An Investigation on the relationship for supplier performance metrics and supply chain strategies

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Abstract – The competitive environment of today's global marketplace is undergoing changes. Customers demand more variety, better quality, and greater service in terms of reliability and response time. The success in this environment is very much determined by how a company forms the whole supply chain. A supplier plays very important role in supply chain management as the production cost and product quality are highly dependent on the supplier. Besides cost and quality, an efficient supply chain that can respond quickly to the market demand is also an important issue in the customer-oriented economics nowadays. Thus, supplier evaluation and selection have become the main concern of the industries and also a hot research topic for the researchers since 1960s. Today, supplier selection becomes even more important as more companies are developing a closer and long-term relationship with their supplier to establish an effective supply chain to increase competitiveness.

Keywords: Supply chain strategy, Supplier performance measurement, Analytic hierarchy process (AHP), Fuzzy logic

1 BACKGROUND

In today's highly competitive environment, an effective supplier evaluation process is very important to the success of any manufacturing organisation. Many manufacturers seek to collaborate with their suppliers in order to upgrade their supply chain performance and competitiveness. The purchasing function is increasingly seen as a strategic issue in organisations. Buyer and supplier relationships in manufacturing enterprises have received a great deal of attention. A number of studies had been emphasising on the strategic importance of supplier evaluation process [1,2].

As cited by Weber et al [3], purchases from outside sup-pliers account for a large percentage of total operating costs for many firms. For most of US firms, the raw materials purchased constitutes 40-60% of the unit cost of a product. For large automotive manufacturers, the purchasing cost of components and parts from outside suppliers may total more than 50% of sales. Purchased materials and services represent up to 80% of total product costs for high technology firms. In other words, once a supplier becomes part of a well-managed and established supply chain, this relationship will have a lasting effect on the competitiveness of the entire supply chain. Therefore, the supplier evaluation and selection problem has become one of the most important issues for establishing an effective supply chain system. The overall objective of supplier evaluation and selection process is to reduce purchase risk, maximise overall value to the purchaser, and build the closeness and long term relationship between buyers and suppliers.

In this project, we first review current literature dealing with existing evaluation criteria and evaluation techniques. We proceed to propose supplier evaluation framework to link supplier performance measurement to a company's supply chain strategy. This is to help the company to understand which measurement metrics really matter to their business strategy and goals, and ensure measurement is aligned with their strategy. Then we illustrate steps for evaluation. We further describe how we implement the performance measurement by using Analytic Hierarchy Process (AHP) and fuzzy logic techniques. AHP is used to prioritise performance attributes based on a supply chain strategy. Fuzzy logic is used to integrate both qualitative and quantitative metrics to provide a complete view of a supplier performance. Finally, we developed a prototyping system based on the proposed framework and AHP & fuzzy logic techniques.

2 OBJECTIVE

The main objective of this project is to investigate and establish relationship between supplier performance metrics and supply chain strategies by using Fuzzy set theory and AHP (Analytical hierarchy Process) approach.

2.1 Aims

The aim of this project is to develop an AHP and Fuzzy Logic system for Supplier Evaluation and Selection to evaluate the supplier's performance in the sourcing section of supply chain according to their performance criteria. This system can be used as a decision support tool that helps the company to effectively design and develop their supply chain by identifying the strengths and weaknesses of each supplier. The main deliverables of this prototype system is to give the score for each key performance measure attributes (Cost, Quality, Reliability, Responsiveness, Flexibility and Re-configurability) and for all sub-attributes under each key attribute, which will indirectly describe the supplier's performance to improve purchasing efficiency and to improve quality and delivery performance of suppliers.

In order to realise the aim of this research project, the following research objectives have been defined:

- To understand the general knowledge of supplier evaluation and selection criteria and techniques
- To build up a prototype system in two subparts: the back-end and the front-end

The backend is a Fuzzy Inference System (FIS), which is to be modelled to assess suppliers with evaluation criteria that are captured in input metrics.

The front-end is a web-based software system, which is to be developed for defining and necessary strategies, templates, etc. and accepting inputs. Notes: The front-end part is collections of Graphical User Interfaces (GUIs) to interact with the user.

Also a web service is to be established to enable deploying the FIS solution into the supplier performance measurement website.

2.2 Scope

The research scope includes:

1. Review of literature on supplier selection performance metrics and supply chain strategies
2. Investigation of the relationship between supplier selection performance metrics and supply chain strategies
3. Establishment of the theoretical relationship framework
4. Validation and refinement of the theoretical relationship framework with case studies
5. Development the mathematical model or algorithms and integrate them into the framework
6. Development the final supplier performance measurement methodology

A three-phase structured research methodology is used in the project, which is outlined as follows:

1. Phase 1:
   In this phase, we reviewed literature on different types of supplier selection methods and approaches and investigated the relationship between supplier performance metrics and supply chain strategies, did a thorough and very comprehensive review of the literature on leading published articles and papers will be carried out with the purpose of defining supplier selection processes and the methods used for supplier evaluation and selection which will help to develop our own method; and, investigated the relationship between supplier se-lection performance metrics and supply chain strategies.
2. Phase 2:
   In this phase, we established the theoretical relationship framework and to validate the framework; formulated a theoretical relationship framework based on literature view and investigation. The framework has been validated through several industry case studies.
3. Phase 3:
   In this phase, we developed the AHP and Fuzzy logic algorithms and formulated supplier performance measurement methodology.

Different evaluation and selection algorithms will be formulated for qualitative and quantitative measurements. Quantitative measurement will be presented in numerical format. Qualitative measurement only can be described subjectively using linguistic terms, which are imprecise and ambiguous. Ah hoc usage of linguistic terms and corresponding membership functions is characteristics of fuzzy logic. Fuzzy logic approach will be used to measure qualitative metrics. The qualitative and quantitative measurement will be aggregated into fuzzy adaptive index and then the fuzzy adaptive index will be translated into an appropriate linguistic level of measurement.

The Analytic Hierarchy Process (AHP) is a method for formalising decision making where there are a limited number of choices but each has a number of attributes and it is difficult to formalise some of those attributes [10]. It provides a structured framework for setting priori-ties on each level of the hierarchy using pair-wise comparisons, a process of comparing each pair of decision factors at a given level of the mode for their relative importance with respect to their parent. The AHP will be used to design the prototype system due to the fact that complexity of metrics, the mixer of tangible and intangible metrics and interaction within the metrics. Based on the identification of the characteristics of supplier strategy, an integrated and comprehensive evaluation and selection system will be designed by applying AHP approach. The company's strategy, market drivers, supply chain strategy, detailed metrics will be considered in the system design.

Based on the proposed method and algorithms, a prototype software system will be developed as a proof-of-concept. A fuzzy logic reasoning engine as well as the AHP technique will be developed and integrated to the database of qualitative & quantitative performance into a complete prototype for supplier evaluation and selection.

3 METHODOLOGY

3.1 Literature Review

The supplier evaluation method has experienced significant changes for the past forty years not only in evaluation criteria but also in evaluation techniques used.

3.1.1 Supplier Evaluation Criteria

The supplier evaluation criteria have been a popular re-search area since 1960's and Dickson's selection criteria are the foundation of most of the later studies [1]. In 1966, Dickson first defined 23 metrics which rank according to their importance and these 23 metrics have become the basis of most of the researches since then. In Dickson's study (1966) [1], the quality, delivery and performance history are ranked as the most important criteria in supplier selection while other important criteria defined by Dickson include warranties and claim policies, production facilities and capacity and price. A comprehensive review of 74 articles by Weber [3], Current and Benton, 1991, indicated that price (discussed in 80% of the articles) is the most important criteria, followed by delivery (59%) and quality (54%). Other criteria like production facilities and capability, geographical location, and technical capability were discussed in 31%, 22% and 20% of the articles respectively while warranties and claim policies were not discussed in any of the 74 articles [1].

After Dickson [1], several researchers (Cardozo & Cagley, Chapman & Carter, Dempsey, Hakansson and Wootz, Monczka et al) had focused their studies on evaluating the relative importance among quality, delivery performance, cost and other selection criteria [4]. Stepping into 1990's, the customer-oriented business environment dominates, flexibility and responsiveness are given considerable attention in supplier evaluation process [5]. While in recent year development, we can observe the latest trend that starts to place emphasis on environment and safety issues [5,6].

Evaluation and selection criteria also differ according to a company's sourcing practices [7,8]. Purchasers with single-sourcing preference consider dependability and reliability as the most important criteria. While for purchasers with multiple sourcing preferences, they tend to place more emphasis on the price.

Besides the typical criteria defined in the early years, the number of metrics defined is actually growing in recent years as there are more and more researchers work on this area and each had defined their own sets of evaluation metrics. From the papers reviewed, the number of metrics de-fined in different literature range from a minimum of 4 metrics to a maximum of 101 metrics [1,5,7,9].

3.1.2 Supplier Evaluation Technique

Supplier evaluation and selection is a multiple objective problem [1]. Various techniques have been used in solving multi-criteria supplier selection problem [2,10]. The traditional techniques used Linear weighting models and Mathematical programming while the recent approaches - statistical models incorporate fuzzy set theory, AHP into the evaluation techniques. Table 1 shows their advantages and limitations.

Table 1. Comparison of evaluation techniques.

Techniques	Characteristics	Advantages (A) or Disadvantages (D)
Linear weighted model	Single-sourcing	D: can only select one best supplier
Mathematical programming	Multiple-sourcing quantitative	A: can choose multiple suppliers and optimum order quantity to get optimum solution when one supplier can not satisfy all the requirements
Goal programming, multi-objective programming	Multiple-objective, Weighted criteria quantitative	A: can assign weight to criteria D: face problems in handling qualitative factor
Linear programming, mixed-integer programming	Single objective, equal important criteria quantitative	D: face problems in handling qualitative factor D: criteria is treated as equal important which are not realistic in practice
AHP	Qualitative	A: can handle qualitative criteria
Integration of AHP with linear programming	Qualitative and quantitative, weighted criteria single objective, multiple sourcing	A: can handle qualitative criteria A: can assign weight to criteria A: can choose multiple suppliers and optimum order qty to get optimum solution when one supplier can not satisfy all the requirements
Integration with fuzzy set theory	Qualitative, fuzzy	A: can handle qualitative criteria A: can handle imprecise data

3.1.3 Limitations and Challenges

Even though many research works have been done in supplier evaluation, but there are still many challenges. One of the greatest challenges in building up the criteria metrics is to balance the completeness and conciseness. While using too few criteria may generate biased, misleading results, including too many criteria for the evaluation process might be impractical in the real business environment. Another challenge is to how to connect supplier's evaluation criteria to a company's supply chain strategy. Most of evaluation criteria have no linkage with supply chain strategy, which should be most important to evaluation criteria setting. Due to the fact that some measurements are in qualitative format, while others are in quantitative format, it remains a challenge to integrate both these types of measurements into one cohesive supplier performance measurement.

3.2 Proposed Supplier Evaluation System

After intensive literature review and analysing various evaluation criteria and methods, we proposed our framework for supplier evaluation which includes evaluation attributes, metrics. We used AHP and Fuzzy set as our evaluation techniques and developed prototyping system.

3.2.1 Building Linkage Between Strategy And Criteria

Different organisations have formed different supply chain management strategies to compete in the market. Supplier performance measurement must be aligned with their supply chain strategies. Four different supply chain strategies have been adopted by different companies in different times to compete in a given market: Lean Supply Chain, Agile Supply Chain, Leagile Supply Chain and Adaptive Supply Chain [11].

First we built up the linkage between supply chain strategies and supplier performance measurement criteria as shown in Fig. 1.

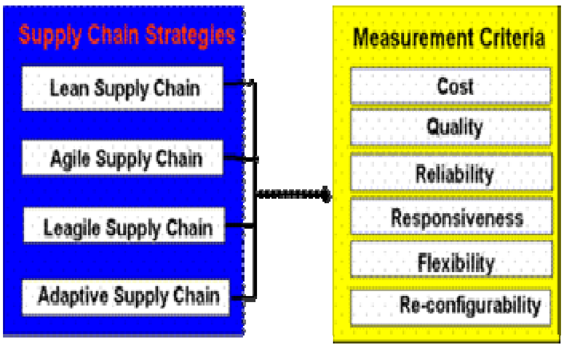

Fig. 1. Supplier performance measurement framework.

In this framework, we identified 6 important criteria to evaluate a supplier. For different strategy, there are same criteria to measure supplier performance, but the focus and weight of these criteria will be different. For example, a lean supply chain will focus on the cost of a supplier while an adaptive supply chain will place more weight on reconfigurablity of a supplier. In the next sub-section, we will discuss how weightage of measurement criteria is decided. Under each criterion, we proposed the level 2 metrics to measure the level one of the criteria shown in Table 2.

3.2.2 AHP for Calculating Weights of Criteria

For different supply chain strategy, weightage for supplier measurement criterion will be different. Current weighting methods can roughly be categorised into two general methods, namely, ratio weights methods and rank-order methods [12]. In the former, the decision maker's ratio scale judgments (exact weighting of every attribute to be weighted) are obtained; in the latter, only the ordinal judgments (the ranking of all the attributes to be weighted) are required, and algorithms are applied to transform ranks into ratios. The rating schemes characterise the ratio weights methods, and the transformation algorithms distinguish different rank-order methods.

One problem of current weighting methods is its subjectivity to decision maker's random response errors. This is because only the minimal pair-wise comparisons are conducted in this method. For *m* attributes the weighting methods make *m-1* pair-wise comparisons and each attribute is relatively weighted to another attribute only once. If the one-time weighting judgment in any of the pair-wise comparison deviates significantly from the true weight, the resultant weights would be wrong.

To offset the random errors, we used Analytic Hierarchy Process [2,10] to decide weights for the six key criteria. AHP makes complete pair-wise comparisons between every two key criteria, so that the response errors tend to cancel out in the multiple relative weightings of each attribute. It provides a fundamental 1-9 scale for the decision makers to make the paired comparison judgments, where the importance intensity of 1, 3, 5, 7, 9 corresponding to the verbal descriptions of "equal importance", "moderate importance", "strong importance", "very strong or demonstrated importance", and "extreme importance", and the grade of 2, 4, 6, 8 representing the hesitations between two neighbouring major grades. The judgment grades are then formed into a relative weight matrix. Figure 2 shows 9 scales pair-wise comparisons inputs.

Table 2. Supplier performance measurement metrics.

Measurement Criteria	Measurement Metrics	Type
Cost	Effective Price	*
	Discount Rate Trend	**
	Product Reduction Trend (relevant when evaluating long term suppliers)	**
	Foreign Exchange Rate Reduction Trend (relevant when global supply chain)	**
Quality	Percentage of Defective Orders Received	*
	Supplier's Quality Assurance System	**
	Warranty Policy	**
Reliability	Percentage of Not-On-Time Order Delivery Received	*
	Percentage of Errors Upon Release of Finished Products	*
Responsiveness	Production Cycle Time	*
	Order Fulfilment Lead Time	*
	Return Product Velocity	*
	Product/Grade Changeover Time	*
Flexibility	Expediting Cycle Time	*
	Expediting Cost	*
	Upper-side Production Flexibility	*
	Down-side Production Flexibility	*
Re-configurability	Excess Capability	**
	New Product Supply Capability	**
Quantitative: *	Qualitative: **	

Peer Comparison Adjustment

Which Attribute is more Important		Degree of Importance								
		Extreme	Very Strong to Extreme	Very Strong	Strong to Very Strong	Strong	Moderate to Strong	Moderate	Equal to Moderate	Equal
⦿ Cost	○ Quality	○ 9	⦿ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1
⦿ Cost	○ Reliability	○ 9	⦿ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1
⦿ Cost	○ Responsiveness	○ 9	⦿ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1
⦿ Cost	○ Flexibility	○ 9	⦿ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1
⦿ Cost	○ Reconfigurability	○ 9	⦿ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1
⦿ Quality	○ Reliability	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Quality	○ Responsiveness	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Quality	○ Flexibility	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Quality	○ Reconfigurability	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Reliability	○ Responsiveness	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Reliability	○ Flexibility	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Reliability	○ Reconfigurability	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Responsiveness	○ Flexibility	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Responsiveness	○ Reconfigurability	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1
⦿ Flexibility	○ Reconfigurability	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	⦿ 1

Fig. 2. The AHP pair-wise comparison input.

Based on the above input, weights for six criteria are calculated as in Table 3 to show the importance of the six evaluation criteria.

Table 3. Importance of evaluation criteria (sample).

Measurement Criteria	Weights
Cost (E)	0.60
Quality	0.08
Reliability (A)	0.08
Responsiveness (B)	0.08
Flexibility (C)	0.08
Re-configurability (D)	0.08

3.2.3 Fuzzy Set for Integrating Quantitative and Qualitative Metrics

There are two types of metrics in the measure-ment sys-tem: quantitative and qualitative metrics. It is relatively easy to evaluate quantitative metrics, as they can be calculated using certain formula and are already expressed in numerical values. For qualitative metrics, however, performances of a supplier are imprecisely described in verbal statements such as excellent, good, fair and poor. They need to be quan-tified before being passed to integration.

To evaluate qualitative metrics, we chose to use a scale of 0% to 100% to express confidence level in the performance of potentials suppliers, 0% for extremely poor and 100% for extremely good. It is quite a simple scale, so it would be easy to map verbal judgment to numerical values.

Most importantly, we need to integrate two types of metrics to synthesise the individual measurement of the level two metrics into a cohesive measurement of their root level one metric. Fuzzy Theory is applied to accomplish the integration. The fuzzy inference process consists of five steps, which are: fuzzification, fuzzy rules reasoning (*if-then* rules), implication, aggregation and de-fuzzification as shown in Fig 3. The goodness of the fuzzy logic is that it can take in both quantitative and qualitative metric input. It can account for imprecision of input and integrate both types of metrics, and generate crisp output [2]. Figure 4 shows an example of reasoning process for cost criteria.

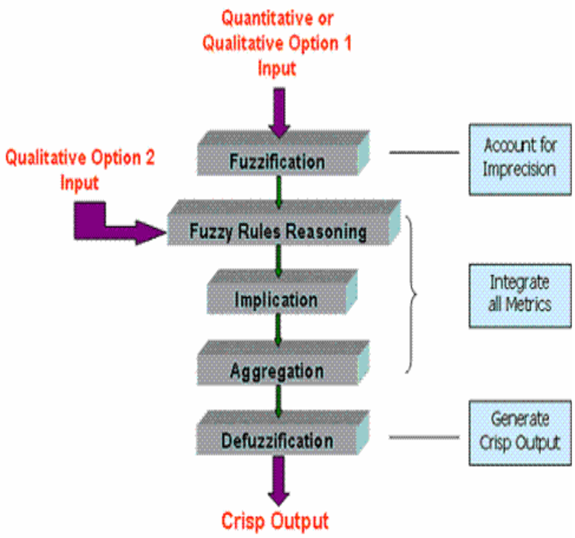

Fig. 3. Fuzzy inference process.

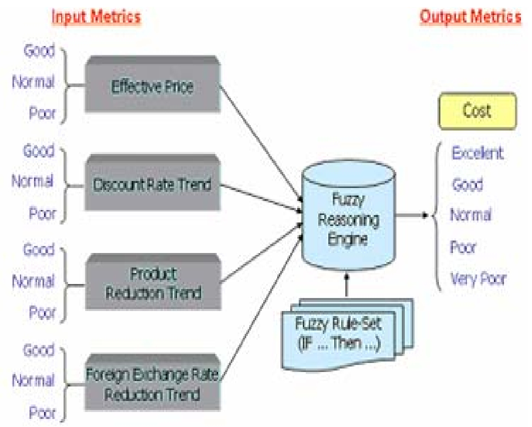

Fig. 4. Sample reasoning for cost criteria.

4 RESULTS & DISCUSSION

To validate our research output – the proposed framework, we developed a prototyping system based on the following five steps for supplier evaluation.

Step 1: Supply chain strategy forming: When a company intends to evaluate their suppliers' performance, they must be clear about their supply chain strategy. At this first step, a company needs to select or form supply chain strategy to guide through whole supplier evaluation process.

Step 2: Evaluation template setting up: Evaluation system gives default template based on selected supply chain strategy. But the company still can define its own evaluation template by adding new or deleting existing metrics. Companies can define many evaluation templates for different benchmarking purposes. Evaluation structure and formula will be built into the template.

Step 3: Data input: According to template defined, the system will require data input. Different types of inputs are expected for different types of metrics. Figure 5 shows two UIs for two types of inputs.

Step 4: Evaluation: Based on data input, the system will calculate score and show evaluation results. Evaluation results, Fig. 6, can be used as benchmarking purpose for supplier comparison.

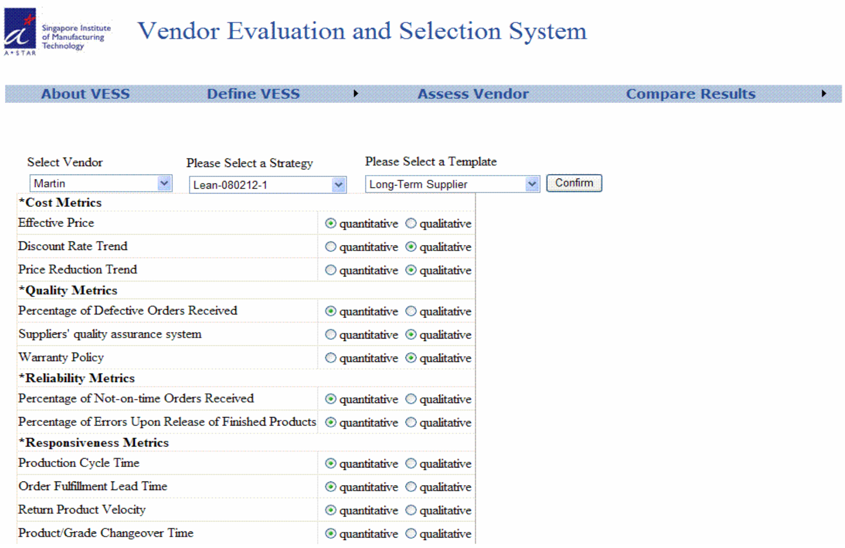

Fig. 5. UI for two types of input.

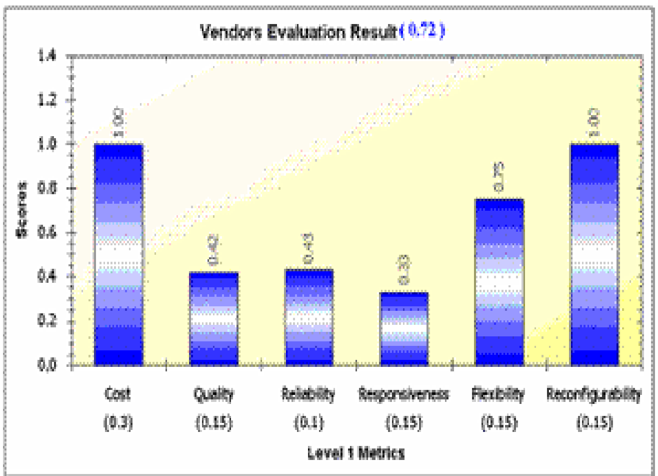

Fig. 6. Evaluation results.

Step 5: What-if analysis: By changing some metrics value, the system will be able to simulate new score. What-if analysis can help companies to identify what kind of supplier a company is looking for to best support its supply chain strategy.

Although lots of efforts have been made towards this study, the system developed could still be further improved. Below are some of the areas that could be worked on: Firstly, the fuzzy reasoning engine needs to be refined. By simplifying the rules the system can generate more reasonable results and by generalising the fuzzy functions the response time can be reduced.

Secondly, a formula builder should be introduced to facilitate future users to define new quantitative metrics. Thirdly, some functionalities can be added to the User Interface to make it more powerful and more user friendly. One example is that this evaluation system could become more sophisticated bench-marking system too. Even though we used few industry partners to validate our evaluation framework, but the whole evaluation system need to be tested thoroughly through industry cases.

5 CONCLUSION

Supplier evaluation and selection, which is one of a company's most important processes, must be systematically considered from the decision makers.

In this project, we stated supplier evaluation and se-lection could be influenced by a supply chain strategy. Based on supply chain strategy, importance level of each criterion is determined. AHP and fuzzy theory are applied to supplier evaluation. The advantages of our supplier evaluation system are:

1. Both quantitative and qualitative factors which are very important in supplier evaluation can be included in the evaluation, while most of existing models can only consider the quantitative metrics.
2. Supply chain strategies can be reflected in supplier evaluation and selection.
3. Using pair-wise comparison reduces dependency of the system on human judgement.
4. Both weight of criteria and scores of suppliers are determined by one systematic approach.

6 INDUSTRIAL SIGNIFICANCE

The outcomes of the project will help manufacturers in Singapore to improve their supply chain performances in order to gain competitive advantages. In Singapore, there are many big manufacturing MNCs which rely on local and overseas suppliers to provide them the materials and semi-finished goods. Selection of right suppliers to serve them has a significant impact on their overall supply chain performance.

This study also helps local SME to do businesses with their customers and to identify what MNCs are looking for when they select suppliers. The order winners and qualifiers will be clearly defined.

The local SMEs can then learn to change their business processes and manufacturing technology to meet their customer needs as well as becoming the MNCs' preferred suppliers. Simultaneously, the local SMEs also can benefit by applying the developed approach to select their own suppliers. Eventually, the whole supply chain will become more synchronized and efficient.

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