An Application of Fuzzy numbers in Quantitative Strategic Planning Method with MCDM

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Abstract

The Quantitative Strategic Planning Matrix (QSPM) is a useful tool to prioritize strategies at any level including corporate, business and functional. The ratings and attractive scores used in QSPM, however, require judgmental decisions and should be based on expert's opinion to ensure the applicability of chosen strategies. A fuzzy multi-criteria decision making method is proposed in this paper with the goal of improving the output of conventional QSPM by allowing the experts to employ linguistic terms (qualitative data) in their judgments. A TOPSIS MCDM (Technique for Order Preference by Similarity to Ideal Solution and Multi criteria Decision Making) index is also adapted to the fuzzy QSPM in finding the sum total attractive scores (TAS) of strategies. As a case study, the proposed method has been applied for strategy prioritization in a Tile Company. The results have been verified with expert knowledge and showed an improvement compared to the non-fuzzy QSPM.

Keywords
Fuzzy numbers, MCDM, QSPM, Fuzzy QSPM

1. Introduction

Strategic management is the art of managing organizations in maximizing the potential of achieving business objectives. It attempts to organize qualitative and quantitative information, allowing effective decisions to be made under different conditions of uncertainty. Strategic management consists of three distinct stages: strategy formulation, strategy implementation, and strategy evaluation. The well-known SWOT (strength, weakness, opportunity and threat) analysis and QSPM (Quantitative Strategic Planning Matrix) fit into the first stage and have been proven to be excellent tools for deciding among feasible alternative strategies (Chin and Klein, 1997, Dyson, 2004, Huan-Jyh and Shihb, 2006, Kahraman 2008, Liang, 1999, Mahapatra, and Roy 2009, Zanakis, et al, 1998). More specifically, QSPM is a tool for assimilating and prioritizing key internal, external, and competitive information needed for devising effective strategic plans (Meredith et al, 2009). Deciding on relative importance of various facts, figures, trends, and data among feasible alternative strategies is critical in arriving at solutions that provide major competitive advantages to a firm. MCDM (Multi-Criteria Decision Making) is one of the known branches of decision science and is commonly used in comparing finite sets of alternatives/scenarios. In management planning processes, MCDM is the study of methods and procedures used to accommodate multiple, often conflicting, decision criteria (Buyukozkan and Ersoy, 2009). While the conventional QSPM has proven to be a useful tool for strategic planning in several organizations, incorporating intuitive (human) judgments with crisp numbers can affect the precision of decision outputs unfavorably. A method of using fuzzy numbers instead of crisp numbers in QSPM along with an MCDM technique is proposed in this paper to address the above shortcoming. After presenting a more detailed background on SWOT analysis, MCDM and QSPM and fuzzy numbers (Section 2), the proposed mixed-methodology is described in Section 3. An illustrative case study and its validation are given in Section 4. Conclusions are included in Section 5.

2. Background

2.1. SWOT analysis

SWOT analysis is a tool in strategy formulation by identifying the strengths, weaknesses, opportunities and threats of a given organization. Several studies have been performed on the SWOT analysis in conjunction to improving the classical strategic planning and management methods. Ozcan and Deha (2008) examined the application of SWOT analysis to formulate strategies that are related to the safe carriage of bulk liquid chemicals in maritime tankers. A qualitative investigation using SWOT analysis was implemented for the ships carrying liquid chemicals in bulk. The authors developed a set of operation plans by means of converting possible threats into opportunities, and changing weaknesses into strengths. Chang and Huang (2006) presented a Quantified SWOT analytical method which could provide more detailed data for SWOT analysis. They adopted the concept of multiple attribute decision making to use a multi-layer scheme to simplify complicated decision problems, and thus were able to perform SWOT analysis in several enterprises simultaneously. Dyson (2004) described another application of SWOT analysis to strategy formulation and its incorporation into the strategic development process. Their method could link SWOT analysis to resource-based planning through an iterative process within an overall planning process. Kahraman1 (2008) proposed a method to evaluate different alternative strategies for e-government applications in Turkey. They used the SWOT in conjunction with the analytic hierarchy process (AHP) to prioritize their strategies.

2.2. Multiple criteria decision making (MCDM)

MCDM models normally consist of a finite set of alternatives among which a decision-maker (DM) has to rank and decide. Often a finite set of criteria need also to be weighted according to their relative importance. One main goal of MCDM is to aid DMs in integrating objective measurements with value judgments that are not based on individuals' opinion but on collective group ideas (Buyukozkan and Ersoy, 2009). In a typical MCDM, a decision matrix consisting of ratings of alternatives with respect to each criterion is used. The evaluation ratings are, then, aggregated taking into account the weights of criteria and a global evaluation score for each alternative is found. There are several methods of MCDM for decision making such as simple additive weighting (SAW), multiplicative exponential weighting (MEW), the technique for order preference by similarity to ideal solution (TOPSIS), and the analytic hierarchy process (AHP) (Ozcan and Deha 2008, Xidonas et al, 2010). Several useful fuzzy MCDM methods have also been developed (Buyukozkan and Ersoy, 2009, Chin, and Klein, 1997, Lee and Lin 2008, Triantaphyllou and Lin 1996). Using a fuzzy MCDM, assessing the importance of criteria and the ratings of alternatives with respect to each criterion can be estimated according to linguistic variables such. Huan-Jyh and Hsu-Shih (2006) proposed a hybrid fuzzy MCDM model for strategic vendor selection. In their method, the vendor evaluation problem was formulated by a combined use of MCDM and a five-step hybrid process through an analytic network process (ANP). Dursun and Karsak (2010) described a fuzzy MCDM approach for personnel selection in which a fuzzy algorithm using the principles of fusion of fuzzy information, 2-tuple linguistic representation model, and TOPSIS is developed. Their proposed method is particularly useful to manage information assessed by both linguistic and numerical scales where multiple information sources are present.

2.3. QSPM method

QSPM is a high-level strategic management approach for evaluating possible strategies and eventually comparing alternative course of actions. The basic components of QSPM are: (1) key factor statements, (2) strategies to be evaluated, (3) ratings, (4) attractive scores, (5) total attractive scores and (6) sum total attractive scores. Conceptually, the QSPM determines the relative attractive of various strategies based on key internal and external factors. The relative attractive of each strategy is computed by determining the cumulative impact of each key internal and external factor. Any number of alternative strategies can be included in QSPM. Nouri et al (2008) applied QSPM for the evaluation of environmental management of coastal regions in the Caspian Sea. They developed 27 strategies using SWOT analysis and ranked them using a QSPM method. The result of their QSPM matrix was used to find the strategic position of coastal regions. Wang et al (2008) analyzed a set of strengths and weaknesses during a regional planning with and without the Hebei Province. They developed 8 feasible strategic projects and using QSPM selected top strategic projects. They concluded that Hebei Province should make more contributions to the adjustment of the economic structure and cooperation within Beijing, Tianjin and Hebei regions. Rafee et al (2008) discussed the development of strategic management for earthquake debris in big cities. They used SWOT analysis to assess actual and potential debris management capacities. Results pointed out that the most important strategies include an accurate estimation of volume, weight and type of earthquake debris; reinforcement of the present structures; proper design of structures under construction; utilization of experience from other earthquake instances; recycling and reuse of debris and construction wastes; and identification of the temporary debris depot sites within the city.

2.4 Fuzzy sets

In the real world, decision makings often take place in fuzzy environments/under judgmental uncertainties. Fuzzy sets were introduced by Zadeh (1965) as an extension of the classical notion of sets. Since then, the fuzzy decision methods have been used in a wide range of domains where input data are incomplete or imprecise. Mahapatra and Roy (2009) applied a fuzzy method for single and multi container maintenance under a limited time interval of interest. They solved their fuzzy models by a geometric programming technique, which was implemented through three different operators, maximin, max-average mean, and max-geometric mean. Eventually, these operators were applied in the single-container maintenance model in a fuzzy environment. Lee et al (1998) presented a mechanism of integrating fuzzy cognitive map knowledge within strategic planning simulations, where the fuzzy cognitive maps (FCMs) help the decision maker understand complex dynamics between certain strategic goals and related environmental factors. Lee and Lin (2008) proposed a fuzzy SWOT method to evaluate the competitive environment of different transshipment locations as international distribution centers (IDC) in the Pacific-Asian region. Their work showed that the fuzzy method could identify more competitive locations in comparison to some other non-fuzzy methods.

3. Proposed Methodology: A Fuzzy QSPM with MCDM

Priority setting of business strategies is perhaps most critical when resources are scarce or limited for a company. Resources may be limited in financial, manpower, production, transportation, distribution, etc. As mentioned in the background section, different methods have been developed to help decision makers prioritize the business strategies (Chin, and Klein, 1997, Dyson 2004, Huan-Jyh and Shihb, 2006, Kahraman 2008, Liang, 1999, Mahapatra, and Roy 2009, Zanakis, et al, 1998). Although the QSPM is a high-level strategic management approach for evaluating possible strategies, it still needs improvements. Particularly, its rating method and the attractive scores are based judgmental decisions in practice, even though ideally they should be based on objective information. In order to accommodate this requirement in the conventional QSPM, this section includes a method of Fuzzy Quantitative Strategic Planning Matrix (FQSPM) where fuzzy numbers are used to calculate total attractive scores instead of crisp numbers. In additions, an MCDM method is employed to aid the DMs in integrating objective measurements with value judgments that are normally based not on individual opinions but on collective group ideas.
The proposed methodology is schematically shown in Figure 1.

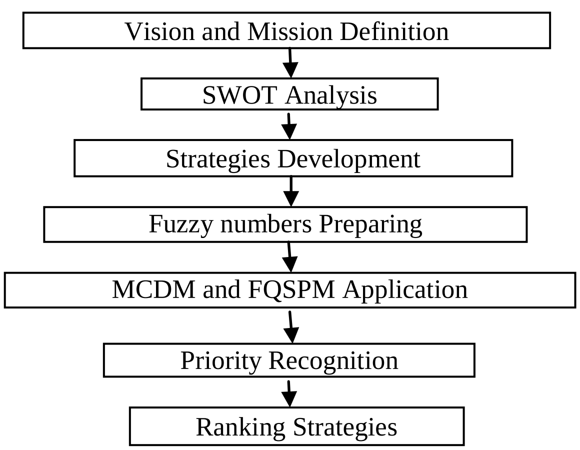

Figure 1: Ranking strategy using Fussy QSPM (FQSPM)

Formulating strategies begins with the development of a clear vision and mission, followed by internal and external assessments, which leads to establishing long term objectives, and finally generating and deciding among specific strategies. Strategies are generated using SWOT and need to be prioritized. In summary, the following steps are taken:

Step 1) Determining company's vision and mission
Step 2) Evaluating company's external and internal factors
Step 3) Performing SWOT analysis and developing company's strategies (alternatives)
Step 4) Aggregating expert opinions using fuzzy numbers
Step 5) Determining criteria weights
Step 6) Calculating fuzzy weighted numbers and applying MCDM
Step 7) Ranking and justifying the alternatives with fuzzy QSPM

Regarding the MCDM part, with m alternatives, n criteria and k decision makers, the decision problem can be expressed as:

$$F = \begin{array}{c|c|c|c|c|} & C_1 & C_2 & \ldots & C_n \\ \hline A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ \hline A_2 & x_{21} & \cdots & \cdots & x_{2n} \\ \hline \vdots & \vdots & \vdots & \vdots & \vdots \\ \hline A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \\ \hline \end{array} \quad . \qquad (1)$$

where, F represents the fuzzy decision matrix with alternatives A_i (i=1,2,…,m) and the criteria C_j , (j=1,2,…,n). Aggregated judgments x_{ij} are calculated as follows:

$$x_{ij=} \ (1/k)\ (x_{ij}^1 + x_{ij}^2 \ldots + x_{ij}^k) \qquad (2)$$

Where x_{ij}^k is the fuzzy judgment of expert k and can be represented using a triangular fuzzy numbers as:

$$x_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k) \qquad (3)$$

Next, a normalization of data can be performed using Eqs. (4) and (5).

$$N = \begin{bmatrix} R_{11} & \cdots & R_{1m} \\ \vdots & \ldots & \vdots \\ R_{n1} & \cdots & R_{nm} \end{bmatrix} \qquad (4)$$

$$\text{Where } R_{ij} = \left(\frac{a_{ij}}{c_j^b}, \ \frac{b_{ij}}{c_j^b}, \ \frac{c_{ij}}{c_j^b}\right) \text{ and } c_j^b = Max(c_{ij}),\ i=1, 2\ldots m \qquad (5)$$

Considering w_j as the weight of criterion j, the weighted normalized fuzzy decision numbers P_{ij} can be calculated as:

$$P_{ij} = R_{ij} \times w_j \qquad (6)$$

The next step is calculating the distance of alternatives. The distance between two triangular fuzzy numbers of $N_i(a_1, a_2, a_3)$ and $N_j(b_1, b_2, b_3)$ is shown in Figure 2 and can be calculated as follows.

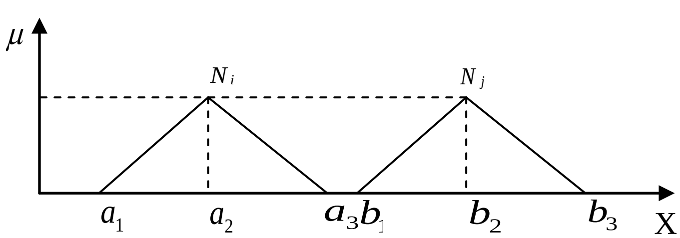

Figure 2: Distance of two fuzzy numbers N_i and N_j

$$S(N_i, N_j) = (1/2)\,[S_L(N_i, N_j) + S_R(N_i, N_j)] \qquad (7)$$

Where, $S_L(N_i, N_j)$ and $S_R(N_i, N_j)$ are:

$$S_L(N_i, N_j) = S_L(N_i, 0) - S_L(N_j, 0) = (\frac{a_1 + a_2}{2} - \frac{b_1 + b_2}{2} \tag{8}$$

$$S_R(N_i, N_j) = S_R(N_i, 0) - S_R(N_j, 0) = \frac{a_2 + a_3}{2} - \frac{b_2 + b_3}{2} \tag{9}$$

The distance between N_i and N_j follows:

$$S(N_i, N_j) = \frac{1}{2}\left[\left(\frac{a_2 + a_3}{2} - \frac{b_2 + b_3}{2}\right)\right] + \left[\left(\frac{a_1 + a_2}{2} - \frac{b_1 + b_2}{2}\right)\right] = \frac{1}{2}\left[\frac{a_1 + 2a_2 + a_3}{2} - \frac{b_1 + 2b_2 + b_3}{2}\right] = \frac{(a_1 + 2a_2 + a_3) - (b_1 + 2b_2 + b_3)}{4} \tag{10}$$

Note that S (N_i, N_j) is defined as the algebraic distance from N_i to N_j which can be positive, negative or zero. Finally to rank each alternative, a fuzzy TOPSIS (MCDM) perormance index can be adapted as:

$$\text{TOPSIS Total Attractive Score}_i = \frac{s_i^-}{s_i^+ + s_i^-},\ i=1, 2 \ldots m \tag{11}$$

Where,

$$S_i^+ = \sum_{j=1}^{n} S(P_{ij}, P_i^+), i = 1,2, \ldots m \tag{12}$$

$$S_i^- = \sum_{j=1}^{n} S(P_{ij}, P_i^-), i = 1,2, \ldots m \tag{13}$$

$$P_i^+ = (1,1,1) \ \&\ P_i^- = (0,0,0) \tag{14}$$

4. An Illustrative Example

To examine the proposed method, priority determinations of strategies for a Tile Company are examined using both the conventional QSPM and the proposed FQSPM.

Tile Company began operations in 1979, producing three classes of tiles. The vision and mission of the company are defined as follows.

Vision: “To be the first Tile Company that realizes the need to thrive in an extremely competitive marketplace, we plan to continue our growth by focusing on our customer satisfaction.”

Mission: “To become the first name in commercial and institutional interiors our focus is on product and service through constant emphasis on process quality and engineering, which we will combine with careful attention to our customers’ needs so as always to deliver superior value to our customers, thereby maximizing all stakeholders’ satisfaction.”

The potential strategies of the company are developed by a group of expertise using SWOT analyses and are shown in Table 1.

Table 1: Developed strategies for the Tile Company

A.	Improving existing production line
B.	Adding new production line
C.	Forward integration
D.	Backward integration
E.	Horizontal integration
F.	Concentric diversification

4.1 Conventional QSPM

The conventional QSPM method was described in Section 2.3. To brief the paper, only two alternative strategies are considered here for illustrative purposes: A) Improving existing production line and B) Adding a new production line. The Tile Company's QSPM is shown in Table 2. Affective factors are extracted from the company's underlying external and internal assessments. The weights and attractive scores (1, 2, 3 or 4) are provided by a group of five experts at the company, where 4 is the best and 1 is the least attractive score.

Table 2: Tile Company's QSPM

Strategies	SWOT	Affective Factors (criteria)		Weight	Attractive Score	Weighted Attractive Score
Improving existing production line	Strengths	c_1	Consistent and high product quality	0.05	3	0.15
		c_2	Reputation for innovative design	0.07	4	0.28
		c_3	experience in exporting to other countries	0.12	2	0.24
	Weaknesses	c_4	Insufficient cash flow	0.08	1	0.08
		c_5	Problems with on-time delivery	0.07	4	0.28
		c_6	Relatively high costs of labor	0.15	4	0.60
	Opportunities	c_7	Demand increasing by %10	0.09	2	0.18
		c_8	luxurious products	0.11	4	0.44
		c_9	Easier access to markets in accession	0.03	4	0.12
	Threats	c_{10}	Increased competition of producers	0.12	3	0.36
		c_{11}	From countries with lower costs of labor	0.07	4	0.28
		c_{12}	Recession in many countries markets	0.04	3	0.12
	Total Attractive Score for strategy A					**3.13**
Adding new production line	Strengths	c_1	Consistent and high product quality	0.05	4	0.20
		c_2	Reputation for innovative design	0.07	2	0.14
		c_3	experience in exporting to other countries	0.12	4	0.48
	Weaknesses	c_4	Insufficient cash flow	0.08	2	0.16
		c_5	Problems with on-time delivery	0.07	4	0.28
		c_6	Relatively high costs of labor	0.15	3	0.45
	Opportunities	c_7	Demand increasing by %10	0.09	4	0.36
		c_8	luxurious products	0.11	4	0.44
		c_9	Easier access to markets in accession	0.03	1	0.03
	Threats	c_{10}	Increased competition of producers	0.12	4	0.48
		c_{11}	From countries with lower costs of labor	0.07	4	0.28
		c_{12}	Recession in many countries markets	0.04	4	0.16
		Total Attractive Score for strategy B				**3.46**

The QSPM sum total attractive score of 3.13 for the strategy A versus 3.46 for the strategy B indicates that strategy B (adding new production line) has the first priority for the Tile Company (Table 3). The magnitude of difference between the two sum total attractive scores gives an indication of the relative attractive of one strategy over another. This can be vital information for a firm in deciding between strategies.

Table 3: Priorities of the strategies for Tile Company using the conventional QSPM method

Strategies	Total Attractive Score	priority
B) Adding new production line	3.46	1
A) Improving existing production line	3.13	2

4.2. Fuzzy QSPM with MCDM

The Tile Company's fuzzy numbers and criteria weights are determined by the same group of experts in the field according to company's internal and external factors. Expert judgments are aggregated and weighted information contents for each alternative are calculated. To establish a FQSPM, the two strategies A and B are considered under the same affective factors (criteria) shown in Table 2. A six-level fuzzy scale used to assess the alternatives (Table 4). Sample results from expert evaluations are given in Table 5.

Table 4: A six-level fuzzy scoring definition

Condition	Very poor (VP)	Poor (P)	Fair (F)	Good (G)	Very good (VG)	Excellent (E)
Fuzzy scale	(0,0.1,0.15)	(0.1,0.25,0.3)	(0.3,0.35,0.5)	(0.5,0.55,0.7)	(0.7,0.75,0.9)	(0.9,1,1)

Table 5: Sample strategic evaluations performed by the company's expert group

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Strategy A	VG	VG	F	P	VG	G	F	G	VG	F	VG	G
Strategy B	G	VG	P	F	VG	P	P	G	P	VG	VG	VG

After developing the linguistic terms, translating the linguistic term into fuzzy numbers, normalizing and multiplying weights to the fuzzy numbers, and using TOPIS MCDM, we summarize the results in Table 6.

Table 6: The fuzzy evaluation of strategies for the Tile Company

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Weight	0.05	0.07	0.12	0.08	0.07	0.15	0.09	0.11	0.03	0.12	0.07	0.04
Strategy A	0.854	0.725	0.324	0.158	0.769	0.431	0.396	0.332	0.762	0.111	0.651	0.291
Strategy B	0.290	0.829	0.100	0.202	0.642	0.139	0.218	0.207	0.461	0.845	0.767	0.609

Using the values of Table 6, a FQSPM sum total weighed attractive scores of 0.424 for the strategy A versus 0.393 for the strategy B was obtained, indicating that strategy A (improving existing production line) has the first priority for the Company (Table 7).

Table 7: Priorities of the strategies for the Tile Company using FQSPM

Strategies	Total Attractive Score	priority
A) Improving existing production line	0.424	1
B) Adding new production line	0.393	2

Comparison of the result in Tables 3 and 7 indicates that using fuzzy numbers could change the priorities of the developed strategies. Furthermore, using Equation 11 for calculating the performance indices shows the same priority results as FQSPM (Table 8).

Table 8: Ranking Alternatives in FQSPM using the TOPSIS index

Strategies	TOPSIS Total Attractive Score	priority
A) Improving existing production line	0.131	1
B) Adding new production line	0.128	2

4.3- Validation

To validate the results in Section 4.2., prioritization worksheets were distributed to a group of independent experts in the field. A total of fifteen experts contributed to rank the six developed strategies of the Tile Company based on their experience. Twelve criteria were used for evaluation of strategies based on the company's external and internal factors (the same criteria applied for the QSPM analysis in Table 2). All fifteen returned prioritization worksheets agreed with the prioritization result of FQSPM.

5. Conclusions

The QSPM method has proven to be a useful strategic planning tool for several types of organizations; large, small, profit, and nonprofit firms. A limitation of QSPM, however, is that it can only be as good as the provided information and the analysis method up on which the strategy rankings are based. As a result, the success of QSPM necessitates careful judgments by experts in assigning attractive scores. In doing so, if crisp numbers are used instead of linguistic terms, the obtained sum total attractive scores may be too idealistic and the difference between strategies can be difficult to distinguish. A method for improving QSPM was proposed using fuzzy numbers as input information and also the TOPSIS MCDM index was suggested in calculating the sum total attractive scores. The results showed improvements in prioritization of strategies for a Tile Company. Similar to other strategic planning tools, the fuzzy QSPM should not dictate final decisions, it should rather be used as decision aid for DMs. As a potential future work, the proposed methodology may be examined for its robustness as compared to the conventional QSPM.

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