Development of Integrated Multi-Criteria Investment Justification Approach Based on Fuzzy Logic

Navee Chiadamrong
Department of Industrial Engineering
Sirindhorn International Institute of Technology
Thammasat University, Pathumthani, Thailand

Abstract

New manufacturing systems have a hugh potential for increasing productivity. But the potential is being roadblocked in many cases by the wrongful use of traditional justification methods. This paper presents a further step in justifying such evaluation by using the concept of the fuzzy set theory in overcoming the precision-based evaluation. The study also suggests an integration of economic with strategic justification approaches as a basis for decision makers to choose the best alternative manufacturing system. Results from the proposed approach present a better understanding of each system performance and an easier approach to decision makers for evaluating justification issues which sometimes cannot be precisely defined.

1. Introduction

The key to survival for many companies is the ability to capitalise effectively on the immense potential of advancing technology and channel it for the economic and strategic well-being of the companies. However, benefits and costs from advancing technology are not innately tangible and intangible. Before we can justify system characteristics, a distinction between "*tangible*" and "*intangible*" needs to be clearly made. Intangible benefits and costs are benefit and cost elements identified but not quantified [1]. Employee morale problems caused by a new system is an example of an intangible cost. Traditionally, it relies heavily on gut feelings in each company to evaluate the magnitude of these strategic intangible benefit/cost values. Until recently, many researchers have employed ranking and scoring methods or multi-criteria decision methods to measure these values. West [2], Canada [3] and Sloggy [4] are among the first group of researchers who used ranking and scoring methods to evaluate their system alternatives. On the other hand, tangible or financial related benefits can be quantified by using traditional financial methods such as payback period, net present value (NPV) and internal rate of return (IRR). These methods are well-known and have been taught in engineering economics courses. Sullivan [5] and Wemmerlov [6] have used these methods to justify investment in their new systems.

Thus, both types of benefits have a big influence on the decision making processes. Methods developed in the past are useful in addressing subsets of factors, but fall short in a comprehensive system analysis. In this study, an integrated justification approach, which considers combined financial and strategic evaluations, has .been proposed. This combination makes use of the benefits provided by each method to compensate for any drawbacks that may arise from using any individual method in isolation.

1. Strategic-based evaluation (for intangible benefits)

Strategic-based evaluations of investments are very important in view of the fact that financial evaluation of investment often implies a strategy that is not consistent with the company's explicit strategy objectives. For example, financial evaluations are biased towards the continuation of what the company has done in the past because the highest short term financial returns are normally generated by improving existing operations rather than by making significant investment in new areas where return is to be realised in the future. In addition, many companies have also differentiated themselves based on their non-financial performances. For instance, with products which have short a life-cycle, the lead time for these products to enter and exit markets may become more critical than product costs.

In an attempt to evaluate the magnitude value of these strategic benefits, ranking and scoring methods are generally used. There have been many types of ranking and scoring methods, depending on different approaches to value weights and rate alternative attributes. However, the main existing drawback of these methods is the requirement in asking evaluators (who are normally not familiar with the new system alternative) to weight and rate all these subjective criteria, which often cannot be precisely defined with a sharp degree of accuracy (e.g., criteria A must be two times more important than criteria B). This sometimes makes these ranking and scoring methods fail in gaining management co-operation. Besides, such evaluation is often expressed in linguistic terms, e.g., "*very low*", "*medium*", "*high*". Thus, it seems that the fuzzy set logic is useful to tackle this problem by integrating various linguistic assessments. Furthermore, the resulting analysis will be more useful and accurate if these uncertain data can be assumed to be a fuzzy number and properly analysed through the use of fuzzy set theory techniques.

2. Fuzzy set logic

A fuzzy subset A of a universe of discourse U is characterised by a membership function $f_A: U \rightarrow [a,b]$ which associates with each element u of U a number $f_A(u)$ in the interval [a,b] where $f_A(u)$ represents the grade of membership of u in A [7]. If the interval [a,b] is the [0,1] one, the fuzzy subset A is called normalised. And a fuzzy number A in R is called a trapezoidal fuzzy number if its membership function $f_A: R \rightarrow [0,1]$ is:

$$f_A(x) = \begin{cases} \frac{x-c}{a-c} & c \le x \le a \\ 1 & a \le x \le b \\ \frac{x-d}{b-d} & b \le x \le d \\ 0 & otherwise \end{cases} \qquad (1)$$

A trapezoidal fuzzy number can be denoted by (c,a,b,d). Figure 1 shows its membership function. If a=c or b=d, the trapezoidal fuzzy number is degenerate. In this case, a membership function redefinition is necessary. A crisp number n can be represented by the trapezoidal fuzzy number notation (n,n,n,n), where the membership function definition is;

$$f_n(x) = \begin{cases} 1 & for\ x = n \\ 0 & otherwise \end{cases} \qquad (2)$$

The trapezoidal fuzzy numbers are easy to use and easy to interpret. For example, approximately equal to £300 can be represented by (295, 300, 300, 305), between £360 and £400 can be represented by (355, 360, 400, 405), and the non-fuzzy number of £500 can be represented by (500, 500, 500, 500).

Then, apply the fuzzy set logic to the justification of the strategic issues. One major step of strategic evaluation is to allocate criteria's weight and alternative rating. With fuzzy multi-criteria decision making, their trapezoidal fuzzy numbers can be presented as follows;

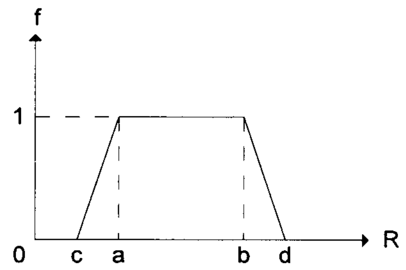

Figure 1: Membership function of a trapezoidal fuzzy number A = (c,a,b,d)

2.1. Weighting variables

These are variables to express the importance of a criterion with a linguistic expression. For example, a weight set (WS), used in this paper's example, can be presented by;

WS = {Rather unimportant, Moderately important, Very important}

According to Figure 2, these linguistic values are represented by normalised trapezoidal fuzzy numbers, in a universe of discourse [0,1], whose member functions may be defined as follows;

- Rather unimportant = (0,0,0.2,0.4)
- Moderately important = (0.3,0.5,0.5,0.7)
- Very important = (0.6,0.8,1,1)

2.2. Rating variables

These variables are used to express any judgement about a criterion of each alternative linguistically. A rating set (RS), used in this paper, may be presented by;

RS = {Very low, Low, Medium, High, Very high}

According to Figure 3, the membership functions of these normalised trapezoidal fuzzy numbers in a universe of discourse (0,1) can be defined as;

- Very low = (0,0,0,0.3)
- Low = (0,0.3,0.3,0.5)
- Medium = (0.2,0.5,0.5,0.8)
- High = (0.5,0.7,0.7,1.0)
- Very high = (0.7,1,1,1)

3. Methodology

In this paper, multiple criteria decision making, belonging to the integrated approach category, based on fuzzy logic is proposed. Figure 4 shows the methodology used in this paper. The methodology allows:

- Consideration of the strategic aspects of the investment. Since the impact of the investment on strategic areas can be expressed using linguistic assessments close to human language, fuzzy logic can be introduced to simplify such decision processes.
- Determination of the quantifiable aspects of the investment. Unlike other researches [2-4] which consider financial aspects as one of the criteria in their strategic aspects, this paper distinguishes financial aspects from the strategic aspects. Having done that, the significance of each aspect can be clearly analysed through the use of sensitivity analysis.
- Aggregation of the results of these two aspects by considering the financial and strategic importance of each and obtaining an overall aggregation index.

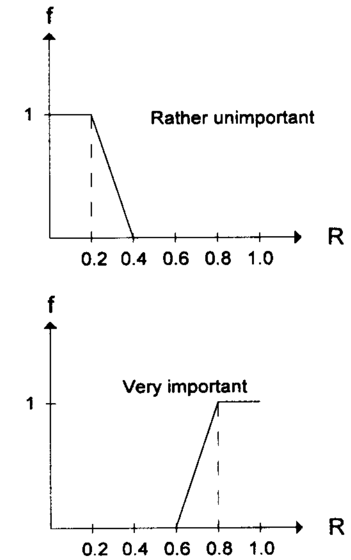

Figure 2: Membership functions of linguistic values of weight

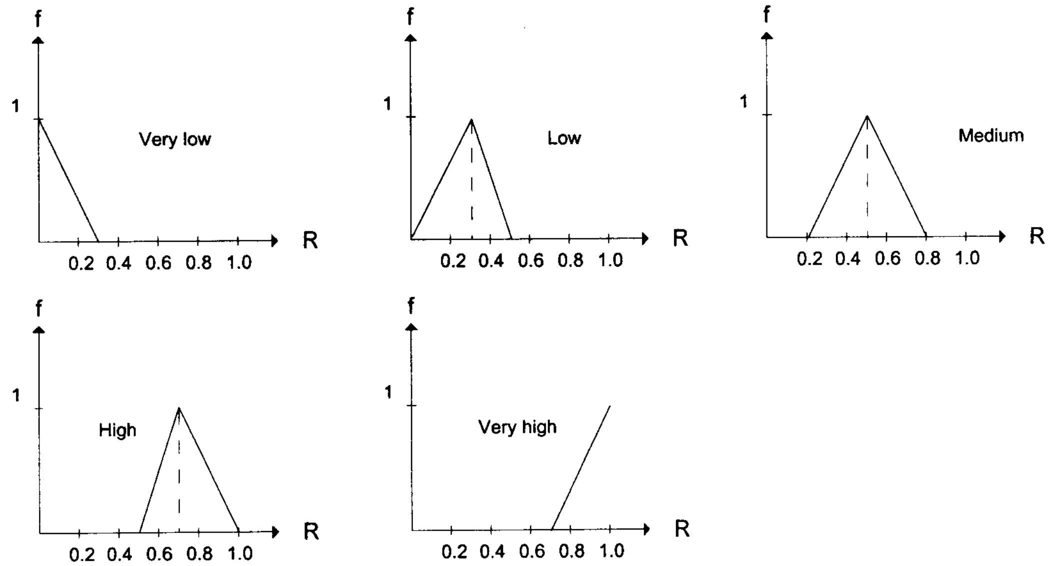

Figure 3: Membership functions of the linguistic values of rating

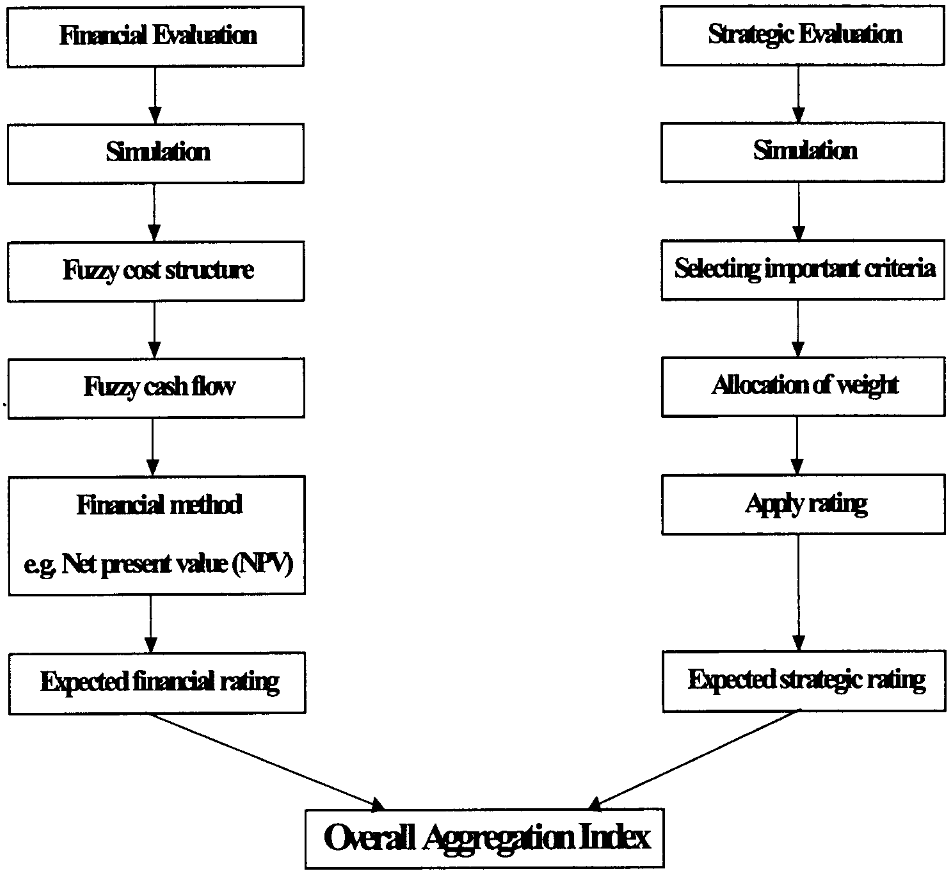

Figure 4: Methodology

3.1. Strategic evaluation processes

The procedures of the fuzzy multi-criteria decision model are as follows;

1. Selection of important criteria or attributes.
2. Allocation of associated weight to each criteria.
3. Apply rating to criteria in each system alternative.
4. Calculation of the combined aggregation scoring (CA) or expected strategic rating.

$$CA = 1/I * [(W_1 * A_1) + \ldots\ldots + (W_{i-1} * A_{i-1}) + (W_i * A_i)] \quad (3)$$

where: I is a number of criteria

A_i are the set of relative rating (judgements) concerning attribute i.

W_i are the set of relative weights.

The extended algebraic operations on trapezoidal fuzzy numbers can be seen in Liang and Wang [8].

5. Ranking alternatives

A set of trapezoidal fuzzy numbers representing each alternative are compared with each other. Chen method [9] is used to rank alternatives. Thus, the system that has the maximum of Chen ranking value provides most strategic related benefits.

3.2. Economic or financial evaluation processes

Troxler and Blank [10] presented difficulties in predicting benefits over an extended time period. Misinterpretation of cost behaviour pattern is listed in one of their evaluation drawbacks. To tackle this problem, quantifiable system performances need to be transformed into monetary units through a pre-constructed cost model. For the sake of limited space, the interpretation of cost pattern and their transformation will not be included in this paper. However, further details of cost estimation model can be seen in [11]. This transformation presents a more accurate estimation of production costs of systems being evaluated. Then, the evaluation of this financial aspect can be made through the construction of the projects' cash flow throughout its planning period. Discounted cash flow methods such as Net present value (NPV) can also be used to perform economic analysis. Results from this analysis in forms of monetary units will be later called present cost value (PCV).

To make it possible to integrate the fuzzy financial results with the fuzzy strategic results, the present cost value, which is expressed in monetary terms, again needs to be transformed to express a trapezoidal fuzzy number in the interval of (0,1). As this transformation has to be able to preserve the rank among the transformed and untransformed fuzzy numbers, we need to invert rank of our alternative financial results (since the lower PCV (lower production cost), the better the alternative). The financial rating for each alternative k can be computed by the following procedures:

$$INVPCV_k \quad 1 \div PCV_k \quad (4)$$

i.e.,

$$(c_{INVPCV_k}, a_{INVPCV_k}, b_{INVPCV_k}, d_{INVPCV_k}) \quad (1,1,1,1) \div (c_{PCV_k}, a_{PCV_k}, b_{PCV_k}, d_{PCV_k}) \quad (5)$$

where: PCV_k is the present cost value of alternative k

$INVPCV_k$ is the invert value of the PCV_k

In this way, the alternative with the highest $INVPCV_k$ ranked with the utility function, should have the highest associated rating. Then, to make it comparable with the expected strategic values, each financial rating which must be expressed in a trapezoidal fuzzy number in the interval [0,1] can be obtained by;

Expected financial rating

$$\left(\frac{c_{INVPCV_k}}{MAX_{d_{INVPCV}}}, \frac{a_{INVPCV_k}}{MAX_{d_{INVPCV}}}, \frac{b_{INVPCV_k}}{MAX_{d_{INVPCV}}}, \frac{d_{INVPCV_k}}{MAX_{d_{INVPCV}}} \right) \quad (6)$$

where: $MAX_{d_{INVPCV}}$ is the maximum inverted present cost value of the trapezoidal fuzzy numbers for all alternatives being evaluated.

3.3. Integration of the results

To make it easier for the evaluators when making the final judgement, the final aggregate result is presented in the form of a single numerical value. This is also done through the use of Chen ranking method [9]. In order to develop such an aggregate index, both results need to combine in the form of the proportion value to the overall aggregate result. Thus, the overall aggregation index can be calculated by;

Overall Aggregation Index = R_f *(Expected Financial Rating)* + R_s *(Expected Strategic Rating)* (7)

Where, R_f and R_s represent the importance of the financial and strategic areas respectively.

With this method, the sensitivity analysis can be carried out on the weight expressions of judgement of the relative importance of the financial and strategic aspects. Thus, different levels of the importance of the R value (e.g. rather unimportant, moderately important and very important) can be tested with both results to check if any variation can cause changes in the investment choice. A program called "fuzzy multi-criteria decision model" (FMCD) has been developed under Lotus 123 macro language to perform such evaluation. The multidimensional structure of the spreadsheet model is useful in representing a number of criteria that are encountered in the justification problem and this makes it easier for the evaluators to use and analyse their own problems. The capability of this software is also extended to incorporate other strategic evaluation methods including the linear addition model and the analytic hierarchy process (AHP).

4. Illustrative example

This example involves a comparison of a make-to-order job shop and cellular manufacturing (CM). Both shops consist of 18 machines, producing 5 products. In job shop, these machines are grouped into six departments (A-F) on the basis of the machine function. In the cellular shop, the machines are grouped into two cells after identifying the family. Table 1 shows the machine-part matrix diagram. Product 1-3 and 4-5 are in the same family group produced in cell 1 and 2.

Table 1: Machine-part matrix diagram

		Product				
		1	2	3	4	5
Machine	A	X	X			
	B	X	X			
	C	X		X	X	X
	D	X	X	X	X	X
	E				X	X
	F				X	

The operation of job shop starts from jobs arriving at a department in batches according to their processing routes. If all the machines in that department are busy, they have to wait in a queue in front of that department. Set-up is not required if identical parts are processed. As each job finishes, it has to wait for all jobs from the same batch to be finished before, as a group, it can be transferred to the next department. Then all jobs are processed in this sequence to the finish. In contrast to the cellular shop, since machines are physically close together, no transportation is required within the cell. Jobs can be transferred in smaller batches and part family based set-ups can help reduce the set-up time. Just in time (JIT) concept is also introduced to control operation in the cell system. Kanban queues are located between two adjacent machines. Production can be started only when a signal is issued from downstream stations asking for the replenishment of the part taken. Parts are pushed through the production, while each small machine centre pulls their supplies.

Since the comparison of both shops will require both shops to be justified under various manufacturing conditions to meet the firm's objectives, computer simulation is a useful tool to trace these operational characteristics. With the limitation of space, details of each model construction and the design of their experiments can be seen in [12]. After transforming shop characteristics obtained from simulating each shop into monetary units through the use of pre-constructed fuzzy cost model, a cash flow of each shop is built for the purpose of financial analysis. Results from this analysis in terms of present cost values and expected financial ratings of each shop can be calculated and presented in Table 2.

The results from financial analysis reveal that cell manufacturing slightly outperforms the job shop due to lower operating costs (PCV). However, it has not presented a distinct difference between these two systems since another part of their benefits are actually intangible and cannot be quantified into monetary units. If ignored, they would be valued at zero and a value of zero is surely less accurate than an informed estimate by a qualified individual. Figure 5 presents a list of intangible benefits which are used in this study for evaluating both systems performance during the strategic evaluation.

For illustration purposes, the relative fuzzy associated weight of each criteria and also all ratings that are allocated to each project alternative are subjective values. Subjective reasons for ratings are based on the grounds that the introduction of cell and JIT concepts would simplify material flow and enable small batches to be manufactured more economically. In addition, results from the simulation also show that the cell can be producing parts after a shorter replanning period. Thus, changes in demand and part mix would be easier to manage. More details of these explanations can be seen in Chiadamrong and O'Brien [12]. Then, the expected strategic rating of each system can be presented in Figure 6.

It can be seen from Figure 6 that the expected strategic rating of the cell shop appears to be higher than the job shop system. This means that, from the evaluator's point of view, the cell shop can also offer better strategic benefits. Then, both results (financial and strategic) need to be integrated to present the best choice in different situations. In each situation, the overall aggregation index can be calculated and shown in Table 3.

Results from Table 3 reveal that the Chen's ranking values of the cell shop are always higher than the ones from the job shop. In this instance, it can be concluded that the cell manufacturing system outperforms the job shop in all impact situations. This is because the cell system can perform better than the job shop system both financially and strategically. However, in many other cases, results from the financial and strategic evaluations are inconsistent with one another. Integration of these two results will present an interesting outcome indicating the best alternative under the scope of available information. Certainly, the decision to choose the best system depends on each company strategy. Results from the approach as a decision support tool can help the company in revealing all possibilities, by presenting a better understanding of each system, and make it possible to evaluate their true worth without limiting this to its precision-. based evaluation constraint.

Table 2: Financial evaluation's results

Alternative system	**PCV - Present cost value (£)**	**Expected financial rating**
Job shop	(304,800, 381,000, 381,000, 457,000)	(0.62, 0.74, 0.74, 0.93)
Cell manufacturing	(282,400, 353,000, 353,000, 423,600)	(0.67, 0.8, 0.8, 1)

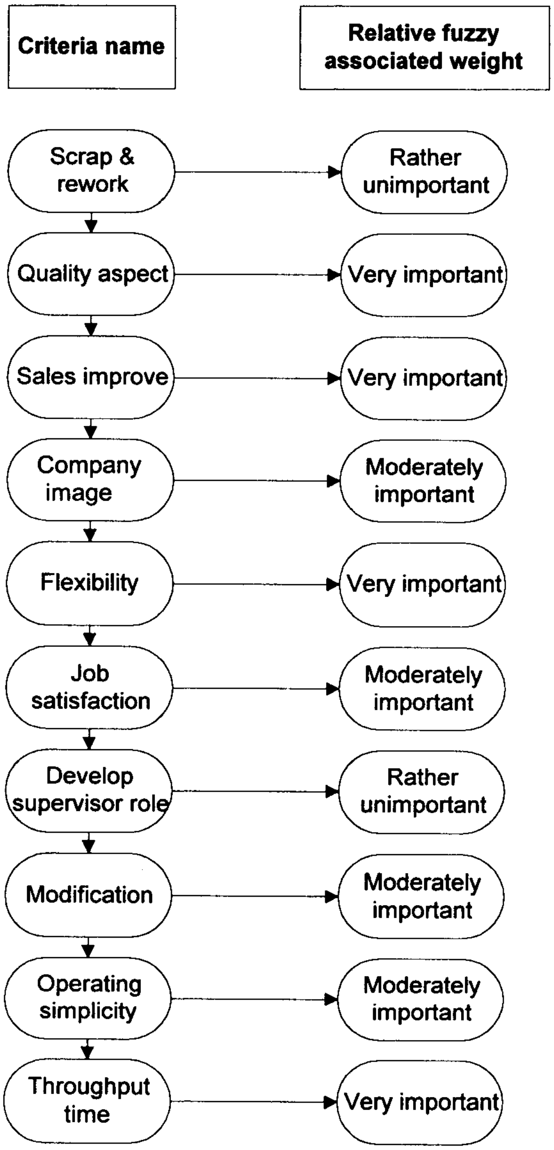

Figure 5: Strategic performance criteria and their relative weights

min. strategic value = 0.0
max. strategic value = 0.7

e.g.	Very low	V L	0.0	0.0	0.0	0.3
	Low	L	0.0	0.3	0.3	0.5
	Medium	M	0.2	0.5	0.5	0.8
	High	H	0.5	0.7	0.7	1.0
	Very high	V H	0.7	1.0	1.0	1.0

	Criteria	Weight				job shop				cell shop			
1	scrap&rework	0.0	0.0	0.2	0.4	0.0	0.3	0.3	0.5	0.5	0.7	0.7	1.0
2	product quality	0.6	0.8	1.0	1.0	0.2	0.5	0.5	0.8	0.5	0.7	0.7	1.0
3	sales improve	0.6	0.8	1.0	1.0	0.0	0.0	0.0	0.3	0.2	0.5	0.5	0.8
4	company image	0.3	0.5	0.5	0.7	0.0	0.3	0.3	0.5	0.5	0.7	0.7	1.0
5	flexibility	0.6	0.8	1.0	1.0	0.0	0.3	0.3	0.5	0.5	0.7	0.7	1.0
6	job satisfaction	0.3	0.5	0.5	0.7	0.0	0.0	0.0	0.3	0.5	0.7	0.7	1.0
7	develop supervisor role	0.0	0.0	0.2	0.4	0.0	0.3	0.3	0.5	0.7	1.0	1.0	1.0
8	modification	0.3	0.5	0.5	0.7	0.7	1.0	1.0	1.0	0.0	0.0	0.0	0.3
9	operating simplicity	0.3	0.5	0.5	0.7	0.0	0.0	0.0	0.3	0.5	0.7	0.7	1.0
10	throughput time	0.6	0.8	1.0	1.0	0.0	0.3	0.3	0.5	0.5	0.7	0.7	1.0
						0.33	1.53	1.87	3.97	1.47	3.13	3.99	6.91
	Expected strategic rating					0.03	0.15	0.19	0.40	0.15	0.31	0.40	0.69

Figure 6: Output from the fuzzy multi-criteria decision model

Table 3: Integrated results

		Alternative system	
Strategic impact	Financial impact	Job shop	Cell manufacturing
Rather unimportant	Rather unimportant	(0,0,0.093,0.265)[1] 0.26[2]	**(0,0,0.12.0.338) 0.3**
Rather unimportant	Moderately important	(0.093,0.185,0.204,0.405) 0.356	**(0.101,0.2,0.24,0.488) 0.415**
Rather unimportant	Very important	(0.186,0.296,0.389,0.544) 0.393	**(0.201,0.32,0.44,0.638) 0.465**
Moderately important	Rather unimportant	(0.005,0.038,0.121,0.325) 0.285	**(0.022,0.078,0.18,0.442) 0.387**
Moderately important	Moderately important	(0.098,0.233,0.232,0.464) 0.353	**(0.123,0.278,0.3,0.592) 0.453**
Moderately important	Very important	(0.191,0.334,0.417,0.604) 0.383	**(0.223,0.398,0.5,0.742) 0.49**
Very important	Rather unimportant	(0.01,0.061,0.168,0.385) 0.293	**(0.044,0.125,0.28,0.546) 0.428**
Very important	Moderately important	(0.103,0.246,0.279,0.524) 0.349	**(0.145,0.325,0.4,0.696) 0.477**
Very important	Very important	(0.196,0.357,0.464,0.664) 0.375	**(0.245,0.445,0.6,0.846) 0.509**

[1] Overall aggregation index
[2] Chen's ranking value
Highlighted cells denote the best system under that scenario.

5. Conclusions

Existing methods have shown to be lacking in some crucial criteria such as poor integration with the results from financial-based evaluation and the loss of popularity for their practical uses due to the complex technical terminology. Since the nature of strategic evaluation is dealing with a large amount of uncertainty and fuzzy defined criteria. This paper proposes an integration of financial and strategic justification approaches based on the fuzzy logic. Results from the integrated approach have presented a better understanding of each alternative choice, informing the overall picture of each scenario. This makes it possible to indicate each alternative's true value. The developed multiattribute spreadsheet model can be of value for an analyser. A numerical example was shown here to demonstrate how the strategic aspect can significantly influence the choice of investment alternative. The sensitivity analysis can also help to determine the critical judgements in the decision process.

6. References

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