainability [2]. Despite of the importance of TICs, the previous studies have not paid much attention to the importance of its assessment criteria and the cause and effect relationships among criteria. In these areas, TICs are regarded not only as one of the firms' solutions but as the method of effective measurement under the multi-dimensions of criteria. Therefore, it is worth more attention.

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Wang et al. [3] viewed that the evaluation of TICs is based on multiple criteria such as R&D, innovation decision, marketing, manufacturing and capital capabilities. TICs are also typically subjective and TICs measurements are imprecise and vague. This increases more complexity of the implementation and performance evaluation process. The evaluators of TICs normally provide the subjective judgments, which depend on past experienced knowledge, and professional information. These are also hard to accurately interpret due to dealing with the vagueness of human thoughts and expression when making a decision. Therefore, the fuzzy set theory is required to solve these problems in a decision making process and to be helpful in converting the linguistics preferences into fuzzy numbers [3], [4], [5].

This study developed a systematic auditing model to establish and rank criteria for evaluating TICs of firms by employing a multi-criteria decision making (MCDM) with a combination of Fuzzy Delphi, Analytic Hierarchy Process (AHP) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. The reasons for choosing an integrated the Fuzzy Delphi, AHP and VIKOR based the proposed framework in this paper are justified as follows: The Fuzzy Delphi method is the solution of a group decision making technique to reduce the vagueness of experts' judgments by applying fuzzy logic for screening and extracting the critical TICs evaluation criteria in a systematic way. The AHP method can provide the hierarchical structure by presenting the complicated decision problem, measuring the consistency of the decision making procedure, and be applicable for qualitative and quantitative criteria. However, after aggregating the relative importance weights, the compensation of higher relative importance weights on some criteria and lower relative importance weights on other criteria can probably occur. In order to overcome this weakness of AHP, the VIKOR method is then utilized to rank the firms' performance with respect to the relative weight of each evaluation index. The VIKOR method is a helpful method for the decision makers to express their preferences by criteria weights in multi-criteria decision making process. Also, the VIKOR method can particularly provide the compromise solution, trading off the maximum "group utility" of the majority and the minimum of the individual regret of the "opponent". The calculations are simple and straightforward. So, the VIKOR method has been widely used to solve multi-criteria group decision making problem [6].

Therefore, we aimed that this proposed hybrid MCDM approach by an integration of Fuzzy Delphi, AHP and VIKOR methods would be appropriated for analyzing the most influential TICs evaluation criteria which impact firms' capabilities and identifying the critical criteria for prioritization in the areas of improvement. Furthermore, this proposed model is to simplify the firms' TICs evaluation, and to be useful for the effective management' decision making.

2. Literature Reviews

2.1. Technological Innovation Capability

The innovation concept is boarded with numerous dimensions and the measurement of innovation is better complex [7]. Previous empirical literatures contain many concepts of innovation capability, and the TICs definitions depend on the application of different elements of innovation capability; for examples, the multi-dimension of context and the specific purposes of each study. The innovation capability was defined as an organization's ability to develop new products and processes and to achieve greater managerial and technological performance [8]. Similarly, Lawson & Samson [9] also determined that "innovation capability is the ability to continuously transform knowledge and ideas into new products, processes and systems for the benefits of the firm and its stakeholders". Also, TICs is a kind of special assets or resources, comprising of the various essential fields of production, process, knowledge, technology, experience and organization [10].

The implementation of TICs has been widely conducted especially to sustain the competitive advantages. For examples, Guan et al. [11] developed an innovation framework to provide a benchmark for auditing the quantitative relationship between competitiveness and TICs based on a traditional DEA approach to enhance the competitiveness of a firm. Tseng [5] supported that firms continuously need their resources management to maintain competitive advantage in order to face with pressure from global competition and environmental fluctuation. Thus, the innovation becomes a main competitive advantage source in the recent knowledge economy, and the effective business strategies to retain firms' competitive advantage are certainly demanded [12]. Chiesa et al. [13] and Wang et al. [3] addressed the features of TICs as the inclusion of multi-dimensional, complex, interactive innovation activities with resource allocation are a mean to increase competitive advantage. The innovation management in the innovative firms is the key business strategy to handle the decision making in terms of resource allocation, environmental investigation, and project implementation [14], [15]. Innovation role will be highly significant as long as the global business is still growing. Yam et al. [16] also pointed out that each independent department within firm is a crucial and fundamental basis in order to initiate a novel idea. This source of information utilization could lead to further development of audition framework in order to evaluate innovation performance and the impact of TICs enhancement. This research drew an attention on utilizing TICs by exploring empirical researches to view the relationship between TICs and firms' competitiveness.

2.2. Fuzzy Delphi Method

The concept of the combination of traditional Delphi Method and fuzzy theory was developed to reduce the ambiguity of the Delphi method. Membership's degree was implemented to make the membership function of each participant [17]. Ishikawa et al. [18] suggested that the Fuzzy Delphi Method was derived from the traditional Delphi technique and fuzzy set theory to improve max-min and fuzzy integration algorithms. The Fuzzy Deplhi method has an advantage to collect the appropriated information on the experts 'opinion. Recently, the Fuzzy Delphi Method had been widely used to collect the useful variables with a more systematic way from experts' opinions and to be integrated in decision making process. The Fuzzy Delphi are employed in various purposes and different areas such as sales forecasting in Printed Circuit Board industry [19], constructing key performance appraisal indicators for mobility in the service industries [20], identifying variables for the real estate projects in Greece [21], evaluating in hydrogen production technologies [22], establishing for road safety performance indicators [23], generating variables of ornamental stone [24], selecting key elements in a strategic planning process [25].

The solution to reduce the vagueness of experts' opinions by using Fuzzy Delphi Method as a group decision making technique can be described in the following steps [26];

Step 1: Gather experts' opinions: Each expert will provide the evaluation score of each evaluation factor in terms of linguistic variables in questionnaire to evaluate criteria.

Step 2: Definite the triangular fuzzy numbers (TFNs): Experts provide the significant triangular fuzzy number of the alternate factor/ criteria, then to calculate the evaluation value of triangular fuzzy number of each alternate factor. This research applied the geometric mean model of mean general model proposed by Klir and Yuan [27], which the computing formula is illustrated as follows:

Assuming the evaluation value of the significance of No. *j* element given by No. *i* expert of n experts is $\widetilde{W}_{ij} = (a_{ij}, b_{ij}, c_{ij})$, $i = 1, 2,\ldots, n$, $j = 1, 2,\ldots,m$. Then the fuzzy weighting $\widetilde{W}_{ij}$ of No. *j* element is $\widetilde{W}_{ij}$.

$$\widetilde{W}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \qquad ;i = 1, 2,\ldots, n, j = 1, 2,\ldots,m$$

$$a_j = min\{a_{ij}\},\ b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij},\ c_j = \max\{c_{ij}\} \tag{1}$$

Step 3: Compute the Defuzzification (D_j): The value of D_j is derived by using a center of gravity method in order to defuzzify the fuzzy weight $\widetilde{W}_{ij}$ of each alternate element. The formula used to find such attributed weight of each criterion is shown in Eq. (2).

$$D_j = \frac{a_j + 4b_j + c_j}{6},\ j = 1, 2, \ldots, m \tag{2}$$

Step 4:The Screening of the evaluation indexes: Finally, the proper factors can be screened out from numerous factors by setting the threshold (α). The threshold value is provided by group of expert consensus. The principle of screening is as follows: If $D_j \geq \alpha$, then No. j factor is the evaluation index. If $D_j < \alpha$, then delete No. j factor.

Table 1 Linguistic variables for importance of each criterion

Linguistic terms	Triangular Fuzzy numbers (TFNs)
Absolutely appropriate	(9,10,10)
Appropriate	(7,9,10)
Slightly appropriate	(5,7,9)
Neutral	(3,5,7)
Slightly inappropriate	(1,3,5)
Inappropriate	(0,1,3)
Absolutely inappropriate	(0,0,1)

For the threshold value r, the 80/20 rule was adopted with r set as 8. This determined that among the factors for selection, "20% of the factors account for an 80% degree of importance of all the factors". The selection criteria were: If $D_j \geq 8$, this appraisal indicator is accepted. If $D_j < 8$, this appraisal indicator is rejected.

2.3. The Analytical Hierarchical Process (AHP)

The methodology of AHP was considered as a rational decision making on various criteria. It is one of the outstanding management tools dealing with the complication of multi-criteria decision problems. It simplifies the solution of not only the qualitative problems but also the quantitative problems. There are several studies utilizing AHP method for computing the relative importance weight among various key determinants. For examples, Karami [28] applied AHP method for selecting an appropriated irrigation method for the farmer's decision. Vidal et al. [29] used AHP approach to select anti cancer drugs in context of production and distribution in a French hospital. Dong et al. [30] developed consensus models for group decision making under row geometric mean prioritization method by using AHP method. Vidal et al. [31] used AHP and a Delphi process to measure the complexity of projects. Görener et al. [32] using AHP to enhance the quantitative side of strategic planning in SWOT analysis.

The steps of AHP process was shown as following [33];

Step 1: Form the pair wise comparison matrix (C), as Eq.(3).

$$C = (C_{ij})_{nxn} = \begin{pmatrix} C_{11} & C_{12} & \ldots & C_{1n} \\ C_{21} & C_{22} & \ldots & C_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ C_{n1} & C_{n2} & \ldots & C_{nn} \end{pmatrix} \tag{3}$$

where C_{ij} is the importance degree of the i^{th} factor compared to the j^{th} factor.

Step 2: Construct the normalized criteria of matrix C. Formula is shown in Eq. (4) and Eq. (5) presented the normalization matrix, C^{Norm}.

$$C_{ij}^{Norm} = \frac{C_{ij}}{\sum_{k=1}^{n} C_{kj}},\quad i, j = 1, 2, \ldots, n \tag{4}$$

$$C^{Norm} = (C_{ij}^{Norm})_{nxn} \tag{5}$$

Step 3: Aggregate each criteria of the same row of C^{Norm}, as computed by Eq. (6).

$$W_i^{Norm} = \sum_{j=1}^{n} C_{ij}^{Norm}, \qquad i = 1, 2, \ldots, n \tag{6}$$

Step 4: Formulate the weights vector W = (w_1, w_2,…, w_n) as in Eq. (7).

$$W_i = \frac{W_i^{Norm}}{\sum_{k=1}^{n} W_k^{Norm}}, \qquad i = 1, 2, \ldots, n \tag{7}$$

Step 5: Calculate the maximum value (λ_{max}) as in Eq. (8), where *n* is the dimension of the comparison matrix.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(CW)_i}{w_i} \tag{8}$$

Step 6: Finally, compute the consistency ratio (CR) as a consistency check as in Eq. (9).

$$CR = \frac{CI}{RI} \tag{9}$$

where *RI* is the random index and its value can change with the dimension variations. *CI* is the consistency index, computed as Eq. (10).

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{10}$$

2.4. The VIKOR Method

The VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje in Serbian, means Multi-criteria Optimization and Compromise Solution) method is one of applicable techniques of multi-criteria decision making method (MCDM), which introduced the multi-criteria ranking index based on the measure comparison of “closeness” to the “ideal” alternative [34]. This method purposes to rank and select a set of alternatives among the conflicting criteria, which could help the decision makers to reach a final decision [35]. The VIKOR method is developed from the L_p-metric that is utilized as an aggregating function in a compromise programming developed into the multi-criteria measure for compromise ranking [36], [37]. Recently, there are many studies applying VIKOR through multi-criteria decision making. For examples, Cristóbal [38] used a combination of AHP and VIKOR methods for selection of renewable energy project in Spain. Tsai et al. [39] proposed a MCDM model by integration of DEMATEL, ANP and VIKOR to select the web-based marketing in the airline industry. Fallahpour and Moghassem [40] used VIKOR method for parameters selection problem in rotor spinning. Liu and Wu [41] used VIKOR method to evaluate human resources managers. Wu et al. [42] employed AHP and VIKOR method for ranking universities based on performance evaluation structure. Chiu et al. [43] proposed a hybrid model of a combination of DANP and VIKOR to improve e-store business. This study adopted the VIKOR method, where the form of the L_p metric was introduced by Duckstein and Opricovic [44] as a formula in Eq. (11).

$$L_i^p = \{\sum_{j=1}^{n}[w_j(|f_j^* - f_{ij}|)/(|f_j^* - f_j^-|)]^p\}^{1/p}, 1 \le p \le \infty; i = 1, 2, \ldots, m \tag{11}$$

where w_j is the weight of the j^{th} criterion, expressing the relative importance of the criteria, j = 1, 2, …,n, where n is the number of criteria, and f_{ij} is the rating (performance score) of the j^{th} criterion for alternative A_i, where the alternatives are denoted as A_1, A_2, A_3,… A_m. The compromise solution; $F^c = (f_1^c, f_2^c, \ldots f_n^c)$, is a set of feasible solution which is the closet to the ideal F^*, as shown in Fig. 1.

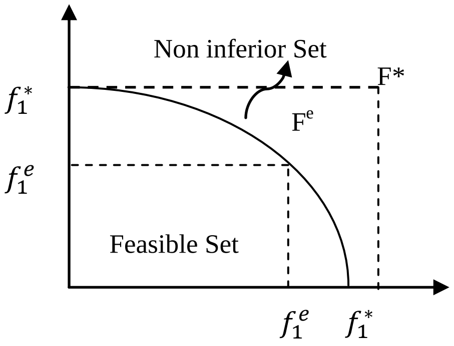


Fig. 1 Ideal and compromise solutions

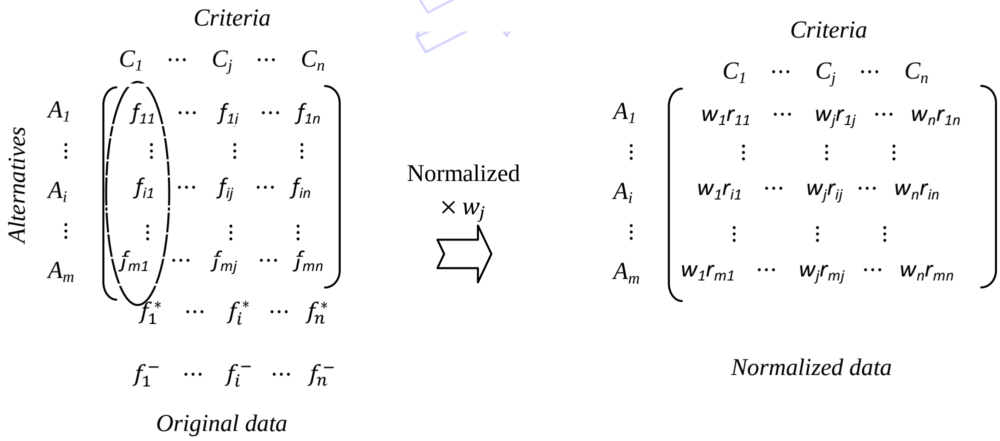
Formula in Eqs. (12) and (13) are used to measure the ranking [34], [35], [45],[46]. When *p* is low (such as *p* =1), the group utility is focused. If *p* is higher, the individual regrets/ gaps receive more weights [47], [48].

$$S_i = L_i^{p=1} = \sum_{j=1}^{n}[\, w_j(|f_j^* - f_{ij}|/(|f_j^* - f_j^-|)] \quad (12)$$

$$R_i = L_i^{p=\infty} = max_j\{w_j(|f_j^* - f_{ij}|)/(\,|f_j^* - f_j^-|);\ j = 1, 2, \ldots n\} \quad (13)$$

The compromise solution $\min_i L_i^p$ is then selected because its value is closest to the ideal level, whereby $\min_i S_i$ expresses to minimize the sum of the individual regrets/gaps and $\min_i Q_i$ expresses to minimize the maximum individual regrets. In other words, $\min_i S_i$ emphasizes the maximum group utility, meanwhile $\min_i Q_i$ emphasizes selecting minimum among the maximum individual regrets. The compromise ranking algorithm VIKOR consists of the following steps.

Step 1: Define the best f_j^*, and the worst f_j^- values of all criterion functions, where j = 1, 2,…*n*. Assuming the j^{th} function represents a benefit, then $f_j^*=\max_i f_{ij}$ (or setting an aspired level) and $f_j^- = \min_i f_{ij}$ (or setting a tolerable level). Alternatively, if we assume the j^{th} function represents a cost/risk, then $f_j^* = \min_i f_{ij}$ (or setting an aspired level) and $f_j^- = \max_i f_{ij}$ (or setting a tolerable level). Also, an original rating matrix and a normalized weight-rating matrix of risk are as follows:



$$r_{ij} = (|f_j^* - f_{ij}|)/(|f_j^* - f_j^-|) \quad (14)$$

where f_j^* denotes the aspired/desired level and f_j^- denotes tolerable level for each criterion, w_j denotes the weight of criteria j which obtained by AHP.

Step 2 Calculate S_i (concordance value) and R_i (discordance value) where i = 1, 2, …m by using Eqs. (15) and (16).

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \quad (15)$$

$$R_i = max_j\{ w_j r_{ij} \mid j = 1, 2, \ldots, n\} \quad (16)$$

Step 3: Calculate the index values R_i, where i = 1, 2, …m, by using Eq (17).

$$Q_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*) \quad (17)$$

where $S^* = \min_i S_i$ (or setting the best $S^* = 0$), $S^- = \max_i S_i$ (or setting the worst $S^- = 1$)

$R^* = \min_i R_i$ (or setting the best $R^* = 0$), R^- $\max_i R_i$ (or setting the worst $R^- = 1$) and v denotes as a weight for the strategy of maximum group utility, where $0 \leq v \leq 1$. The $1-v$ means the weight of the individual regret. If $v > 0.5$, this means a decision making process that could use the strategy of maximum group utility (i.e., if v is big, group utility is emphasized), or by consensus when $v \approx 0.5$, or by veto when $v < 0.5$.

Step 4: Rank the alternatives by sorting the values of $\{S_i$, Q_i and $R_i \mid i = 1, 2, \ldots, m\}$, in the decreasing order. If the alternative A_1 is proposed as a compromise, which is the first ranked by the measure min $\{R_i \mid i = 1, 2, \ldots, m\}$, the two conditions are satisfied, as follows.

T_1. Test the acceptable advantage: $Q(A_2) - Q(A_1) \geq DQ$, where A_2 is the alternative with the second position in the ranking list by Q_i, m is the number of alternatives and $DQ = 1/(m-1)$; where DQ is the acceptable advantage threshold. T_2. Test the acceptable stability in decision making: Alternative A_1 must also be the best ranked by $\{S_i$ or/ and R_i $i = 1, 2, \ldots, m\}$

If one of these conditions is not satisfied, then a set of compromise solutions is proposed, comprising of:

(1) Alternatives A1 and A2 if only condition T2 is not satisfied.

(2) Alternatives A1, A2, …AM, if condition T1 is not satisfied. AM is defined by the relation Q (AM) – Q (A1) < 1/(m-1) for maximum M (the positions of these alternatives are close).

3. An Empirical Study

3.1. Research framework

By employing the integrated methods of Fuzzy Delphi, AHP, and the VIKOR, this section explained the proposed model of analytical TICs evaluation criteria development in order to explore the relationship among critical factors and to rank the selected firms based on TICs. Main procedure was displayed in the following order (Fig 2).

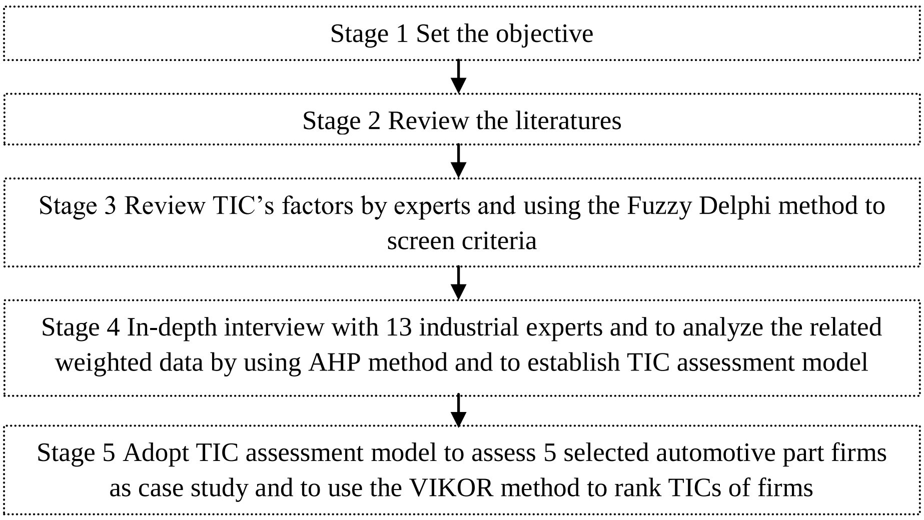


Fig. 2 The overview of methodological framework of TICs assessment

Table 2 TICs evaluation criteria extracted by literatures

Perspectives	Assessment Criteria	Description	Authors
Strategic Innovation planning	Vision for innovation	The existing strategic innovation planning of a firm conveys the clear vision, which can effectively communicate to all levels in organization.	[14], [49]
	Fit with business strategy	A firm has the existing strategic innovation planning, aligning and fitting with its business strategy.	[50], [51], [52], [53], [16]
	Fit with technology strategy	A firm has the existing strategic innovation planning, which is in line and fit with its technology strategy.	[54]
	Innovation road map in place	Firm's innovation roadmap provides a framework for future innovations in various key technological areas in order to ensure that investment in technological innovation and research is linked to the business' drivers and market trends.	[55], [56]
	Resource Commitment and Allocation	Firm's ability is required to appropriately acquire and allocate capital & technology	[57], [51], [3], [16]
Organizational innovation	Management Leadership and Commitment	Firm's top management has an active participation in decision-making process, which is related to technological innovation.	[57], [58], [59], [50], [52], [53], [60]
	Culture of innovation	Firm's culture in innovation addresses the managing in a set of widely adopted values, norms and attitudes towards organizational innovation	[61], [62], [16],[60],[63]
	Innovation Climate	The ability of firm includes the encouragement of an idea generation, risk taking, and the failure acceptance as a lesson to learn.	[14], [57]
	Design innovatory organizations	Design of the organizational structures of firm can promote the creativity.	[64], [65], [66]
	Response to change	Firm's capability involves in risk assessment, risk taking and responding to technological innovation change and adopting.	[67], [68], [59], [69], [70]
	Systematic external network collaboration and interfacing	Firm is able to transmit information, skills and technology, and to receive them from other departments, clients, suppliers, consultants, technological institutions, etc.	[71], [72], [73], [74], [75]
Collective learning and Absorptive Capacity	Internal knowledge development	Firm is able to internal knowledge development addresses management of the development and exploration of knowledge generated internally for organizational innovation.	[76], [52]
	External knowledge acquisition and exchange	Firm is enable to acquire and exchange the external knowledge addresses the management of an external information influencing organizational innovation in terms of competition, market, acquisition and the communication of technology.	[10], [77], [70], [78]
	Organizational learning	Firm's ability is required to create organizational learning addresses the management of learning and education mechanisms for organizational innovation.	[10]
	Knowledge communication and utilization	Firm is able to drive knowledge of communication mechanism and ability to utilize knowledge in order to enhance an organizational innovation.	[79], [80]
	Knowledge accumulation	Firm is able to pursue knowledge accumulation addresses management of a knowledge storage mechanism in managing the flow of information and technology and its effect on organizational innovation.	[61], [76]
R&D Capability	Seed for future technological development	Firm's R&D projects are enabling to be a seed for the future technology development for a firm.	[49], [81]
	Create new technological trajectories	Firm's R&D project can create the new technological trajectories.	[49], [81]
	Acceleration of technological learning	Firm's R&D project can accelerate the technological learning.	[49], [81]
	R&D project interfacing	Firm is able to integrate all phases of R&D process and to systematically connect to other functions e.g. engineering, production, marketing..	[82], [77], [83], [16]
Innovation Process	Employees participation process	Firm has an effective process to obtain the employees' participation in order to get an innovative idea.	[84], [85]
	Customer feedback process	Firm has an effective process for customer feedback to improve innovation.	[84], [85]
	Mechanism for continuous improvement	Firm has mechanism for continuous improvement which addresses management of revision and improvement projects that influence organizational innovation.	[76]
	Systematic idea management	Firm has an ability to create a systematic idea leading to the new source of ideas.	[86]
Robustness Product & Process Capability	Product Structure design	Firm is able to design a product structure, modularization and process compatibility.	[82], [87], [88], [89]
	Production Process design	Firm has an ability to design a manufacturing process including the assembly activities.	[87], [88], [89]
Innovation Transformation & Commercialization	Manufacturing Capability	Firm is able to transform R&D outputs into production and to acquire the innovation of an advanced manufacturing technology/ method.	[3], [11], [16], [50], [82], [83], [90],[91]
	Marketing Capability	Firm has an ability to public and sell products on the basis of the understanding of customers' needs, the competitive environment, costs and benefits, and the innovation acceptance.	[3], [11], [16], [62], [69], [70], [82], [83] [90],

Stage 1: To define the objective. Regarding to the importance of TICs, the objective of this research is to develop a model to measure and compare the firms' TICs in the same industry in order to improve their competitive advantages. The result of this study can be applied to generate guidelines for TICs appraisal of firms.

Stage 2: To review the literatures related to overall TICs assessment criteria. The literature reviews were performed to view the set of TICs evaluation criteria. The result showed the seven perspectives and the twenty-eight criteria with their sources and definitions, as presented in Table 2.

Stage 3: A decision group of six experts (2 of which were from academic institutions and the rest was from automotive parts firms) reviewed the above TIC's assessment perspective and criteria (from Table 2).

Table 3 The screened TICs criteria by Fuzzy Delphi method

Perspectives	**Criteria**	**Defuzzification (D_i)**	**Result (Accept/ Reject)**
Strategic innovation Planning Capability	Vision for innovation	6.27*	***Rejected***
	Fit with business strategy	5.38*	***Rejected***
	Fit with technology strategy	8.87	Accepted
	Innovation road map in place	8.36	Accepted
	Resource commitment and allocation	8.23	Accepted
Organization Innovation Capability	Management leadership and commitment	9.02	Accepted
	Culture of innovation	8.24	Accepted
	Innovation Climate	5.72*	***Rejected***
	Design innovatory organization	8.44	Accepted
	Response to change	8.08	Accepted
	Systematic external network & collaboration & interfacing	8.18	Accepted
Collective Learning and Absorptive Capability	Internal knowledge development	9.30	Accepted
	External knowledge acquisition	8.54	Accepted
	Organization learning	8.72	Accepted
	Knowledge communication and utilization	7.58*	***Rejected***
	Knowledge accumulation	8.85	Accepted
R&D and Technology Development Capability	Seed for future technological development	9.07	Accepted
	Create new technology trajectory	8.86	Accepted
	Acceleration of technology learning	8.27	Accepted
	R&D project interfacing	5.87*	***Rejected***
Innovation Process Capability	Employee participation process	8.28	Accepted
	Customer feedback process	8.18	Accepted
	Mechanism for continuous improvement	8.74	Accepted
	Systematic idea management	7.48*	***Rejected***
Robustness Product & Process Design Capability	Product structure design	8.65	Accepted
	Production process design	8.33	Accepted
Innovation Transformation & Commercialization Capability	Manufacturing capability	8.21	Accepted
	Marketing capability	8.36	Accepted

[*] Remark: If the value of defuzzification (D_i) is less than the threshold value ($\alpha < 8.0$), then reject the criterion

Each expert would express their opinions on the evaluation scores in term of linguistic variables in interview questionnaire, which would be converted to Triangular fuzzy numbers as in Table 1. Then, the expert confirmed the model of TICs assessment, including the general outlined TICs evaluation criteria classification to establish the proper criteria and the hierarchy structure. Thereafter, the data gathered from experts was processed by using the Fuzzy Delphi method in order to screen the appropriated criteria. In this stage, total 6 criteria were rejected because their defuzzification values (Di) were lower than the threshold value (α=8). Then, the remaining of 22 criteria under 7 perspectives was accepted. The results of the criteria screening and the proposed TICs evaluation model were shown in Table 3 and Fig. 3 respectively.

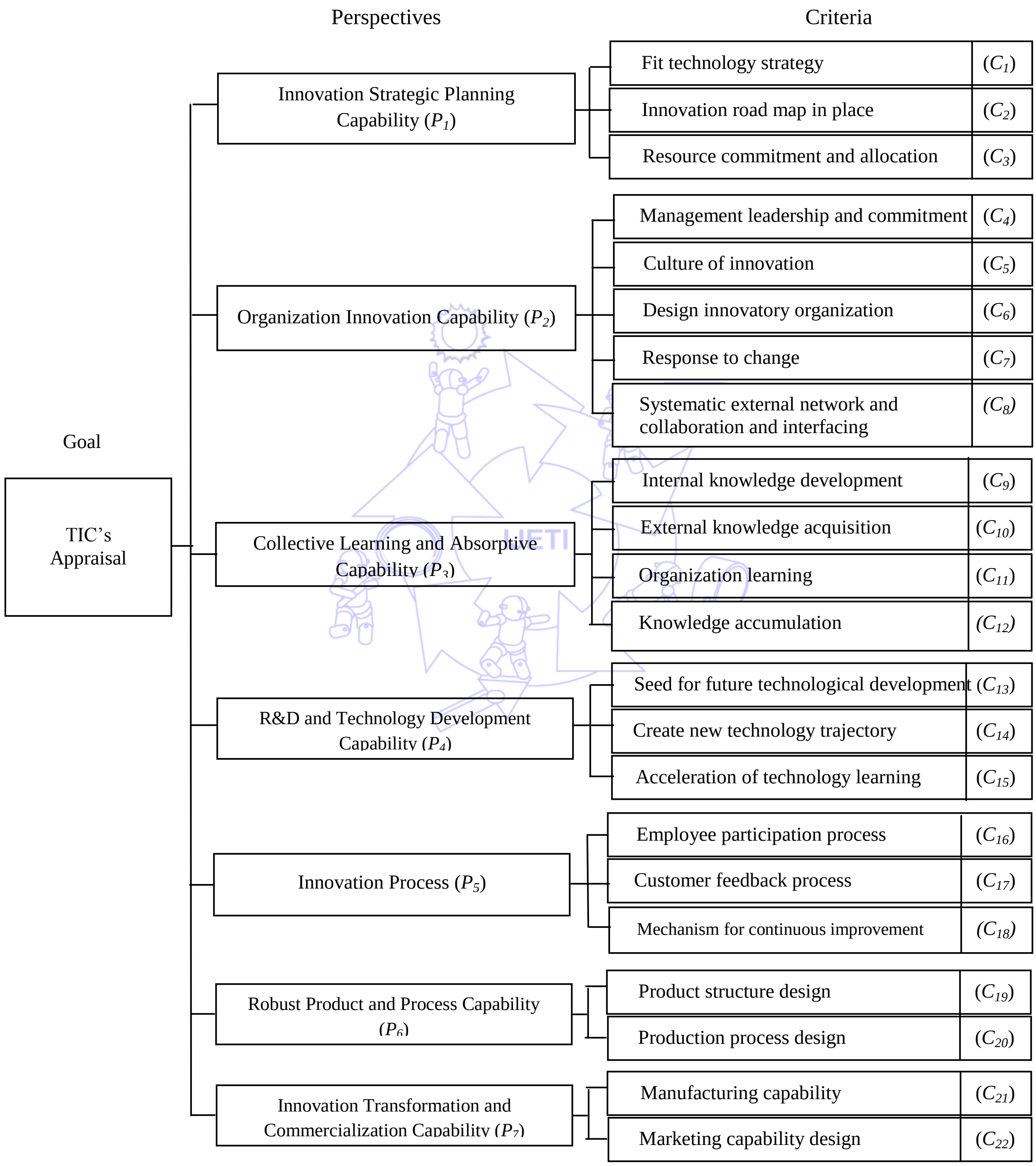


Fig. 3 Proposed TIC assessment model

Stage 4: In-depth interview session with the thirteen selective industrial experts by utilizing the designed questionnaire. These experienced experts are at the top and middle management levels and their functionally involved in innovation development in the firms. These firms valued the importance of R&D development, and they have also acquired the award of Thailand's Outstanding Innovative Automotive Parts Company in year 2010. When the experts provided the weight on the basis of pair-wise comparison, the AHP method is used to calculate the relative important weight among perspective/ criteria, by using Expert Choice version 11.0 software. The result was shown in Table 4. The top five criteria were ranked by the important global weights of TICs evaluation criteria, which were C_1-Fit with technology strategy (0.260), C_{11}-Organization learning (0.118), C_2-Innovation road map in place (0.099), C_{15}-Acceleration of technology learning (0.087) and C_5-Culture of innovation (0.057). All consistency ratio (CR) were less than 0.1.

Table 4 The final relative weights of criteria based on pair-wise comparison by AHP method

Perspectives	Criteria	Local weights	Global weights
Innovation Strategic Planning Capability (P_1)	Fit with technology strategy (C_1)	0.625	0.260
	Innovation road map in place (C_2)	0.238	0.099
	Resource commitment and allocation (C_3)	0.136	0.057
Organization Innovation Capability (P_2)	Management leadership and commitment (C_4)	0.312	0.043
	Culture of innovation (C_5)	0.407	0.057
	Design innovatory organization (C_6)	0.181	0.025
	Response to change (C_7)	0.056	0.008
	Systematic external network & collaboration & interfacing (C_8)	0.045	0.006
Collective Learning and Absorptive Capability (P_3)	Internal knowledge development (C_9)	0.185	0.033
	External knowledge acquisition (C_{10})	0.060	0.011
	Organization learning (C_{11})	0.660	0.118
	Knowledge accumulation (C_{12})	0.095	0.017
R&D and Technology Development Capability (P_4)	Seed for future technological development (C_{13})	0.117	0.017
	Create new technology trajectory (C_{14})	0.268	0.038
	Acceleration of technology learning (C_{15})	0.614	0.087
Innovation Process Capability (P_5)	Employee participation process (C_{16})	0.229	0.015
	Customer feedback process (C_{17})	0.075	0.005
	Mechanism for continuous improvement (C_{18})	0.696	0.046
Robust Product and Process Capability (P_6)	Product structure design (C_{19})	0.857	0.029
	Production process design (C_{20})	0.143	0.005
Innovation Transformation & Commercialization Capability (P_7)	Manufacturing capability (C_{21})	0.750	0.017
	Marketing capability (C_{22})	0.250	0.006

Remark: Inconsistency index = 0.08 (desirable value to be less than 0.1)

Stage 5: Rank and select the appropriate alternative by using the VIKOR method. The proposed TICs model was illustrated throughout the five oriented technological innovation of Thai automotive parts firms, as a case study. A group of thirteen experts provided the rating score of TICs assessment, ranging from 0 (the worst) to 100 (the best) based on their perceptions on TICs performance of each selected firm. The geometric mean of scores gathered from all experts was then computed as shown in Table 5. These scores were normalized to present the performance gap of each selected firm, which was calculated by using Eq.(14). The results were shown in Table 6. The multivariate observation of many criteria could be simply represented by the radar chart, as displayed in Fig.4, which showed each TIC performance variance score of five selected firms. In this research, the v value of VIKOR was set at 0.5 as considering the basis of the majority and simultaneously the lowest opposed opinion. The index values of S_i, R_i, and Q_i were computed by using formulas as Eq.(15), Eq.(16) and Eq.(17), respectively, as illustrated in Table 7 and Table 8. It was also found that based on the ranking of Q_i, firm A had the best TICs performance (the smaller the value is, the better it is).

The compromise solution was thereafter tested by two following conditions in order to obtain the satisfaction result. The first test (T_1) was to test a condition of the acceptable advantage. The numbers of alternatives empirically analyzed in this study are five firms; therefore, the acceptable advantage threshold (DQ) is 1/ (5-1) = 0.25. The result of $T_1$was accepted because the value of (Q(B) - Q(A)) (or 0.341 - 0.000 = 0.341) was higher than DQ (0.25). And the second test (T_2) was to test a condition of the acceptable stability in decision making. The result of T_2 was shown that the ranking of five firms were still unchanged (firm A, B, C, D, E) based on the index values of S_i, R_i, and Q_i (the smaller, the better). Since the results of analysis obtained from two testing conditions (T_1 and T_2) were satisfied; therefore the TICs assessment rankings were acceptable, which firm A is considered as the compromise solution with the best overall performance, followed by firms B, C, E, and D, respectively.

Table 5 Geometric mean of TICs evaluation score for the five automotive parts firms

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}
Firm A	91.91	94.26	94.53	89.55	91.99	95.63	77.81	88.99	94.98	91.35	93.63	92.36	94.81	90.79	91.41	91.82	78.83	85.06	92.90	90.99	92.45	91.54
Firm B	85.90	88.44	88.77	82.71	85.63	89.36	66.91	78.05	91.08	80.62	84.06	81.91	86.16	86.77	85.34	82.98	66.24	72.32	83.63	80.90	81.88	83.27
Firm C	84.17	86.27	84.63	81.81	83.08	87.99	86.45	77.08	82.36	83.17	76.99	84.63	82.90	84.09	82.79	87.90	86.00	87.00	87.09	86.09	80.08	78.08
Firm D	70.54	77.54	77.54	84.54	81.45	83.45	89.45	74.54	72.08	83.08	68.45	71.45	71.90	70.45	64.45	66.45	63.45	75.45	63.45	91.54	75.45	77.45
Firm E	84.54	84.09	9.90	80.62	83.62	87.90	82.62	72.90	76.45	86.45	72.45	79.54	77.45	72.54	71.00	82.08	88.54	85.45	68.45	91.54	75.45	77.45

Table 6 Normalized performance gap between status quo and ideal point of fives automotive part firms

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}
Firm A	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.13	0.00	0.05	0.00	0.00
Firm B	0.28	0.35	0.34	0.77	0.60	0.51	1.00	0.68	0.17	1.00	0.38	0.50	0.38	0.20	0.23	0.35	0.89	1.00	0.31	1.00	0.62	0.59
Firm C	0.36	0.48	0.58	0.87	0.85	0.63	0.13	0.74	0.55	0.76	0.66	0.37	0.52	0.33	0.32	0.15	0.10	0.00	0.20	0.51	0.73	0.96
Firm D	1.00	1.00	1.00	0.56	1.00	1.00	0.00	0.90	1.00	0.77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	1.00	0.00	1.00	1.00
Firm E	0.34	0.61	0.86	1.00	0.79	0.63	0.30	1.00	0.81	0.46	0.84	0.61	0.76	0.90	0.76	0.38	0.00	0.11	0.83	0.00	1.00	1.00
Average	0.39	0.48	0.55	0.63	0.64	0.55	0.39	0.66	0.50	0.59	0.57	0.49	0.53	0.48	0.46	0.37	0.47	0.40	0.46	0.31	0.67	0.70

Table 7 The multiple of normalized performance gap and AHP weight

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}
AHP Weight	0.260	0.099	0.057	0.043	0.057	0.025	0.008	0.006	0.033	0.011	0.118	0.017	0.017	0.038	0.087	0.015	0.005	0.046	0.029	0.005	0.017	0.006
Firm A	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.000	0.000	0.000	0.000
Firm B	0.073	0.034	0.019	0.033	0.034	0.013	0.008	0.004	0.006	0.011	0.045	0.008	0.006	0.008	0.020	0.005	0.004	0.046	0.009	0.005	0.011	0.004
Firm C	0.094	0.047	0.033	0.037	0.048	0.016	0.001	0.004	0.018	0.008	0.078	0.006	0.009	0.013	0.028	0.002	0.001	0.000	0.006	0.003	0.012	0.006
Firm D	0.260	0.099	0.057	0.024	0.057	0.025	0.000	0.005	0.033	0.008	0.118	0.017	0.017	0.038	0.087	0.015	0.005	0.036	0.029	0.000	0.017	0.006
Firm E	0.090	0.060	0.049	0.043	0.045	0.016	0.002	0.006	0.027	0.005	0.099	0.010	0.013	0.034	0.066	0.006	0.000	0.005	0.024	0.000	0.017	0.006

Remark: * indicated the top three largest performance gap of criteria for each firm

Table 8 The result index values of S_i, R_i and Q_i with the ranking of the five selected automotive parts firms (ν = 0.5)

	S_i		R_i		Q_i	
	Values	Ranking	Values	Ranking	Values	Ranking
Firm A	0.012	1	0.006	1	0.000	1
Firm B	0.407	2	0.073	2	0.341	2
Firm C	0.471	3	0.094	3	0.417	3
Firm D	0.954	5	0.260	5	1.000	5
Firm E	0.623	4	0.099	4	0.508	4

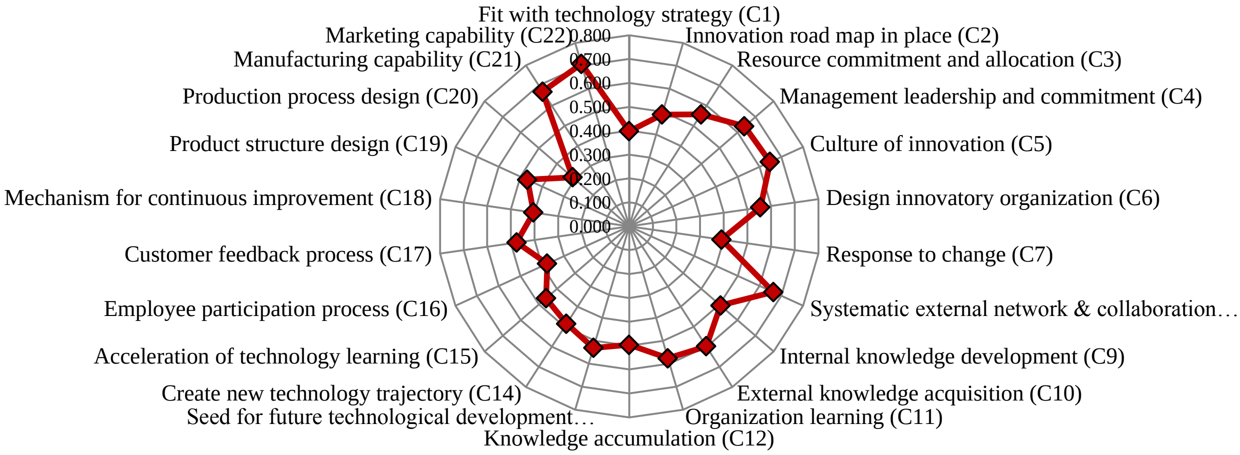


Fig. 4 Average TIC performance variance scores of 22 criteria for five selected firms

3.2. Sensitivity Analysis

A sensitivity analysis was performed in order to test the robustness of the preference ranking results among the alternatives and to enhance more understanding of the relationships between input and output variables in a proposed model. The sensitivity analysis was measured by monitoring changes in the weights of the decision-making strategy "the maximum group utility" or "the majority of criteria (v)", where 1- v was the weight of the individual regret. A compromise could be selected with "voting by majority" (v < 0.5), with "consensus" (v = 0.5), or with "veto" (v < 0.5). In this study, the sensitivity analysis was performed with the changes of the weights level of v =0.3, and 0.7. The VIKOR index Q_i was obtained by weighting the utility and regret measures of each alternative.

By selecting v = 0.3, the ranking result of the index values of S_i, R_i, and Q_i was presented in the following orders: firm A, B, C, E, and D, as displayed in Table 9. The testing of the accepted advantage condition (T_1) was satisfied because the value of Q(B) – Q(A) was larger than DQ (0.372 - 0.000 = 0.372 > 0.25). Simultaneously, the testing of the acceptable stability in decision making (T_2) was also presented in a satisfaction with unchanged of the ranking order. Therefore, based on v = 0.3, firm A was considered in the best ranked or as a compromise alternative.

By selecting v = 0.7, the result in Table 10 was shown the rankings of the index values of S_i, R_i, and Q_i as follows: firm A, B, C, E, and D. Two testing conditions of T_1 and T_2 under v = 0.7 were also accepted because Q(B) – Q(A) was larger than DQ (0.312 - 0.000 = 0.312 > 0.25). And the acceptable stability in decision making was satisfied. Hence, for v = 0.7, firm A was also a compromise solution with the best ranked.

In conclusion, the ranking orders of the five firms were still consistent despite changing the values of weights level of v, based on the value of Q_i as illustrated in Fig. 5. The results of VIKOR evaluation value indicated that firm A had the best TICs performance (the smaller the value is, the better it is). In contrast, firm D had the worst TICs performance.

In pursuance to the multiply between normalized performance gap and AHP weight in Table 7, firm A was regarded as the first rank among the five firms regarding to the closeness to ideal point of each criterion. Moreover, the following firms were also implied to improve in the context of management: firm B was recommended to improve the top three important criteria i.e. Fit with technology strategy (C_1), Mechanism for continuous improvement (C_{18}), and Organization learning (C_{11}); Firm C was recommended to improve the three most important criteria i.e. Fit with technology strategy (C_1), Culture of innovation (C_5), and Innovation road map in place (C_2); Firm D was needed to modify the three most essential criteria i.e. Fit with technology strategy (C_1), Organization learning (C_{11}), and Acceleration of technology learning (C_{15}); and the criteria needed to have the most improvement in firm E were Organization learning (C_{11}), Fit with technology strategy (C_1), and Acceleration of technology learning (C_{15}).

Table 9 VIKOR ranking of the five selected automotive parts firms for v = 0.3

	S_i		R_i		Q_i	
	Values	Ranking	Values	Ranking	Values	Ranking
Firm A	0.012	1	0.006	1	0.000	1
Firm B	0.407	2	0.073	2	0.372	2
Firm C	0.471	3	0.094	3	0.444	3
Firm D	0.954	5	0.260	5	1.000	5
Firm E	0.623	4	0.099	4	0.564	4

Table 10 VIKOR ranking of the five selected automotive parts firms for v = 0.7

	S_i		R_i		Q_i	
	Values	Ranking	Values	Ranking	Values	Ranking
Firm A	0.012	1	0.006	1	0.000	1
Firm B	0.407	2	0.073	2	0.310	2
Firm C	0.471	3	0.094	3	0.389	3
Firm D	0.954	5	0.260	5	1.000	5
Firm E	0.623	4	0.099	4	0.451	4

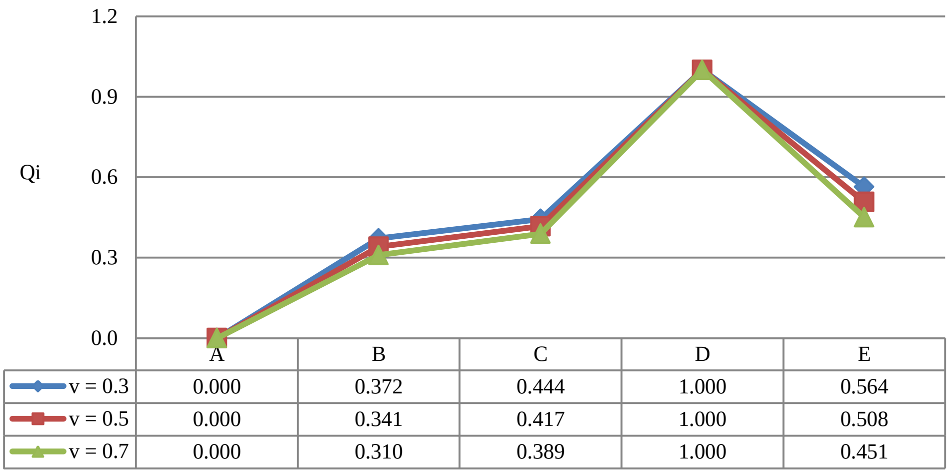


Fig. 5 The sensitivity analysis of VIKOR (v = 0.3, 0.5, and 0.7)

4. Conclusion

There are different approaches to evaluate the technological innovation capabilities of firms, including the efficient ranking. For this paper, a multi-criteria decision making approach by the integration methods of Fuzzy Delphi, AHP and VIKOR were proposed to develop the evaluation of TIC framework and rank the selected Thai automotive parts firms based on each TICs attribution. The knowledge and experiences extracted from Thai industrial experts' panel is also by mean of the most effective practices for Thai automotive parts firms in order to improve the rank based on TICs evaluation criteria. This TICs criteria evaluation framework will be a useful solution to assist the management in the self-assessment that can indicate the most important criteria which are needed to be improved. It also enables the third independent parties e.g. auditing or consulting firms to apply model as a systematic tool in their auditions or consultations because it can render the better solution. Additionally, other related industries can use this model by adjusting the specific experts' judgments to suit each unique characteristics of the specific industry. Hence, the improvement of TICs will be one of the key drivers when enterprises are facing the rapid changes in technological and global economic environment entering AEC in 2015 in order for the Thai industries to enhance competitive advantages and long-term sustainable growth. The ranking result among the firms would be useful as a benchmark for other firms' direction to improve their competitiveness. There might been some limitations of this study that the assumption of AHP method was relied on the independent criteria and hierarchy structure of decision making model; despite there are the interdependent relationship and feedbacks among criteria in certain practices. In this sense, for future research, it could apply the Analytical Network Process (ANP) method or DEMATEL based ANP method in order to solve the interrelationship among criteria.

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