A NOVEL APPROACH TO SUPPLIER SELECTION AND ORDER ALLOCATION IN SMES MANUFACTURING NETWORKS

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ABSTRACT

In recent years supplier selection and order allocation as an important part of supply chain management are facing unprecedented challenges and difficulties. High customization and fast changing market demands pressure the modern supply chain management. The problem is even more serious in Small to Medium Enterprises manufacturing (SMEs) networks. The problem of how to form and coordinate manufacturing networks effectively continues to form the basis of much research. A hybrid Fuzzy Analytical Hierarchy process (FAHP) and Genetic Algorithms (GA) approach is presented in this thesis to address the problem. This research is based on an industrial case study. Data and information of suppliers are collected from a company acting as a system integrator in SMEs manufacturing network. The weights of supplier in terms of both qualitative and quantitative criteria are identified. And then, as a result of GA optimization, optimum combinations of suppliers and their production tasks are determined corresponding to the requirement of orders and their own capabilities. The results show that the proposed method is capable of optimizing the configuration of manufacturing networks and provides visualized information for decision makers.

Keywords - FAHP; GA; Supplier selection; Order allocation; SMEs manufacturing networks

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CHAPTER 1 - INTRODUCTION

1.1 A case for supply chain management

Supply chain management typically consists of all the activities from procuring, production to inventory and marketing (Monczka et al, 2010). It coordinates and manages flow of products and their relevant activities, which ensures that the best service is provided to customers. An efficient and effective supply chain helps companies gain advantages in this fierce and competitive market (Hugos, 2011).

In the last 20 years, the transformation of manufacturing and supply chain management from a vertical model to a collaborative model has occurred (Panetto and Molina, 2008). Instead of controlling the whole process of production, companies have outsourced a large portion of production and design process to other partners. By doing so, companies could then focus on the core design and product integration process which helps them improve competitiveness and the fast reaction to the changes of market. From the end of 20th century, IBM, HP and GM could be viewed as good examples and amongst pioneers that have conducted the transformation of supply chain management (Lin et al, 2000, Prater et al, 2001, and Mikkola et al, 2004). During the transformation, high Delivery rate, high order fill-in rate, high product quality, and flexibility to the changes of customized product gradually became one of the important criteria of a successful supply chain management.

The reason behind this phenomenon could be divided into two parts: the competitive market with more players and the fast changing demands from customers. First of all, the rise of economies in Asian countries brought increasing level of competitors in the manufacturing market (Mcmullan, 1996). Globalization provided a boarder and relatively fair platform for all the countries and companies to compete with one another. And at the same time, many Small-to-Medium sized companies tended to work less on their own. Instead, they reached out and formed networks and partnerships to increase their competitiveness (Vanhaverbeke, 2001). So there are increasing numbers of manufacturing networks that could compete with giant companies or qualified enough to take large orders from customers.

Secondly, customers do not buy what manufacturers produce but what they actually need. User-oriented production mode is recognized worldwide, which requires that services and products should be based on the various requirements of customers (Veryzer et al, 2005). As a result, the high customization and fast changes of products drives down the batch sizes of production. Traditional manufacturing management method could no longer fulfill the needs of customer and companies.

Hence in the new supply chain management system, the role of supply chain integrator, or network integrator, was identified and created in order to keep the alignment of quality and production with all the suppliers. Its role is to coordinate, negotiate and manage across the supply chain. High integrity of product vision should be maintained from the process of initial concept, production to customer delivery. Traditionally, the work of supply chain integrator was usually assumed by human labors which required outstanding abilities to manage and coordinate participants in the networks (Middle et al, 2007).

However due to the increasing complexity of coordination and the requirements for faster reaction to changes, human-operated supply chain management has encountered more challenges in the current environment (Coe et al, 2008). It is argued that the primary challenges facing modern supply chain are lack of communication across departments, lack of communication with external partners and lack of alignment between business goals and information technology (Henderson et al, 2011). With the current trend of globalization for supply chain, the complexity of coordinating suppliers and manufacturing networks increases significantly. More factors should be considered such as continental transportation, economic environment, political stability and trade policy. And the various locations of factories and manufacturers demand a comprehensive coordination and seamless cooperation among all the suppliers (Chilin et al, 2012). Especially in terms of selecting suppliers, coordinating and optimizing production schedule, good and efficient techniques are essential for managers to make the right decisions.

Within the SMEs manufacturing network environment, the challenges of managing and coordinating the production are paramount. SMEs suppliers and manufacturers are usually limited by their technology level, capacities and quality control, which in turn lead to the disadvantages of reputation and branding. More importantly, SMEs could not take a complex and big order on their own due to the weaknesses on capacity and manufacturing competency. As a result, large amount of SMEs have begun to establish partnership and cooperation with other companies (Havnes, 2001). They work with one another on the same order, and productions are scheduled and coordinated based on the production process of each participant. However, in the case of a large order requiring several manufacturing processes, manufacturing competencies and large amount of workforce, how should the most suitable suppliers be selected and the work be divide them?

Selection of the right suppliers is more crucial than the success of the whole manufacturing networks (Mchugh et al, 1995). Therefore, understanding the requirements for suppliers in this area and producing a practical and meaningful criteria system is necessary. Although the supplier selection has been thoroughly researched in many industrial areas, the criteria for supplier selection show many similarities and differences at the same time. The criteria and their weights cannot simply be applied to SMEs manufacturing due to their different characteristic. So it is of great interests to find out the right criteria and the process of evaluating and selecting suppliers in SMEs manufacturing environment.

1.2 Aim and objectives of the research

The aim of this research is to understand, model and optimize the supplier selection and order allocation process. This thesis approaches the problem of supplier selection and order allocation in SMEs manufacturing network using a novel integrated Fuzzy Analytical Hierarchy Process-Genetic Algorithm (AHP-GA) method. Both the supplier selection criteria hierarchy and optimization method are provided accordingly.

In this research, Fuzzy AHP is applied to determine and manage the weights of SMEs suppliers with respect to different competencies and orders. The set of criteria is used to evaluate and select suppliers for a certain production. Statistical analysis method is employed in the Fuzzy AHP (Kahraman et al, 2003) for the first time to enhance the evaluation of suppliers against quantitative criteria. The use of Kernel Density Estimation (Sheather et al, 1991) enables a dynamic evaluation which makes sure the best suppliers are selected for the specific requirement of customers. Moreover, the proposed method reduces the bias and uncertainty in the subjective judgments made by the decision makers, which is commonly used in previous research studies. According to various industrial case studies, managers held the opinions that it is hard to visually distinguish the differences between each scale in AHP. To be more specific, without the support of historical data and suppliers' information, subjective judgment might lead to biased results in evaluation and comparing suppliers. Therefore, a systematic approach to evaluate suppliers, especially on quantitative criteria, is needed. This method in this thesis utilizes statistical analysis method to generate a comprehensive analysis of all the suppliers. Pair-wised comparison is used to calculate the weight of criteria and suppliers with respect to the qualitative criteria, while the quantitative criteria are evaluated by using statistical analysis techniques. This approach is able to generate more accurate results for supplier's evaluation and is self-adaptive to different customers' requirements and the updates of suppliers' performance. The weights of suppliers are then used as Utilization score which will be used in GA optimization as a factor. GA helps determine the optimal combination of suppliers for each order and schedule the production tasks. Managers could alter and adjust the optimization results by changing the priorities of different factors in network configuration. The solutions could eventually help managers visually make the right decision about the manufacturing networks.

1.3 Thesis layout

In the following chapter, a study in supplier selection and order allocation is reviewed and discussed. Chapter 3 introduces the industrial case study, on which this research is based and presents the supplier evaluation and selection process using FAHP and statistical analysis method. Problem definition and mathematical model for GA optimization are shown in Chapter 4. The proposed Fuzzy AHP and GA are further elaborated with numerical example in Chapter 5. Industrial data are presented in tables and the mechanisms of GA optimization are also discussed. In Chapters 6 and 7 discussion and conclusions are presented respectively.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

As an important part of supply chain management, supplier selection and order allocation influence the efficiency and success of supply chain and production to a large extent. Therefore extensive research during the past two decades has focused on this area. De Boer (2001) introduced a supplier selection framework in 1998 which divided the selection process into 4 steps: Problem definition, formulation of criteria, qualification and final selection. Problem formulation looks at the ultimate goals and helps decide what kind of selection strategy is suitable for this specific situation. Then criteria for selecting suppliers are determined based on the experience of managers and decision makers. These criteria are further applied in the third and fourth steps. In the qualification process, the number of available suppliers is reduced according to their previous performance and these criteria, where suppliers are chosen after the qualification process in the final selection process for order allocation and optimization. This thesis thus categorizes the literatures according to the supplier selection framework.

2.2 Formulation of problem and criteria

The definitions of good suppliers are always changing alone with the development of economy and market. The most common criterion includes Price, quality, lead-time and delivery. But their priorities have changed from time to time. In 1978, Dempsey (1978) demonstrated the influence of 18 criteria on supplier selection process. The decreased number of criteria showed the inherently multi-objective nature in selection process. Weber (1991) has reviewed 74 related articles related to this topic and found out the changes of importance for each criterion on the traditional environment and the new Just-In-Time (JIT) system. The most significant changes are the increasing importance of production facilities & capabilities and geographical locations. This is due to the emphasis on local suppliers and flexible production abilities. Vendor selection criteria were firstly summarized by Dickson (1996). Results gathered from experienced managers indicated that Quality and Delivery are more important than the rest 21 criteria such as cost, geographic location and financial positions. The least important criteria were amount of past business, training aids and reciprocal arrangements.

Nowadays, the emerging of communication technology, globalization and competitive market drives the changes of criteria and their ranks. Cheraghi (2004) compared the criteria between 1966-1990 and 1990-2001 based on the previous researched. Criteria such as repair service, communication system, procedural compliance and financial position have become more and more important. While the priorities of Price, packaging ability and operation controls decreased to some extent respectively. Price was used to be viewed as the most important criterion but now quality has taken the role. New criteria are also added, for example, reliability and flexibility. And in terms of global supply chain management, economic status, trade restriction and government stability are generally accepted by managers as important criteria in selection process (Chan et al, 2004).

Differences on criteria also are reflected at different industries and production types with their special characteristic. The differences of supplier selection criteria among three types of products were discussed by Shipley (1993). His research aimed to identify the inherit selection preference in those three types of product. As his research showed, the priority of each criterion varies not only from the type of production but also from countries. Economic environment and culture of a country also play a part in forming the selection criteria. In electronic marketplaces, remedy for quality problem is taken into consideration for selecting suppliers (Chamodrakas et al, 2010). Even for single resource and multi-resource purchasing modes, differences exist on the criteria of price, reliability and technical support (Swift, 1995).

2.3 Qualification and final selection

As discussed above, these two steps involve reducing the number of suppliers by evaluating the performance of suppliers and deciding the optimum quantity of orders for each supplier. Firstly, for evaluating the performance of supplier, there are several popular techniques namely AHP, ANP, Data envelopment analysis (DEA), Cluster analysis (CA), Multi-attribute-utilize-technique (MAUT) and ANN. Talluri (2006) and Narasimhan et al (2001) employed DEA to measure the performance of suppliers in which evaluation is based on the efficiencies of alternative suppliers. Those suppliers rated as high performance and efficiency is usually selected in the end. AHP and ANP are also common methods that are used to determine the relative importance between different criteria as well as suppliers as shown in Chan (2007) and Muralidharan's work (Muralidharan, 1999). Integrated methods were then developed to compensate the weaknesses of each single method. An integrated fuzzy AHP and cluster analysis method was developed by Bottani and Rizzi (2008). Suppliers are ranked and grouped which helps reduce the number of alternatives and selection is based on the most suitable cluster. Choy et al (2003) presented a novel hybrid artificial neural network (ANN) and case based reasoning (CBR) method. CBR was applied to choose suppliers using previous experience and cases.

Then for determining the optimum allocation of production among suppliers, there are two categories of approaches to deal with the problem: Single objective and multi-objective. For single objective approach, linear or integer programming is often applied. But for multi-objective problem, methods such Genetic algorithms, goal programming and multi-objective programming are among the common techniques. Ng (2008) modeled the supplier selection problem using weighted linear programming which aims to maximizing the supplier score for an order. Hong et al (2005) utilized an integer non-linear programming for this problem. The optimum allocation of products could be decided to reduce the total cost. Multi-objective programming was applied to optimize three objective functions including price, lead time and rejects by Wadhwa and Ravindran (2007).

2.4 Gaps in literature review

The gaps are identified according to literature review and could be summarized into two parts: FAHP with Statistical analysis and SMEs supplier selection and order allocation optimization model.

First of all, among all the technique, AHP is a common method and widely used in all kinds of industries (Subramanian et al, 2012). Compared with mathematical programming, the weights of both qualitative and quantitative criteria could be determined. Pair-wised comparisons also make the decision making process easier than assigning precise weight values directly in mathematical programming. Even though the results of AHP are significantly depending on the subjective judgments, techniques such as fuzzy set theory could complement this disadvantage.

However, in spite of stating that AHP is capable of evaluating both quantitative and qualitative criteria, more attentions are given to the evaluation of qualitative criteria. In terms of quantitative criteria, there aren't many discussions about how to compare suppliers against quantitative criteria. For instance, in Chamodrakas et al (2010)research, a straight-forward 5-scale scores is used to rate suppliers against quantitative criteria, and the ranges for different scores are simply assumed to be linear from 90% to 100%. Historical data and information of each supplier has not been considered into this scoring system. And also based on the industrial case study, the performances of suppliers vary according to the type of production, its complexity and quality requirement of customers. Single scoring system could not accurately reflect the real weights and importance of suppliers when compared with each other.

While statistics is a technique that helps process, summarize, analyze and interpret information and data for better decision making in uncertain environment (Dixon et al, 1957). Statistics has been widely used in many areas like Business & Economics, Finance, Sociology, Psychology, Engineering and Management science (Gray, 1998)(Willinger et al, 1997). Who is the best worker in the company? What is your preference on shopping? How does the weather affect the growth of plant? All this questions can be answered by understanding the numbers that come with these events. Once the data are collected, proper statistical analysis is needed to find out the similarity, changes and trends. Methods including Parameter estimation, test of Hypotheses, Regression and correlation are popular in the statistical analysis. Finally the data are summarized in tables and graphs such as Bar chart, Pareto Diagram and histogram.

With respect to the supplier selection process, there are some researches mainly focusing on analyzing the effects of selection criteria on suppliers' performance. Verma (1998) examined the differences between managers' rating on perceived importance of suppliers' attributes and their actual choice of suppliers in experimental environment. Statistical analysis such as Discrete Choice Analysis (DCA) is used to find out the choice of suppliers. Vonderembse et.al (1999) used the data and information of suppliers to evaluate the impact of supplier selection criteria and involvement on manufacturing performance. The research supports that implementing supplier selection does help improving the performance of suppliers. Sanayei et.al (2008) used the statistical analysis to incorporate uncertainties in group decision making process for supplier selection. However, according to the literature up to now, there aren't many papers discussing about the use of statistics in evaluating suppliers, especially there isn't any work combining FAHP with statistical analysis for rate suppliers against quantitative criteria. This study thus tackles this problem using the novel method under the SMEs background.

Secondly during the literature review, there aren't a lot of works focusing on SMEs environment. Especially there isn't any work discussing about the supplier selection process for system integrator in manufacturing network. Kumaraswamy (2011) tackled the supplier selection in SMEs with integrated QFD-TOPSIS method. But only 7 criteria were taken into consideration and the thesis only focus on evaluating suppliers without generating optimum order allocation plan. Other research such as the one done by Arend (2006) focused on the role and performance of SMEs in supply chain.

Hence is there any new criterion that is specifically used by SMEs manufacturing network? What are the differences between SMEs supplier selection and other industries? How could we provide suitable supplier selection and order allocation methodologies? Those questions motivated our research presented in this thesis. Apart from that, literature review shows that GA is seldom used in supplier selection due to the low complexity of the problem for artificial intelligence. Fuzzy AHP also has not been integrated with GA before. Hence this approach in the thesis not only provides a new insight view of SMEs supplier selection and order allocation but also proposes a novel integration of FAHP and GA.

2.5 Conclusion

The focuses of literature review in the research are divided into two main categories: Formulation of problem/criteria and Qualification/Final selection. Based on the literature review, two major gaps in current research are identified:

- Lack of a systematic way to make use of historical data for supplier selection in most of Multi-criteria decision making techniques

- A practical and precise criteria system for supplier selection and order allocation specific for SEMs manufacturing environment

Hence this research aims to address these two gaps in the following aspects:

- A statistical analysis method is integrated with Fuzzy AHP to take historical data into evaluation process.

- GA is combined with modified FAHP to enhance the optimization accuracy

- A case study based on SMEs manufacturing industry is conducted to understand and model the supplier selection and order allocation process

The next chapter presents the industrial case study with a detailed introduction of the company, and other aspects of supplier selection and evaluation will be presented in the following chapters.

CHAPTER 3 - SUPPLIER EVALUATION AND SELECTION

3.1 Introduction

This Chapter presents the proposed methodology to supplier evaluation and selection in SMEs manufacturing networks. The industrial case study offered data and information of around 20 suppliers providing services including raw material, heat treatment and various manufacturing processes. All the suppliers have long term cooperation with the company in the case study of this project. In this research, Fuzzy AHP is employed as the technique to tackle the selection problem as mentioned above; however some major changes have been made for FAHP in terms of the comparison and evaluation of suppliers. First of all, suitable and important criteria have been identified and evaluated in one-to-one meetings with the managers in different functional areas. Then the traditional step of comparing suppliers is divided into two different steps: suppliers are evaluated against qualitative and quantitative criteria separately. Finally the global weights of suppliers are determined by combining the weights of criteria and suppliers. The whole process is shown as follows

1) Identify the important and suitable criteria and construct the decision hierarchy

2) Pair-wise comparison of the criteria and determine the weights

3) Compare suppliers against qualitative criteria

4) Rate suppliers using statistical analysis with respect to quantitative criteria

5) Calculate the global weights of suppliers

3.2 Industrial case study

To be able to understand and model the supplier selection and order allocation process, an Italian company called GFM s.r.l is chosen to conduct the industrial case study due to its specialty in SMEs manufacturing networks. Although GFM is a supplier of OEM parts for manufacturers of gas and steam turbines, it does not have any manufacturing capabilities and capacities. GFM actually acts as a central company to a group of local SMEs suppliers in Italy. Those SMEs suppliers provide various production capabilities ranging from machining, milling to raw material treatments. GFM has evolved from a local manufacturer and uses its reputation and networks to attract customers and orders. Now it is providing manufacturing and production solutions to the big companies such as Siemens. Their methods of forming manufacturing networks can be described in the following patterns:

- Single resource: If the order is not complex and could be accomplished by single supplier, then the order is given to one of the best suppliers based on their supplier evaluation system. Normally 2 or 3 candidates are available for selection.
- Multi-resource: If the order needs several production process and single suppliers could not fulfill the tasks, GFM would coordinate the production processes from raw material, manufacturing, transportation to quality inspections. One or more suppliers are selected for each process according to their capacities and availability. Logistics and Transportation will also be arranged from one manufacture to another.

No matter which pattern it is, GFM is in charge of inspecting the quality of products before they are sent to customers. The whole industrial case study involves:

- Interviewing managers with respect to current supplier selection process and relevant criteria
- Understanding the requirement for suppliers through survey and group discussion
- Visiting the SMEs suppliers to understand the formation of manufacturing networks

As indicated above, GFM is a typical and experienced company in managing, evaluating and selecting suppliers in SMEs manufacturing networks. Due to their expertise and experience, data and information collected from the managers and its suppliers could be assumed as meaningful and helpful to understand the supplier evaluation and selection in the proposed area.

3.3 Analytical Hierarchy Process and Fuzzy Set theory

AHP is one of the most useful and popular methods for Multi-Criteria Decision making due to its simplicity and capacity of handling complex problem. Saaty (1990) firstly proposed the method in 1970s which aims to help decision makers to rationalize their way of solving problems. AHP could be implemented in three steps: Firstly, the objective and a hierarchy of relevant criteria or factors are defined. The potential alternatives are represented at the lowest level in the hierarchy. Then the local weights for both criteria and suppliers are measured using numerical scales and pair-wise comparison. Usually a nine-point numerical scale is used to represent the relative importance between two factors. For instance, if criterion 1 is more important than criterion 2, then "7" is attributed to a_{12}. While if a_{14}=1, it means that criterion 1 is equally important with criterion 4. After the similar judgment process is applied to all the criteria, a positive reciprocal matrix is formed as shown in equation 1. $\tilde{a}_{nm}$ stands for the relative importance of the nth factor compared with mth factor. The matrix is used to calculate the weights of criterion. Methods such as Logarithmic least squares methods, Extent Analysis and Eigenvector analysis are commonly applied. Eventually the global weights of alternatives are determined.

$$A = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1m} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2m} \\ \vdots & \vdots & \dots & \vdots \\ 1/\tilde{a}_{1m} & 1/\tilde{a}_{2m} & \dots & 1 \end{bmatrix} \quad (1)$$

TABLE.I LINGUISTIC VARIABLES FOR WEIGHTS

Linguistic variables for weight of each criterion	TFNs
Extremely Important	(9,9,9)
Intermediate	(8,9,9)
Very Important	(7,8,9)
Intermediate	(5,6,7)
Important	(4,5,6)
Intermediate	(3,4,5)
Moderately Important	(2,3,4)
Intermediate	(1,2,3)
Equally Important	(1,1,1)

But as we discussed above, AHP is depending on the subjective judgment which undermines the accuracy of judgments. It is not capable of handling the vagueness and fuzziness in human's judgment, so fuzzy set theory is employed to compensate this disadvantage of AHP. Different with classic number or Crisp set, Fuzzy Set theory is formed of a class of objects defined by a membership function μ(x) which attribute a grade of membership to an object (Zadeh, 1978). The value of μ(x) changes with x within a certain range. Triangular fuzzy numbers (TFNs) is used in this research to represent the judgment of managers for the criteria in Figure 1 (Baliamoune-Lutz, 2009). As illustrated in Table I, a nine-point numerical scale is proposed. Each fuzzy number represents a degree of importance. When making decisions, managers only need to select one linguistic variable to represent their judgment of importance. The corresponding fuzzy number will be attributed to the matrix.

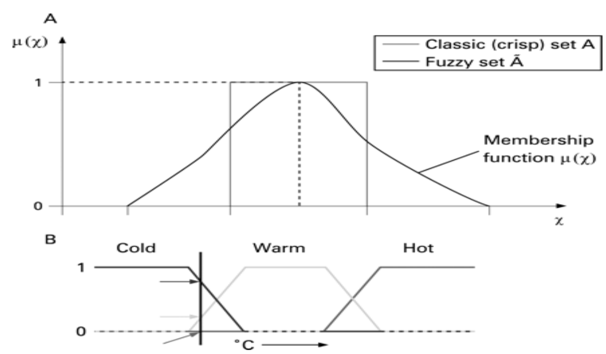

Figure.1 the fuzzy number and classic crisp number

Similar to the traditional AHP, first of all, the fuzzy comparison matrix is formed. This thesis utilizes the method proposed by Buckley (1985) to calculate the fuzzy weight of both the criteria and alternatives.

$$\widetilde{w_i} = \left(\prod_{j=1}^{m} \tilde{a}_{ij}\right)^{\frac{1}{m}} * \left(\sum_{i}^{m} \left(\prod_{j=1}^{m} \tilde{a}_{ij}\right)^{\frac{1}{m}}\right)^{-1} \quad i,j = 1,2,3 \ldots m \qquad (2)$$

With the fuzzy weights obtained, the defuzzication process is necessary to transform a fuzzy number to a crisp number. Centre of Gravity method (Broekhoven and Baets, 2006) is used and shown in Equation 3 due to its simplicity.

$$w = \frac{\int u_i(x) x dx}{\int u_i(x) dx} \qquad (3)$$

Finally, the global weights of each supplier are determined in equation 4:

$$W_{global} = \sum (w_{criterion} * w_{supplier}) \qquad (4)$$

3.4 Evaluate the performance of suppliers against quantitative criteria

In this research, the occurrence of an event such as delivery delay and quality failure is regarded as independent stochastic. For those data with known data pattern, their distribution of population could be estimated using methods like Maximum likelihood estimation, least square estimation. Both of them could fulfill the tasks with minor difference of accuracy. However since the patterns of distribution and parameters in this data set are unknown, a non-parameter estimation method is required to estimate the distribution with limited data.

Kernel density estimation is a non-parameter method of estimating the probability density function for random variables (Ruan, 2010).It is also named as Parzen-Rosenblatt window method and used in many fields. The estimation is based on finite data set and inferences about the population. Equation 5 shows working principle of Kernel estimation where $x \ldots x_i$ are the random data taken from a population with unknown distribution. K (●) is the kernel which is a function that integrates to one. And h is the smoothing parameter which is also named as bandwidth. For more information, please refer to the literature indicated above. The whole process is operated using Matlab.

$$\widehat{f_h}(x) = \frac{1}{n}\sum\nolimits_{i=1}^{n} K_h(x - x_i) \qquad (5)$$

Sheather et al. (1991) used Kernel density estimation for data-based Bandwidth selection which shows superior theoretical performance. Anderson (2009) has applied Kernel density estimation in road accident hotspots profiling. The method specifically modeled the spatial patterns of injury related to road accident.

By applying Kernel density estimation, the quantitative behavior of suppliers could be modeled in the form of probability distribution and probability density function (PDF). PDF shows the relative likelihood for a random variable to take on a given value. In our research, it describes the probability of occurrence for different values in one criterion which in turn indicates the priority of a given performance in quantitative criteria. The proposed method is operated in the following steps: First of all, histogram is generated using the data collected from industrial case study. Then the continuous probability density function is generated using Kernel Density estimation method. Eventually the cumulative probability distribution is determined and a corresponding scoring system is decided based on the overall performance in the whole data set.

3.5 Conclusion

This chapter presents the methodology that has been used to evaluate suppliers' performance. Fuzzy Analytical Hierarchy Process is further elaborated and the functions are clearly defined and discussed. Statistical analysis is introduced next and Kernel density estimation is selected to process the historical data of suppliers due to its capability of handling non-parametric data set. In chapter 5, a numerical example of this methodology is provided to show the performance of the proposed method to supplier evaluation and selection.

CHAPTER 4 - GA OPTIMIZATION AND ORDER ALLOCATION

4.1 Introduction

Identifying the best suppliers is only a part of the whole supplier selection and order allocation process. In most cases for SMEs manufacturing networks, more than one supplier is employed to undertake the manufacturing tasks. A serious challenge that was identified for GFM was in relation to the availability of suppliers. To be more specific, for complex order, usually only 2 or 3 suppliers could be qualified to manage the majority of the production processes. If all of the suppliers have full production schedules, then the order will be delayed. One solution for this problem is to divide the complex product and its manufacturing processes into different components and processes including assembling. If required, the components could be further divided into sub-components. Then GFM will find the suitable suppliers for each component and subcomponent and coordinate the rest of activities for suppliers. However, a major issue here would be complexity of management and high management cost using current coordination methods.

4.2 Problem definition and mathematical model

Based on the challenge stated, a practical example is defined and a mathematical model is generated. A complex product such as gas turbine is divided into 20 orders covering the raw material, component, subcomponent and assembly. 10 manufacturing competencies are required for all the production process and each process needs up to 2 competencies. There are 10 suppliers in total are available for selection and the type of order and quantities that could attributed to them are restricted by their competencies and capacities.

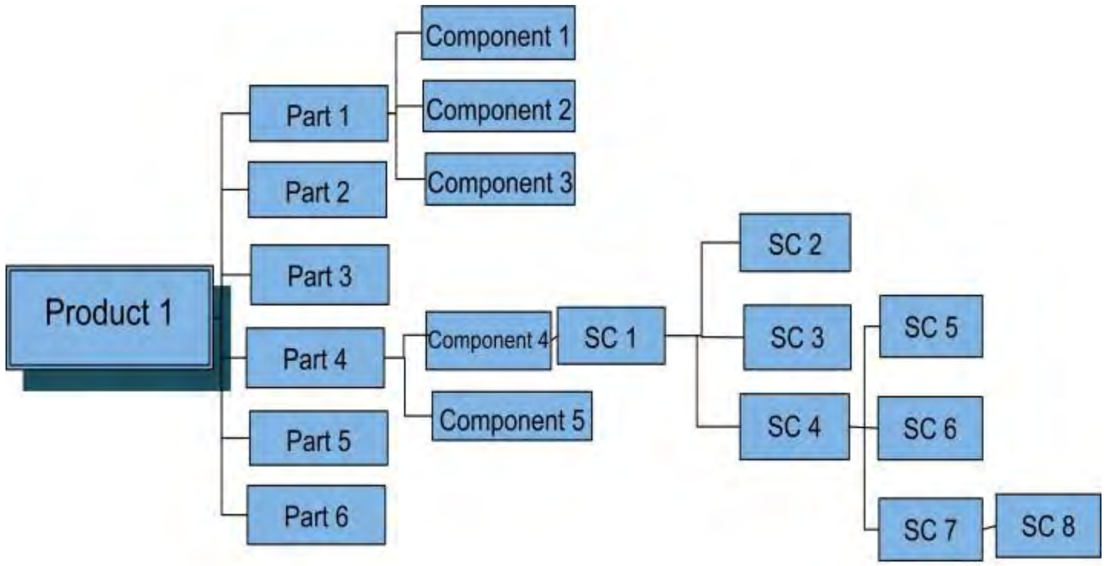

Fig.2 The Structure of Production

The simulation aims to generate the optimum combination of suppliers and make the most of their capacities.

The model is built based on the following assumption:

1. The capacity of each manufacturer's competency is known to system integrator.
2. Suppliers bid for different number of orders according to their own capabilities and production schedule
3. Suppliers' capacity on one competency could bid for different orders.
4. The total quantity allocated to one supplier cannot exceed the capacity of the supplier on that specific competency.
5. Management cost is decided by the number of participants and the cost remains the same with all the participants in one order.

6. The number of suppliers selected for one order is not limited and is decided by the optimization.
7. The sequence of each order is defined and the total lead time of production is the aggregation of the lead time in each phrase.

Notation:

s	The index for Suppliers, s = 1…S, where S is the number of suppliers
o	The index for orders, p =1…O, where O is the number of orders
o’	The precedence order of order o
mc	The index for Manufacturing Competencies, mc=1…MC, where MC is the number of competencies
$UC_s^{o,mc}$	The unit cost of supplier on manufacturing competency mc for order o
$UL_s^{o,mc}$	The unit lead-time of supplier s for production of order o and competency mc
$AQ_s^{o,mc}$	The average quality of supplier s for production of order o and competency mc
MGC_s	The management cost of one supplier
D_o	Demanded quantity of order o
ω_s^{mc}	The weight of supplier s on the competency mc determined by FAHP
α_i	The weight of KPIs for different optimum solution, i = 1….I, I is the number

	of KPIs.
US	Utilization score
$Q_s^{o,mc}$	Quantity distributed to supplier “s” on order o for competency mc
$Lg_{s,s'}$	Logistics time between supplier s and supplier s’
$LgC_{s,s'}$	Logistics cost between supplier s and supplier s’
ST_o	Starting time of order o
FT_o	Finishing time of order o
L_o	Lead-time of order o
TL	Total lead-time of the whole product
TC	Total cost of the whole product
TQ	Total Quality of the whole product

Objective function:

$$\text{Max } X = (\alpha_1/TC) + (\alpha_2/TL) + \alpha_3 US + \alpha_4 TQ \qquad (6)$$

Where:

$$TC = \sum_O \sum_S \{((UC_s^{o,mc} * Q_s^{o,mc}) + LgC_{s,s'} + MGC_s)\} \quad (7)$$

$$TL = \sum_o (L_o + L_{(o')}) \quad (8)$$

$$TQ = \sum_O \frac{\sum_S (AQ_s^{o,mc} * Q_s^{o,mc})}{\sum_S (Q_s^{o,mc})} \quad (9)$$

$$L_o = Max_s(UL_s^{o,mc} * Q_s^{o,mc}) \quad (10)$$

$$US = \sum_O \sum_S (\omega_s^{mc} * Q_s^{o,mc}) \quad (11)$$

Subject to:

$$C_s^{mc} \geq \sum_o Q_s^{o,mc} \quad (12)$$

$$D_o = \sum_s Q_s^{o,mc} \quad (13)$$

$$ST_o = FT_{o'} \quad (14)$$

$$Q_s^{o,mc} \geq 0 \quad (15)$$

$$\sum_i \alpha_i = 1 \quad 1 > \alpha_i > 0; \quad (16)$$

The objective function is used to maximum the value combining lead time, quality, cost and utilization score. To be noticed that in equation 6, the increase of cost and lead time lead to the decrease of the overall value while the increase of quality and utilization rate would help improve the final results. α_i represents the weights of cost, lead time, quality and utilization score for optimization respectively. Total cost of production consists of the cost for manufacturing, management cost and the logistic cost as shown in equation 7.

To calculate the total lead time, the lead time of each order should be determined in equation 10. The lead time of one order is decided by the biggest lead time among all the suppliers. Then the total lead time could be calculated by summing up the lead time of each order according to their pre-defined sequences in equation 8. Equation 9 indicates the total quality which is the sum of average quality for each order. Utilization score is calculated by taking the weights of suppliers into consideration. Weights of suppliers obtained from FAHP are multiplied by their quantity allocated. So if most quantity of an order is allocated to the best supplier, the value of US for this specific order would be high which reflects the selection preference of managers. Equ.13 and 16 require that the sum of quantity allocated to a supplier on specific competency needs to be equal or less than total capacity on this competency. And in equation 13, the sum of quantity given to each supplier should equal the demanded quantity of the order. Equation 15 assumes that the finishing time of previous order is the same with the start time of the following order. The value of α_i should varies between 1 and 0 and the sum of all the four values should equals to 1 by all means.

4.3 GA optimization

GA is one of the evolutionary algorithms that mimic the process of natural evolution and inspired by Darwin's principle "Survival of the fittest" (Goldberg and Holland, 1988). GA applies the natural selection law to search for global optimum result and solution for complex problem. Natural inspired techniques such as mutation, selection and crossover are used in GA. Solutions in GA are represented by a chromosome, while the data are represented by gene in each chromosome. During the optimization process, genes are constantly changing the value which leads to new solution and the overall performances of chromosome are improved. Chromosomes are evaluated by a pre-defined fitness function. In each generation only the best chromosomes are selected for next round of optimization which reflects the evolution process in natural selection.

As a representative of heuristic search algorithms, GA is widely used for global optimization problems such as scheduling and work allocation. Cheng et al (1996) applied GA to Job-shop scheduling problems; hybrid genetic search strategies are used in their research to improve the efficiency of optimization. Bierwirth and Mattfeld (1999) added rescheduling problem into the production scheduling and solved the problem with GA. Smith and Smith (2002) applied GA to tackle the assembling planning problem and GA shows advantages both in its optimization speed and reliability compared with other methods. Hence this research utilizes Genetic algorithms to find the optimum combination of suppliers.

The proposed modified GA optimization is shown as follows:

Step 1: Encoding of Chromosome

The quantity attributed to a supplier on a specific manufacturing competency is represented by a gene in Figure 3. The adjacent genes such as Gene 6, 7 and 8 are those quantities bid for order 3. This restriction is decided by the number of participants available and qualified for this order. Meanwhile, the total capacity of capability 1 from supplier 1 is divided among gene 6, 10 and 12 which means supplier 1 bids for order 3 to 5 at the same time using the same capability. The values of these three genes should meet the capacity limit based on equation 12. For instance, the quantity allocated to supplier 1 base on capability 1 and bided for order 3 is determined by the value in Gene 6. The number of gene or participants is decided by the availability of suppliers and the demanded quantity of the order.

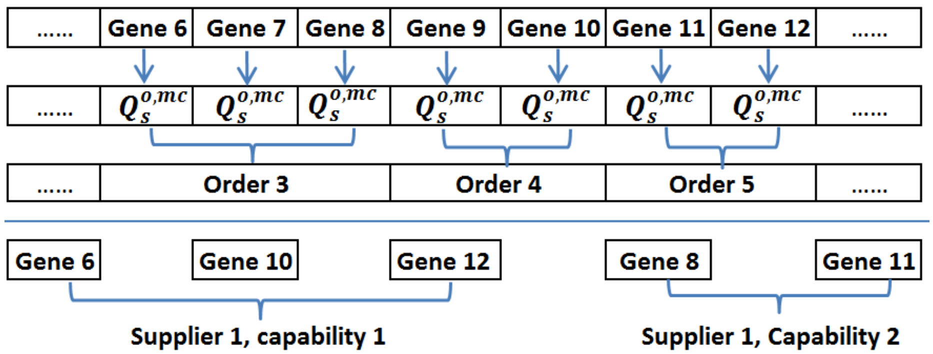

Fig.3 The encoding of chromosome

Step 2: Initiation:

Data and values for genes are generated according to the constraints mentioned in mathematical model. Especially the values generated should obey the capacity constraints and demanded quantity for orders. Suppliers randomly bid some of the orders for which they are qualified. The number of genes is determined by counting the number of active bids for all the suppliers.

Step 3: Evaluation

Objective function in mathematical model is used as the fitness function in GA optimization. Chromosomes in each generation are evaluated against the function and the top five with the highest fitness value are selected into the second generation.

Step 4: Crossover and mutation

In this research, traditional single point crossover and mutation are operated. To be more specific, in crossover, two chromosomes are selected according to their fitness value. And then a random gene on the chromosome is generated and the part of chromosome after this gene is swapped with another chromosome. While in mutation, one chromosome is selected by roulette-wheel selection and the value in one of its gene mutate to a new value which is within the limit of capacity.

However, to be noticed, genes are interlinked with each other due to the constraints of capacity and demanded quantity. As indicated in the previous part, Gene 6, 7 and 8 represent those quantities bid for order 3. So if the value in Gene 6 is changed, then the number in Gene 7 and 8 should be altered accordingly to satisfy the constraint in equation 13 for demanded quantity of orders. Meanwhile, since Gene 6 is linked to Gene 10 and 12 due to the limit of supplier's capacity, Gene 10 and 12 should also be changed. To solve this problem and maintain the validity of chromosomes after mutation and crossover, a repair mechanism is created and the details are shown below.

Step 5: Repairing mechanism

Take the mutation as example, one of the chromosomes is selected for mutation. The original chromosome is shown below.

Gene	……	***6***	***7***	8	9	10	***11***	12	……
Original	……	10	*35*	*42*	35	15	*17*	26	……

Fig.4 An example of a chromosome

If the value in Gene 8 is chosen and mutate from 42 to 20 with a quantity change of 22, other interlinked genes should be altered as well. According to equation 12 and 13, two separate repairing operations are needed under two different constraints:

1. Order demanded quantity: As shown in Figure 5, Gene 8 contributes to Order 3 together with Gene 6 and 7 and the quantity of order should always remain the same. Hence the quantity change brought by Gene 8 should be divided between Gene 6 and 7. As shown in figure, X and Y are added to the value of Gene 6 and 7 separately. The sum of X and Y should equals to 22.

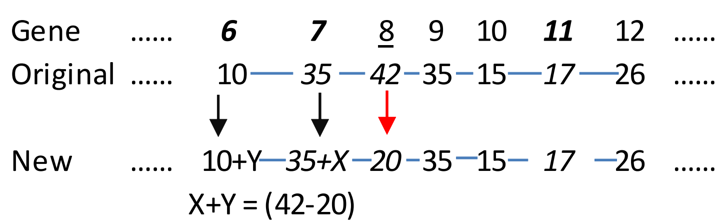

Fig.5 Change of Chromosome due to constraint 1

2. Suppliers' capacity: Different with step 1, the supplier capacity constraint requires the total quantity allocated to genes should be equal or smaller than the capacity of supplier. In Figure 6, for Gene 8, Gene 11 shares the capacity of supplier with it. So unless the new quantity value makes the total value of Gene 8 and 11 excesses the capacity of Supplier 1, the value of Gene 11 does not need to be changed. On the other hand, if the value of Gene 8 increase from 42 to 100 and the sum of Gene 8 and 11 is more than the capacity, then the value of Gene 11 should be reduced to satisfy equation 7.

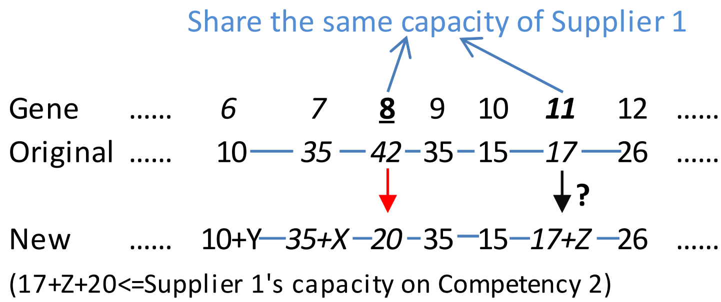

Fig.6 Change of Chromosome due to constraint 2

Iterative process for step 1 and 2 are implemented until the whole chromosome is restored back into validity and meet the requirement of equation 12 and 13. And then the chromosome is ready for further evaluation and optimization.

4.4 Conclusion

Chapter 4 focuses on the optimization problem definition and presents the detailed mechanism of Genetic Algorithms. A mathematical model is established with all the parameters and notions defined. Through this mathematical model, the process of supplier selection and order allocation for SMEs manufacturing networks could be fully reflected and modeled. GA optimization is strictly based the four objective functions shown in the previous chapter. The mechanism of GA is indicated later in this chapter. The encoding of chromosome, crossover & mutation and evaluation are introduced in depth to show the principle of Genetic algorithms. Furthermore, a repairing mechanism is proposed to improve the efficiency of optimization.

CHAPTER 5 - ILLUSTRATION EXAMPLE

5.1 Introduction

In this chapter, the methodologies presented in the previous chapters are applied in an illustrated example. The complete supplier selection and order allocation processes are shown using tables of data. First of all, the supplier selection process is conducted and then GA optimization is applied with the use of global weights generated from FAHP. The detailed description is shown as follows.

5.2 Supplier selection

5.2.1 Identify the important criteria and construct the decision hierarchy

Different industries process different criteria and requirements for suppliers. It is same for a single company that different departments have various understanding of a good supplier. In order to include the criteria of every important aspect for a supplier, a group interview was proposed and implemented. 7 managers from Sales department, Quality control, Logistics, Production, Purchasing, Finance and general management participated in this interview. The interview aimed at discovering what criteria are crucial and how important they are. Managers from different departments suggested those criteria related to their functional areas and the comparison process followed the method in AHP. As a result, the proposed hierarchy of criteria is presented in Fig.7.

Delivery, Quality, Capacity & Technology, Service, Management and Cost are selected as the key criteria in the evaluation which form the first hierarchy. Both qualitative and quantitative sub-criteria are further considered in the second hierarchy. The suppliers are placed in the third hierarchy and are compared with each other against those sub-criteria.

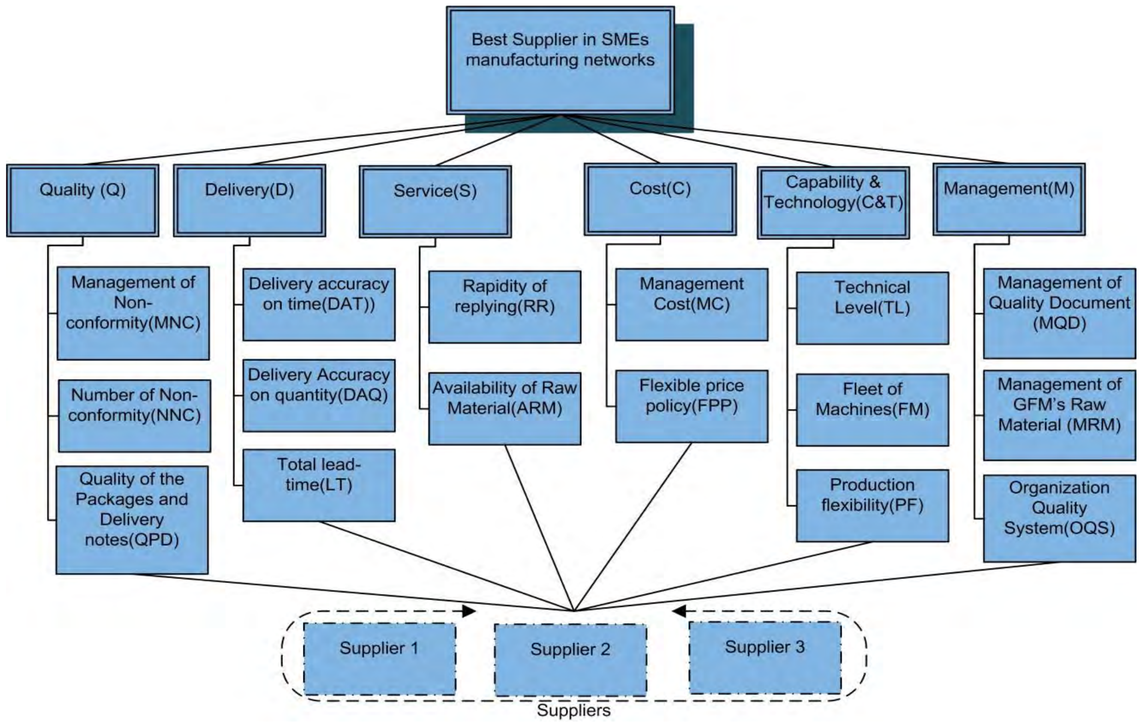

Fig.7 The identified Criteria for selecting criteria

5.2.2 Pair-wise Comparison of Criteria

Then the criteria and sub-criteria are compared and the results are assigned to comparison matrix tables. The comparison results based on the judgment of managers are shown in Table II-VI. The meaning of abbreviations could be found in Figure 7 accordingly.

TABLE.II THE FUZZY MATRIX OF CRITERIA FOR BEST SUPPLIERS

Criteria	Q	D	S	C	C&T	M
Q	1	(2,3,4)	(5,6,7)	(5,6,7)	(2,3,4)	(2,3,4)
D	1/(2,3,4)	1	(3,4,5)	(3,4,5)	(2,3,4)	(2,3,4)
S	1/(5,6,7)	1/(3,4,5)	1	(1,2,3)	1/(2,3,4)	1/(2,3,4)
C	1/(5,6,7)	1/(3,4,5)	1/(1,2,3)	1	(3,4,5)	1/(3,4,5)
C&T	1/(2,3,4)	1/(2,3,4)	(2,3,4)	1/(3,4,5)	1	(1,2,3)
M	1/(2,3,4)	1/(2,3,4)	(2,3,4)	(2,3,4)	1/(1,2,3)	1

TABLE.III THE EVALUATION MATRIX REGARDING THE CRITERIA IN **CAPABILITY & TECHNOLOGY**

Criteria	TL	FM	PF
TL	1	(1,2,3)	(1,2,3)
FM	1/(1,2,3)	1	(1,2,3)
PF	1/(1,2,3)	1/(1,2,3)	1

TABLE.IV THE FUZZY MATRIX FOR SUB-CRITERIA IN **QUALITY**

Criteria	MNC	NNC	QPD
MNC	1	1/(1,2,3)	(1,2,3)
NNC	(1,2,3)	1	(2,3,4)
QPD	1/(1,2,3)	1/(2,3,4)	1

TABLE.V THE EVALUATION MATRIX REGARDING THE SUB-CRITERIA IN **DELIVERY**

Criteria	DAT	DAQ	LT
DAT	1	(1,2,3)	(1,1,1)
DAQ	1/(1,2,3)	1	(1,2,3)
LT	(1,1,1)	1/(1,2,3)	1

Due to the large number of comparison tables, Technic level is used as an example in Table VI to show the comparison between suppliers.

TABLE.VI THE COMPARISON MATRIX OF SUPPLIERS WITH RESPECT TO **TECHNIC LEVEL (QUALITATIVE)**

Suppliers	S1	S2	S3
Supplier 1	1	(1,2,3)	(2,3,4)
Supplier 2	1/(1,2,3)	1	(2,3,4)
Supplier 3	1/(2,3,4)	1/(2,3,4)	1

Table .VII illustrated the overall weights of each criterion and sub-criterion calculated by the method proposed in the previous chapter. Similar to the results from other industries, Quality and Delivery are the most important criteria which accounts for 0.3413 and 0.2400 respectively. Number of non-conformity is the most important sub-criterion both in Quality part and among all the sub-criterion. Management of Non-conformity also plays a crucial role in the whole system. While in Delivery part, both the accuracy on time and quantity have more priorities than the total lead-time. Capacity & Technology and Management are less important than Quality and delivery but still influence the selection of suppliers. Especially Technical Level constrains the number of candidates due to the limited capabilities for SMEs manufactures. Traceability of GFM's raw material, Management of GFM's Quality Document and Quality system are equally important in GFM's point of view. To be noted that the Traceability of GFM's Raw material is a typical criterion in manufacturing networks, since usually the raw material is provided by GFM or other suppliers to this manufacturer. Cost is the least important criterion which consists of management cost and Flexible billing policy.

TABLE.VII THE OVERALL WEIGHTS FOR ALL THE CRITERIA

Criteria		Global Weights
Quality		0.3413
Management of Non- conformity	**(Qualitative)**	0.1051
Number of non-conformity	**(Quantitative)**	0.1772
Quality of the packages and delivery notes	**(Qualitative)**	0.0591
Delivery		0.2400
Delivery accuracy on time	**(Quantitative)**	0.0944
Delivery Accuracy in quantity	**(Quantitative)**	0.0822
Lead time	**(Quantitative)**	0.0635
Service		0.0655
Rapidity of replying	**(Qualitative)**	0.0164
Availability of raw material	**(Qualitative)**	0.0491
Cost		0.0386
Management cost	**(Quantitative)**	0.0193
Flexible billing policy	**(Qualitative)**	0.0193
Capability		0.1685
Technical level	**(Qualitative)**	0.0817
Fleet of Machines	**(Qualitative)**	0.0497
Flexibility of production	**(Qualitative)**	0.0371
Management		0.1461
Management of GFM's Quality Document	**(Qualitative)**	0.0487
Traceability of GFM's Raw material	**(Qualitative)**	0.0487
Organization –Quality system	**(Qualitative)**	0.0487

It helps prove the fact that cost is no longer an important factor in choosing suppliers.

5.2.3Pair-wised comparison between suppliers with respect to qualitative criterion

For qualitative criteria such as management of Non-conformity and rapidity of replying, there isn't any data or information to back up the judgment of their performance. Managers' and staffs' experience is sufficient enough to compare the suppliers' performance. Hence pair-wised comparison is also used for this part to calculate the supplier's weights on qualitative criteria using equation 2 and 3. Two examples are shown below. In Table VI, 3 suppliers are compared against their management of Non-conformity. Managers, first of all, choose one of the linguistic variables that match their preference and then the corresponding fuzzy number is attributed to the matrix table. In this example, supplier 1 is regarded as moderately important when compared with supplier 3, so fuzzy number (2, 3, 4) is assigned according to table. I.

5.2.4Rate suppliers using statistical analysis with respect to quantitative criteria

The industrial case study shows that the types of production process influence the performance of suppliers on different criteria such as delivery and quality. To be specific, the complexity of production would affect the overall performance of suppliers. For example, complex production process has high possibility to long lead-time or delivery delay. So in order to generate an accurate estimation in statistical analysis, the complexity of production is taken into consideration and used to categorize the orders accomplished by suppliers. It is divided into 3 types: "Standard", "Complex" and "Very complex". The categorizing of orders is based on the experience of managers which makes sure that the comparisons are made between similar types of production complexity. In this thesis, the "Delivery accuracy on time" is used as an example to demonstrate the calculation process.

Table VIII presented the data of all the suppliers' delivery accuracy for production type "Complex" in the past one year.

TABLE.VIII DELIVERY DELAYS IN 2011 WITH PRODUCTION TYPE **"COMPLEX"**

Order number	Supplier	Production type	Delivery delay(Days)	Date
1	S1	Complex	12	01/02/2011
2	S2	Complex	5	01/05/2011
…	…	…	…	…
216	S1	Complex	17	12/21/2011

Using Matlab®, the data and values are processed in the following steps:

1) Plotting histogram of the delivery delay

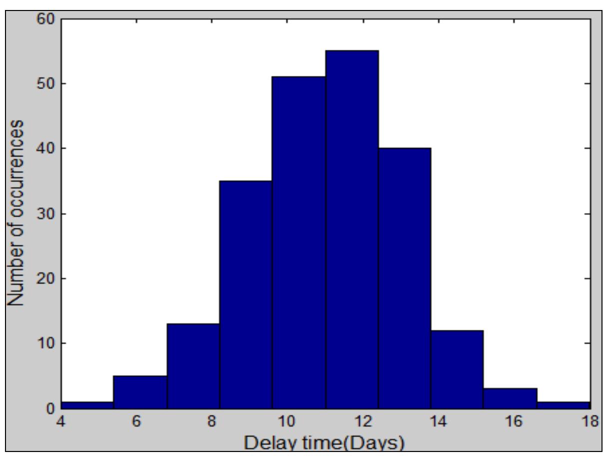

Fig.8 Histogram of delay time

The histogram reflects the occurrence of delivery delay time according to Table VIII. Based on the figure, the delay time ranges from 4 days to 18 days and the majority of delay time locate between 8 and 14 days. The average delay time is around 11 days.

Delay time of 10 to 12 days happens more than 55 times which is the highest among all the values.

2) Estimating the probability density function (PDF) and cumulate density function (CDF)

As introduced in the previous chapter, Kernel density estimation is chosen to estimate and generate the PDF and CDF which are presented in Figure 9 and 10 separately.

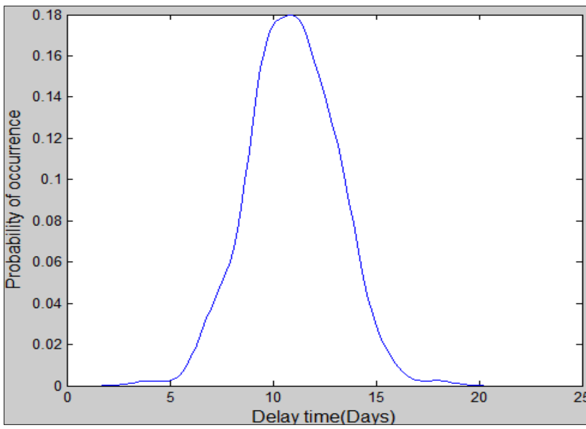

Fig.9 Estimated PD distribution

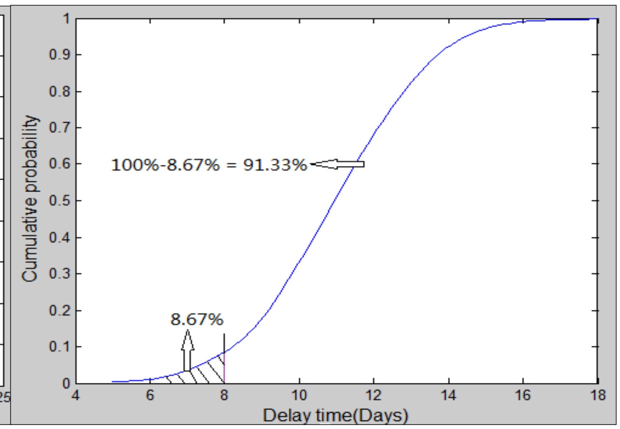

Fig.10 CP Distribution

The probability distribution function stands for the possibilities that a delay time could occur. The ranges of delay time increase from 4-18 days to 2-20 days. The probability for delay time of 20 days is estimated through Kernel density estimation. Meanwhile, the cumulative probability (CP) shows the likelihood that a delay time is less than or equal to a given value. Table IX illustrates the cumulative probability for each delivery delay. For instance, the occurrences of delivery delay, which are less than 8 days, account for 8.67% of all the orders. The value of 8.67% covers the delivery delay of 5, 6, 7 and 8 days.

To be noticed, if Q is defined as:

$$Q = 1 - CP \tag{17}$$

Then Q represents the possibility that the delay time is more than the given value. In the previous example,

$$Q = 1-0.0867 = 0.9133 \quad (18)$$

Hence the orders with delivery delay which is more than 8 days takes 91.33% of all the orders. In terms of this application, the value of Q indicates the relative preference of a certain delay among the whole population. When Q = 0.3042, it shows that the delay time of 12 days is better than the delay time in 30.42% of all the orders. The value of Q statistically reveals the relative importance of a certain delay time and could be employed as a scoring system for quantitative criteria.

3) Rating suppliers according to the quantitative criteria scoring system

With the value cumulative probability and Q determined, a rule is defined in table X. As seen in this table, If $Q > 0.8$, then the corresponding delivery delay time satisfying this constraint is rated as 5. And if $0.4 > Q > 0.2$, then a score of 2 is assigned to those delivery delay time. Specifically, if a delay time in one order is better than the delay time in 80% of all the orders, the performance of this order on delivery delay is rated as 5. But if the performance is only better than 40% of the orders, the order can only be rated as 2 point.

Then the rule created is applied to evaluate suppliers. The average delay time of a certain supplier in the past one year is selected as a key performance indicator and compared with the values in scoring system. If three suppliers are compared with each other with respect to their delivery delay, according to the data in Table XI, the average delivery delay of supplier 1 2 and 3 is 12, 6 and 18 days respectively.

TABLE.IX THE RELATIONSHIP BETWEEN CP AND Q

Delivery Delay	**Cumulative probability(CP)**	**Q = 1-CP**
5 days	0.0050	0.9950
6days	0.0100	0.9900
7days	0.0346	0.9654
8days	0.0867	0.9133
9days	0.1847	0.8153
10days	0.3298	0.6702
11days	0.5171	0.4829
12days	0.6958	0.3042
13days	0.8238	0.1762
14days	0.9263	0.0737
15days	0.9705	0.0295
16days	0.9901	0.0099
17days	0.9952	0.0048
18days	0.9977	0.0023

Based on the scoring system, score of 2, 5 and 1 would be attributed to each of them. Then the overall weights of them can be obtained by normalized the scores. The local weights generated in this step are used in the calculation for global weights of suppliers.

TABLE.X THE RULES TO CONVERT PROBABILITIES INTO SCORES

If	Then score	Delay time Range	Score
1.0>Q>=0.8	5	Delay <= 9 days	5
0.8>Q>=0.6	4	Delay =10 days	4
0.6>Q>=0.4	3	Delay =11 days	3
0.4>Q>=0.2	2	Delay =12 days	2
0.2>Q>=0	1	Delay>=13 days	1

TABLE.XI SUPPLIERS' WEIGHTS BASED ON THE NEW RULE

Supplier	Average Delivery Delay (Days)	Score	Weights
S1	12	2	0.250
S2	6	5	0.625
S3	18	1	0.125

TABLE.XII THE FINAL SUPPLIER SELECTION RESULTS

Weight	Supplier			
Criterion	**S1**	**S2**	**S3**	**Best supplier**
Quality	***0.1853***	0.1230	0.1444	S1
Delivery	***0.1235***	0.1022	0.0507	S1
Service	0.0146	0.0179	***0.0202***	S3
Capability & Tech	0.0370	***0.0687***	0.0370	S2
Cost	**0.0091**	0.0071	0.0081	S1
Management	0.0171	0.0119	***0.0223***	S3
Global	***0.3866***	0.3307	0.2828	S1

5.2.5 Calculating the global weights for suppliers

By combining the weights of criteria and suppliers, the overall weights could be calculated using Equation 4. The weights of suppliers on certain sub-criteria are determined and then the sum-up attribute to the weights of suppliers on each criterion. The results of 3 suppliers are shown as an example in Table XII. As indicated in the table, each supplier has its own advantages and disadvantages. The numbers indicate the preference of choosing this supplier among all the candidates or priority of choice. Supplier 1 is the best supplier on Quality, Delivery and Cost. Supplier 3 has the best performance on service and management. While supplier 2 only shows advantage on its capability and technology level. After all, due to the high priority of Quality and Delivery, supplier 1 is the overall best supplier for this order with the priority of 0.3866. Supplier 3 is slightly behind supplier 1 with 0.05 differences in selection preference.

5.3 Order allocation

GA in this research is programmed using C++. Mutation rate and crossover rate are set as 0.95 and 0.10 respectively. The data of suppliers and other parameters such as cost, Unit lead-time are generated based on industrial case study samples. Four objectives are taken into consideration which is Cost, Lead-time, Quality and Utilization score respectively. By changing the weights distributed to each objective, different solutions could be generated. Take cost and Lead-time as an example, the weights of cost and Lead-time are changed from 0.75 to 0.05 and 0.05 to 0.75 respectively while the weights of utilization score and quality are kept the same at 0.1. Table XIII shows the results from GA optimization:

TABLE.XIII GA OPTIMIZATION RESULTS SCENARIO 1-9

Scenario	Weights	Cost/Pound	Lead-time/Hour	Utilization score	Quality
1	**(0.75, 0.05, 0.1, 0.1)**	**396066**	**1867**	**0.7355**	**0.8732**
2	(0.7, 0.1, 0.1, 0.1)	396796	2301	0.7657	0.9112
3	(0.6, 0.2, 0.1, 0.1)	397397	2208	0.7443	0.8823
4	(0.5, 0.3, 0.1, 0.1)	402804	1089	0.742	0.8736
5	(0.4, 0.4, 0.1, 0.1)	410868	992	0.6831	0.8589
6	(0.3, 0.5, 0.1, 0.1)	409910	995	0.6887	0.8624
7	(0.2, 0.6, 0.1, 0.1)	414286	981	0.7084	0.8718
8	(0.1, 0.7, 0.1, 0.1)	415060	975	0.7041	0.8703
9	**(0.05, 0.75, 0.1, 0.1)**	**418414**	**996**	**0.7094**	**0.8714**

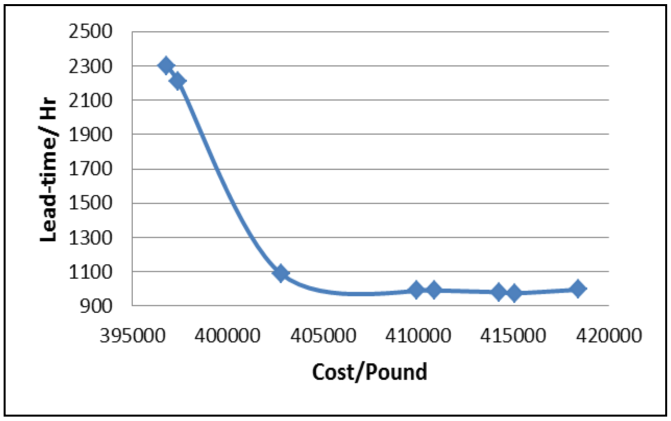

Fig.11 The relationship between Cost and Lead-time

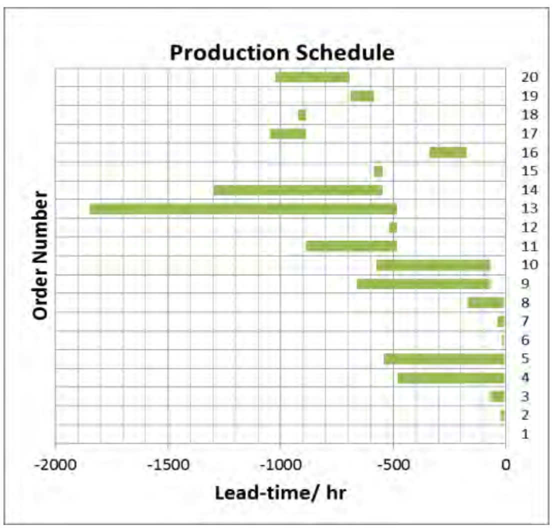

Fig.12 The production schedule of Scenario 1

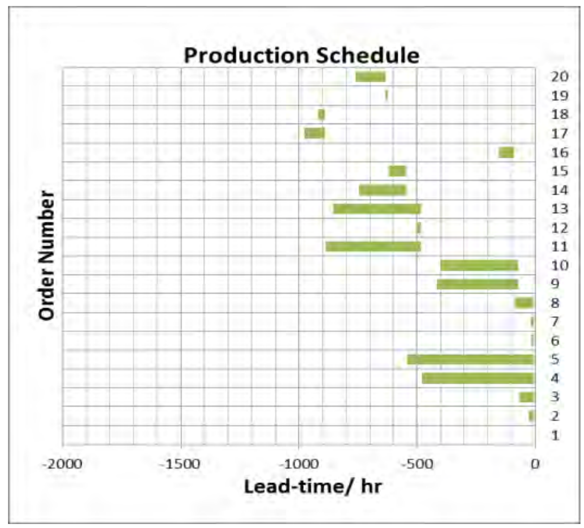

Fig.13 The production schedule of Scenario 7

It is clear in Figure 11 that the value of Lead-time increases along with the decrease of Cost. For example, the cost in scenario 2 is around 6% less than the value in scenario 9 while the lead-time is reduced to 43% of the original value. The reason behind this phenomenon is the spread of order among suppliers. When low Cost is the main objective for optimization, the order will be allocated to the supplier with the lowest bidding price. So the lead-time is relatively higher than the order is undertaken by several suppliers at the same time. Figure 12 and 13 could help prove this point which is shown.

Figure 12 shows the production schedule for scenario of (0.75, 0.05, 0.1, 0.1) while the result of scenario of (0.2, 0.6, 0.1, 0.1) is presented in Figure 13. In Figure 12 which is cost-oriented, the lead-time of production is of 1867 hours. But in lead-time-oriented scenario, the lead-time is of 981 hours.

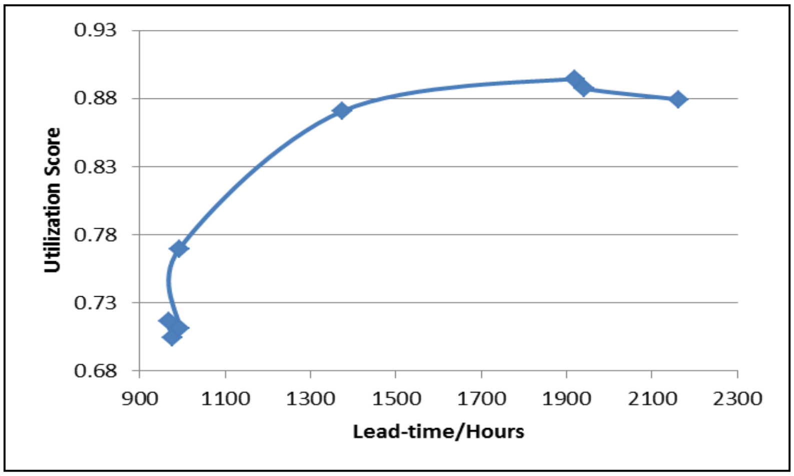

Fig.14 The relationship between Lead-time and Utilization Score

Another example is of the relationship between Lead-time and Utilization score. Table XIV presents the optimization results where the weights of cost and Quality are fixed at 0.1.

According to Figure 14, the Utilization score increases with the rise of Lead-time. For instance, the value of lead-time increases from 975 to 2162 while the weights change from 0.7/0.1 to 0.1/0.7 between Lead-time and Utilization score. High utilization score means that majority of orders are attributed to the best suppliers for each order. So the lead-time is significantly increased due to less number of participants in one order.

TABLE.XIV GA OPTMIZATION RESULTS SCENARIO 10-17

Scenario	Weights	Cost/Pound	Lead-time/Hours	Utilization score	Quality
10	(0.1, 0.7, 0.1, 0.1)	415060	975	0.7041	0.8703
11	(0.1, 0.6, 0.2, 0.1)	416391	968	0.7162	0.8789
12	(0.1, 0.5, 0.3, 0.1)	413731	992	0.7111	0.8756
13	(0.1, 0.4, 0.4, 0.1)	418858	992	0.7696	0.9182
14	(0.1, 0.3, 0.5, 0.1)	415248	1374	0.8707	0.9516
15	(0.1, 0.2, 0.6, 0.1)	411849	1919	0.8945	0.9497
16	(0.1, 0.1, 0.7, 0.1)	415069	1942	0.8873	0.9512
17	(0.1, 0.05, 0.75, 0.1)	411706	2162	0.8793	0.9504

5.4 Conclusion

In the first part of this chapter, a hierarchy of criteria is generated through industrial case study and then suppliers are evaluated based on both their qualitative and quantitative criteria. Especially for quantitative criteria, historical data are used to reveal and evaluate the past performance of each supplier. To be noticed, a new concept that divides the production into different complexities has been proposed. It makes the evaluation of suppliers based on different types of production possible and the results are more accurate. The global weights of suppliers are then used in GA optimization as utilization score. The results of optimization offer different scenarios according to the priority of different parameter. In each scenario, the value of cost, lead-time, utilization score and quality vary and the relationships between each parameter are illustrated.

CHAPTER 6 - DISCUSSION

6.1 The contribution of this research

Chapter 5 presented the application of proposed method in supplier selection and order allocation in which a practical supplier selection criteria system is generated. And suppliers are compared using two different methods for qualitative and quantitative criteria separately. Although the calculation process and theories are clearly stated, the novelty and significance of this approach needs to be stressed by comparing with current methods in literature review. Table XV lists two scoring methods adopted by GFM and another research work.

TABLE.XV COMPARISON OF EXISTING EVALUATION METHODS

GFM s.r.l		**Chamodrakas et al. (2010)**	
Range	**Score**	**Range**	**Score**
<10 days	5	99–100% within promised time	5
..	..	96–99% within promised time	4
10-20 days	3	93–96% within promised time	3
..	..	90–93% within promised time	2
>20 days	1	< 90% within promised time	1

Similar to the application in this thesis, Delivery delay on time is selected again as an example to view the differences between each scoring system. In GFM, a simple 3-point scale is applied. For those suppliers with average delivery delay less than 10 days, they are rated as 5. And if their average delay is between 10 to 20 days, then the suppliers are only qualified for 3 point. The other suppliers are attributed to 1 point. While in the second example which is mentioned in Chamodrakas et al (2010), similar 5-point scale rating system is employed. The criterion or range of each score is complex than the one in GFM. From 1 to 5 point, the range increases from 90% to 100% by average 3% per score. The relationship between the score and range is assumed to be linear. In fact, these two methods used in GFM and literature review do provide a systematic way to evaluate supplier. However the evaluation is not directly linked with the performance of suppliers and shows disadvantages in the following aspects:

- The scores do not reflect the selection preference for a certain supplier among of all the candidates. On the contrary it shows the requirements that managers expect for the suppliers. To be specific, suppliers are evaluated by the experience of managers without considering the overall performance of all the suppliers. For example in Chamodrakas et al scoring system, if there were 10 suppliers (8 suppliers could provide 96% production within promised time, 2 suppliers could provide the performance of 99%), then all of them are rated as 4. In this way, the method failed to distinguish those 8 suppliers with best suppliers.
- The scores are applied to all the productions and orders which ignores the inherited differences between each production. As discussed above, the industrial case study reveals that the complexity of order could significantly influenced the performance of suppliers. Even the quality requirement is a key factor as well. Some suppliers have better performance on a certain type of production, so a single scoring system could not accurately evaluate all the suppliers.

- The scoring system is static and cannot adapt to the new development of suppliers' performance. The performances of suppliers vary from time to time which makes the overall performance of suppliers change accordingly. A static system is usually used for a long period of time during which the criteria is no longer valid and meaningful.

Hence when compared with those traditional methods, the proposed approach shows great advantages. Statistical analysis method introduces dynamic element into the supplier selection and evaluation. When orders are accomplished and the information about delivery delay is updated, the average delivery delay of a supplier and the overall probability distribution function will change accordingly. In turn, the scores and ranges evolve from the old version to updated one. It constantly reflects the simultaneous selection preference of the supplier among all the others. What's more, different sets of scores and ranges are used for different types of orders. If the orders are of "Very complex" production, then only the historical information for this type of production will be processed. The process is shown in Figure 15. The

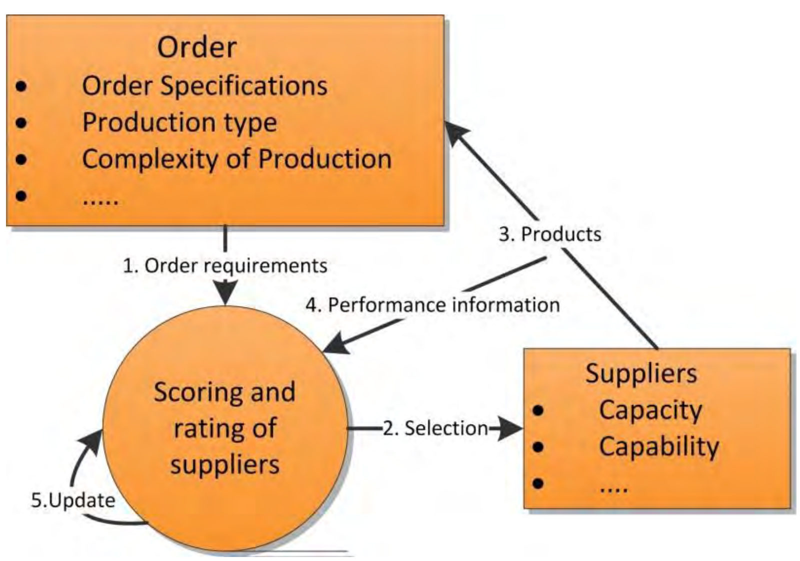

Fig. 15 The dynamic scoring system

categorization based on criteria such as production complexity, quality requirement and batch size guarantee the best supplier for a certain type of production is selected.

6.2 The limitations of this study

Although this study could provide valid and useful results for supplier selection and order allocation problem, there are some limitations existing in these methodologies that have been used.

From the methodologies itself, the nature of Fuzzy AHP leads to a certain complexity of implementing FAHP in practice. It takes a relatively long time for pair-wise comparison when the number of candidates is big. So for the companies with a large number of suppliers, it is time-consuming to implement the evaluation and selection process.

Meanwhile, the selection process on quantitative criteria strongly depends on the historical data of suppliers. Then for new production and new suppliers, the lack of evaluation data could affects the accuracy of selection process. So at present, this research could only be applied to a company with a stable manufacturing network and possesses long relationship with its suppliers.

CHAPTER 7 – CONCLUSION

7.1 Overall aim of the research

Current supply chain management has encountered a series of challenges in the past decade or so due to the fast changing market demand and the trend of globalization. Supply chain is then required to be fast and effective enough to react to the changes of the market. Supplier selection and order allocation is a key process in supply chain management; especially for SMEs manufacturing networks this problem affects the performance of the whole network. Due to the increasing importance of this problem, this research aims to improve the accuracy and efficiency of supplier selection and order allocation process. At the same time, this research also aims to generate a meaningful and practical set of criteria for supplier selection for SMEs manufacturing network environment.

7.2 Summary

To achieve the aims mentioned above, this research proposes a novel method integrating Fuzzy AHP with Genetic algorithms to solve the supplier selection and order allocation problem in SMEs manufacturing networks.

Chapter 1 outlines the research background and the demand of new methods to improve the efficiency and tackle the new challenges of supply chain management. The results of relevant literature review are given in Chapter 2. The needs for using statistical analysis in supplier selection and integrating FAHP with Genetic algorithms for order allocation are emphasized. The supplier selection method introduced in Chapters 3 and 5 is proved to be effective to evaluate suppliers not only on qualitative but also on quantitative criteria. The hierarchy of the criteria and their evaluation could help managers visualize the actual performance of suppliers on various production processes. The weights of each supplier are also attributed according to their historical data, information and comparisons in terms of qualitative criteria. For quantitative criteria, instead of depending on their experience of the supplier, managers could use the ratings which reflect the overall performance for all the suppliers to make the decision. In this way, the subjective judgments and bias could be eliminated to a large extent.

Furthermore, in chapter 3 the concept of Utilization score is developed and used to evaluate the extent that orders are attributed to the best supplier. Utilization scores reflect the evaluation results from Fuzzy AHP and provide an extra objective for GA optimization apart from Cost, Quality and Lead-time. If the weight of the utilization score in the optimization is high, then suppliers with better performance on specific competency have higher possibilities to be chosen for the corresponding production. In chapter 4 and 6, by constantly changing the weights of Cost, Lead-time, Utilization score and Quality, GA is able to generate different optimum solutions based on the requirement of customer and decision makers. In different solutions, both the combination of suppliers for orders and the number of participants will change as well as the quantity allocated to each supplier. The capacities of suppliers could be employed in such a way that optimizes the overall performance of the manufacturing network. All of these are achieved through a modified Genetic Algorithms with the constraints given in the mathematical model. A repairing mechanism is implemented in Genetic algorithms to fix the invalidity of chromosome after mutation and crossover. Hence the efficiency of optimization is significantly improved. In chapter 6, the proposed supplier selection method was compared with two existing methods: one obtained from GFM, and another through the literature review, respectively. The relatively good performance of the proposed method is illustrated through this comparison. The element of dynamic supplier selection makes the new method outperform the traditional static evaluation.

7.3 Contribution of the research

The original contribution of this thesis is summarized into three categories:

- A hybrid GA-Fuzzy AHP method is proposed for supplier selection and order allocation for the first time
- Statistical analysis is integrated with FAHP which enhanced the performance of FAHP
- The hierarchies of criteria specific for SMEs manufacturing network are determined

For practical applications, this research helps aid the decision making process in supplier selection and order allocation. Suppliers are evaluated and scored based on their historical performance using FAHP. Then by combining the data and information from supplier with the requirements of customers, GA provides different optimum solutions. Here, GA offers the combination of suppliers for multi-product planning situation. Even for complex production, managers could obtain a visualized understanding about the potential options available for specific production. If there is an urgent order, then managers could look for those solutions with short lead-time but with relatively higher cost. Furthermore, a weighting system for SMEs manufacturing networks has been produced. Since data and information are collected from an experienced systems integrator company (i.e. GFM), the criteria and their corresponding weights could be used as a reference for similar industries and companies.

7.4 Future Work

There are several directions in which this research could be expanded. First of all, for the mathematical model, more parameters could be taken into consideration. For instance, cost should be divided into different types such as transportation cost, management cost and penalty cost. For each type of cost, there could also be a systematic way to calculate the values. In terms of multi-criteria decision making techniques, the integration of Fuzzy AHP and Kernel density estimation could be further developed. Especially for statistical analysis, more thorough research will be needed to improve the accuracy of evaluation. Moreover, the statistical analysis is a promising technique to forecast the performance of suppliers which could be used to evaluate and manage the risks of network configuration. Questions such as “What is the possibility for a supplier to achieve 80%, for example, of its best performance?” need appropriate solutions. Statistical analysis is able to provide the answer to the questions like this. For Genetic algorithms, the efficiency of optimization could also be enhanced by finding the optimum operators and parameters. Finally, the hierarchies of criteria for SMEs manufacturing networks could be expanded and modified through more industrial case studies. The common criteria and unique criteria for different companies could be identified in order for a more comprehensive set of criteria could be generated.

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APPENDIX

1. Industrial Case study questionnaire

Part A---GFM current supplier selection criteria

The appropriate interviewees should be familiar with the supplier selection process and evaluation mechanism.

Note that these tables should be filled in during the interview process.

No.	Supplier type	Criteria	Weighing (How important?)*

Table 1

* 9 means the most important; 1 mean the least import; Values in between depends on your judgment.

- Q1: What is the current supplier selection and evaluation mechanism in GFM?
- Q2: Is there evaluation case or example that could be used for research purpose?
- Q3: Is the current selection mechanism qualified enough to guarantee the quality of suppliers?
- Q4: Are there any **positive** and **negative** feedback for the current selection mechanism? Please detail the feedback.
- Q5: Do you prefer to distribute one production task to one manufacturer or to several manufacturers? What kind of cost involve within the process of managing manufacturers?

Part B----The real needs and criteria for suppliers and manufacturers

The REAL need and criteria for suppliers can only be dug out by combining the opinions from every functional branch in a company. This part of the questionnaire involves interviews with every single major department with the same set of questions.

The demanded departments or functional areas for the interviews are:

Quality Control; Purchasing; Sales (both national and international); Logistics; Quality system; Production; Financial sector; General management

Note that these tables should be filled in during the interview process.

<table>
<tr><th colspan="3">What criteria do you think is important from the perspective of your functional area?</th></tr>
<tr><td colspan="2">Your Functional area:</td><td>Your position:</td></tr>
<tr><td>No.</td><td>Criterion</td><td>Importance(1-9)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Table 2

<table>
<tr><th colspan="6">How important is one criterion compared with others?</th></tr>
<tr><th>Criteria Number</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td>A</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3

Note: 1 means equally important; 9 mean one is extremely important than the other; Value in between then depends on your judgment on the importance.

Section 4 Scheduling and work allocation

The part of questionnaire aims to find out the current methods or techniques your company applied to production work allocation and scheduling and the feedback and comment on the existing system.

- Q1: How do you do the scheduling or work allocation task at present?
- Q2: Where exactly do you need scheduling techniques and how do you use it?

- Q3: Could the current system fulfill your requirements?
- Q4: What kind of functions do you need or demand with the scheduling software or techniques. (Your needs and expectation for the scheduling techniques?)
- Q5: Is there any case and data available for a scheduling example that could be used for research purpose?

Scheduling and work allocation case information			
Product	XXX		
Lead time	XXX		
Quantity	XXX		
Component	A	B	C
Quality requirement			
Quantity			
Manufacturing Process			

Manufacturer/workshop/supplier					
		Manufacturing capability			
Attributes	Capacity				
	Lead time				
	Price				
	Quality				

Overall performance indicator after scheduling and work allocation				
Cost	Lead time	Quality	…	…

2. Programming Pseudo code in C++

Algorithm 1 Genetic Algorithm (GA)

```
1.    While (number of generations || KPI target are not met)
2.      Initialization() → populations
3.      Evaluate(population) → Fitness
4.      Selection() → Best individual
5.      IF (Best individual is the same in continuous 10 generations)
6.         Initialization() → populations
7.         Best individual → first population in new generation
8.      End if
9.      Crossover() → New Populations
10.     Mutation() → New Populations
11.   End while
```

Algorithm 2 GA-Initialization

```
1.    IF agent j is active (can manage production)
2.       IF  Gene_Count[p] < Number of Agents bidding for the same product p
3.            Bided quantity limit   ← the smaller value between (rPQ, rMC)
4.            Bided quantity (Q)     ← Random()% bided quantity limit
5.            rPQ= rPQ - Q
6.            rMC = rMC - Q
7.            Agent_Count[p] ++
8.       ELSE
9.             IF  Remaining PQ[product ID] <= Remaining MC[CompetencyID]
10.                 Q ← Remaining product required quantity
11.            ELSE
12.                 GOTO step 4
13.            ENDIF
14.      ENDIF
15.   ENDIF
```

Algorithm 3 Pseudo-code of Crossover and Repair mechanism

```
k = Random()%100/100.0
IF k < Crossover Possibility value
   Gene ID ← Random()% Total_Number_of_Gene (choose a Gene out of a Chromosome)
   Q Gene-ID ← Random()%Manufacturer Relevant capacity
   While (Gene "G" exist)
     CallForG(Return status information of G)
     IF (G does not exist)
        Break out of while loop
     Else (G cannot take the Quantity change)
          Generate a new quantity change
       Else (G exists and have capacity to take Quantity change)
          CallForF' (Return status information)
    End While
  While
     IF(F' does not exist or manufacturer can take the quantity change)
        Go to the end of function
    ELSE
       CallForG(Return status information)
       IF( G do not exist)
          Go to the end of Function
       IF( G cannot take the quantity change)
          Break out of while loop
  End While
```

Variable:
rPQ: Remaining required product quantity
rMC: Remaining manufacturing Capacity
$Q_{Gene\text{-}ID}$: Quantity distributed to one RBA with certain ID
Gene G: the specific Gene that contribute to the same order using the same competency together with selected Gene
Gene F: the specific Gene that share the capacity of same manufacturer with the selected Gene.