A Cloud Manufacturing Based Approach to Suppliers Selection and its Implementation and Application Perspectives

A thesis submitted for the degree of Doctor of Philosophy

by

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Abstract

Multi-service outsourcing has become an important business approach since it can significantly reduce service cost, shorten waiting time, improve the customer satisfaction and enhance the firm's core competence. In fact, on-demand cloud resources can lead manufacturers to improve their business processes and use an integrated and intelligent supply chain network. In addition, cloud manufacturing, as an emerging manufacturing system technology, will likely enable small and medium sized enterprises (SMEs) to move towards using dynamic scalability and 'free' available data resources in a virtual manner.

Although there has been some research in these areas, there is still a lack of proper cloud based solutions for the whole manufacturing supply chain network. In addition, of the research papers studied, only a few reviewed and implemented the cloud based supply chain from a decision-making point of view, especially in suppliers evaluation and selection studies. Most studies only focused on cloud-based supply chain definitions, architectures, applications, advantages and limitations which can be offered to SMEs. Hence, a comprehensive research study to find an optimum set of suppliers for a number of goods and services required for a project within the cloud manufacturing context is necessary.

Providing real and multi-way relationships through a suppliers selection process based on an intelligent cloud-based manufacturing supply chain network, by using the Internet, is the main aim of this research. The research has an emphasis on multi-criteria decision making approach. The proposed model is based on 'Goal Integer 0-1 Programming' method for the suppliers selection part and 'Linear Programming' method for the project planning part.

The proposed framework consists of four modules, namely a) multi-criteria module, b) bidding module, c) optimisation module, and d) learning module.

Learning module allows the model to learn about the suppliers' past performance over the course of the system's life. Average performance measures are calculated over a moving fixed period, results of which are stored in a 'dynamic memory' element as linked to the suppliers' database.

The methodological approach is validated based on a case study in the oil and gas industry, characterised by 29 services linked together in a network structure, 108 suppliers, and 128 proposals for the services. The case study covers a variety of services from designing to manufacturing and delivery.

On the implementation side, a cloud manufacturing based suppliers selection system (OPTiSupply.uk®) is designed and uploaded on the virtual server of Amazon EC2. The system enables customers and suppliers to offer and receive various services on the Web. Apart from the user interface functionality, the system also allows interaction with the MS-Excel© based data and the associated mathematical programming.

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Abbreviations

AHP	Analytic hierarchy process
AHP-GP	AHP weighting with goal programming
AHP-FMP	AHP and fuzzy mathematical programming
AM	Agile manufacturing
ANP	Analytic network process
AOA	Activity on arrow
AON	Activity on network
ASP	Application service provider
BPM	Business process management
CAD/CAM	Computer aided design and manufacturing
CC	Cloud computing
CM	Cloud manufacturing
CPM	Critical path method
CQI	Chartered quality institute
CRM	Customer relationship management
DEA	Data envelopment analysis
DEAHP	Data envelopment analytic hierarchy process
EC2	Elastic compute cloud
EF	Early finish
ERP	Enterprise resource planning
ES	Early start
GP	Goal programming
HaaS	Hardware as a service
HRM	Human resource management
IaaS	Infrastructure as a service
ILP	Integer linear programming
IOT	Internet of things
IP	Integer programming
IT	Information technology
LP	Linear programming
MCDM	Multi criteria decision making

MGrid	Manufacturing grid
MIGP	Mixed integer-goal programming
MILP	Mixed integer-linear programming
MP	Mathematical programming
NM	Networked manufacturing
OR	Operation research
PaaS	Platform as a service
PD	Procurement department
PMI	Project management institute
QMSC	Quality management system certifications
RFP	Request for proposal
RSD	Resource service demander
RSP	Resource service provider
SAW	Simple additive weighting
SaaS	Software as a service
SCM	Supply chain management
SIP	Stochastic integer programming
SMEs	Small and medium sized enterprises
SOA	Service-orientated architecture
UFI	User friendly interface
WB	What's best

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Nowadays, the trend of globalisation is a great motivation for small and medium sized enterprises (SMEs) worldwide. Many companies have decided to use other companies' competencies and outsource part of their manufacturing and business processes to suppliers from abroad in order to reduce costs, improve quality of products, and offer better services to customers. On the other hand, this decision has faced organisations with new challenges. Organisations need to evaluate their supplier's performance, and consider their weakness and strength to survive in high competitive markets. Hence, suppliers evaluation and selection acts as an important strategy within enterprises.

The thesis is titled 'a cloud manufacturing based approach to suppliers selection and its implementation and application perspectives'. The suppliers section is one of the main concepts of this research, which is considered as a procurement strategy in the supply chain management (SCM) network. This network facilitates a close relationship among enterprises, people, new technologies, information, and various activities in order to deliver products (both goods and services) to final customers.

In addition, Internet and new computing technologies provides a better collaboration between customer, manufacturers, and suppliers. There are many studies about the influence of Internet on marketing and sales. However, there is a paucity of studies considering the role of novel technologies such as Internet, intranet, and cloud technologies on manufacturing supply chain, especially on selecting the most appropriate suppliers in whole SCM network.

This chapter includes seven sections. In Section 1.2, the historical trend of the emergence of cloud manufacturing (CM) and the key concepts, such as, SCM, agile manufacturing (AM), manufacturing grid (MGrid), networked manufacturing (NM), cloud computing (CC) and the analysis of all mentioned approaches will be discussed. In Section 1.3, CM, and its advantages and challenges will be discussed. To complete the chapter, motivations, aims and objectives, the scope of the thesis, and the overview of the thesis structure are presented.

1.2 Advances in Manufacturing Systems and Operations

Nowadays, manufacturing enterprises, especially SMEs, are faced with issues such as different ranges of services, innovation, and fast changing customer requirements, and, to deal with these, 'agility' is used as one of the main factors to survive in highly competitive, manufacturing markets. In order to cope with these issues and respond to new manufacturing requirements, existing advanced manufacturing models require to be improved. Figure 1.1 shows the development of the manufacturing paradigms from mass production to CM. According to customer requirements, manufacturing paradigms have evolved through various approaches since the 1900s (Hu *et al.,* 2011). Mass production inspiring by 'craft production' is a model with low-cost products through large scale manufacturing. Mass production had been introduced by Henry Ford in the USA and adopted widely by other countries after Second World War. Mass production was enabled by various concepts such as interchangeability, moving assembly, and scientific management. Although mass production enables customer to purchase their desirable product in an affordable prices, limit production variety could not provide all of the customer requirements. In other words, different ranges of customer requirements were not included. High inventory costs were another main problem that faced enterprises, especially when considering the number of unsold products left on stock shelves.

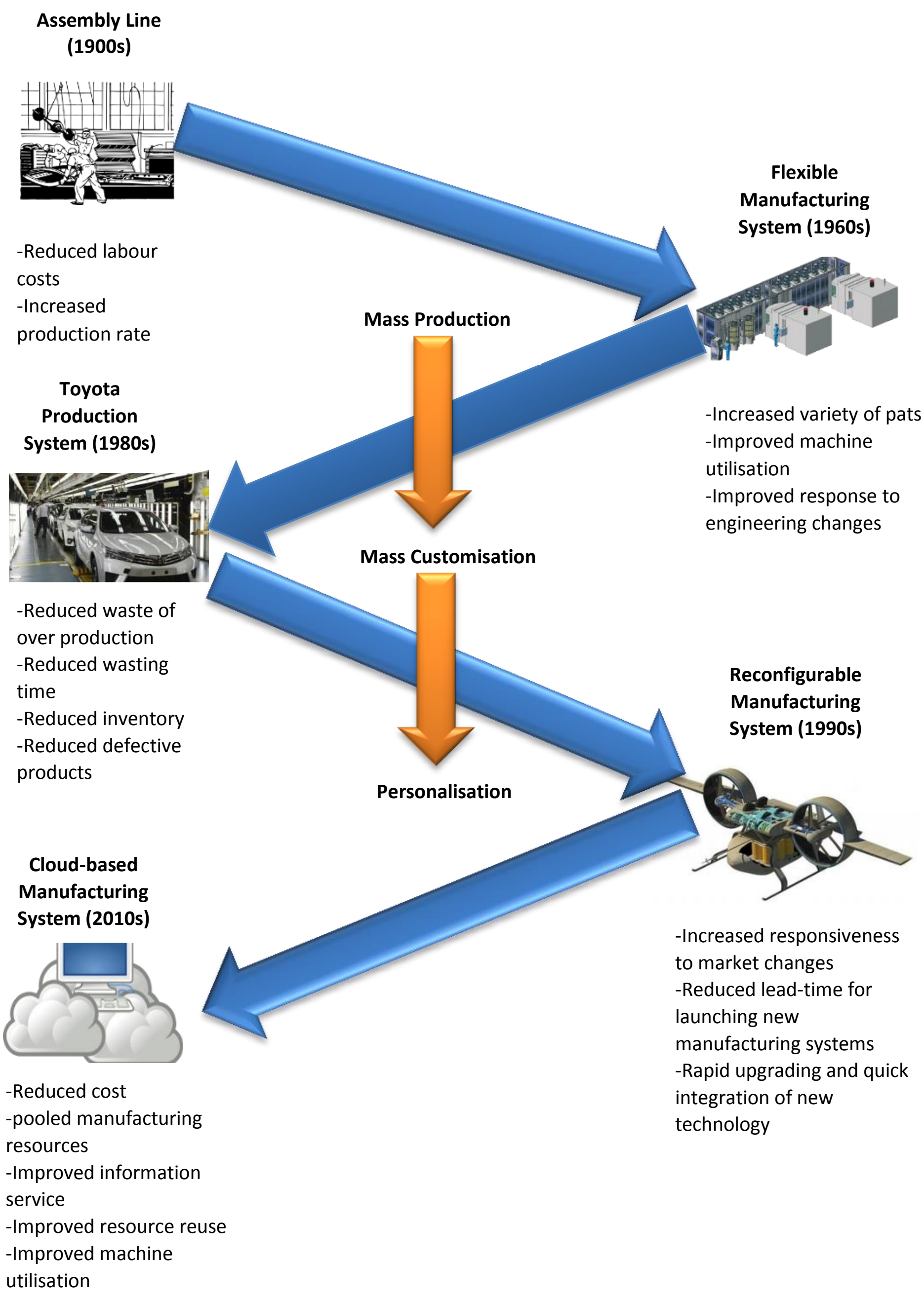

Figure 1.1: A trend of manufacturing systems development

The paradigms of mass customisation were introduced in 1980s by focusing on the 'Toyota Production System' and a 'Lean Manufacturing' philosophy in order to reduce inventory, minimise defective products, and diminish the waste of over production (Pine II, 1993). As a result, variety and customisation through flexibility and responsiveness has increased considerably. Hence, loyalty from closer connection with the final user has grown while high supply chain costs have been eliminated. Figure 1.2 indicates that mass customisation provides collaboration between end users and suppliers, manufacturers, and distributors, which reduce costs related to the supply chain and logistics.

Product family architecture, reconfigurable manufacturing system, and computer aided design and manufacturing (CAD/CAM) are categorised as multiple systems and technology enablers for mass customisation.

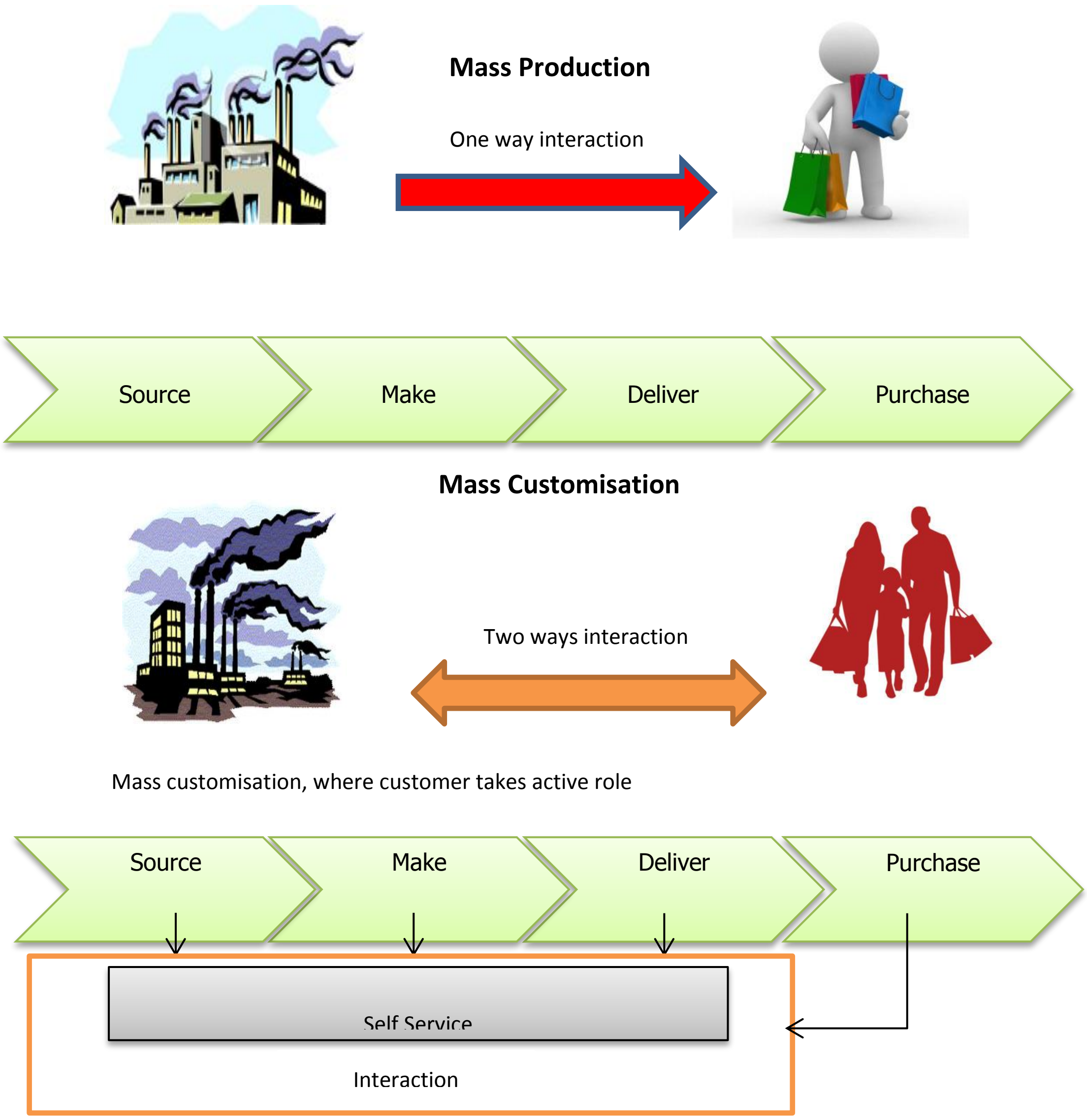

Figure 1.2: Mass production against mass customisation

Hu *et al.,* (2008) argued that high product variety has enabled enterprises to meet customer demands, however, it had a direct influence on production performance due to causing a complexity in the assembly systems. In addition, the advent and widespread use of the Internet and computing has produced positive results in the highly competitive market worldwide in recent years. Innovation in products and more collaboration between manufacturers and end users have shifted manufacturing paradigms through personalisation. Moreover, one of the supportive concepts for realising the novel manufacturing paradigms is to realise and share manufacturing resources. In fact, the key to improve the existing manufacturing models is to exploit fully all kinds of potential manufacturing resources and capabilities (Hassanzadeh and Cheng, 2013). Hence, concepts such as SCM, AM, MGrid and, NM have emerged to face the new challenges and evolved to optimise traditional methods.

1.2.1 Supply Chain Management

Collaborative relationship and shared-resource utilisation offered by various enterprises help SMEs to deal with resource allocation issues. Collaborative relationships between enterprises enable SMEs not only to have innovation in process improvement, and product and technology development, but also to provide better knowledge exchange between different organisations around the globe (Choi and Hong, 2002). Hence, the supply chain can become an independent, intermediate type of network to connect enterprises, including manufacturers, transporters, warehouses, and retailers, where supplies both goods and services (see Figure 1.3).

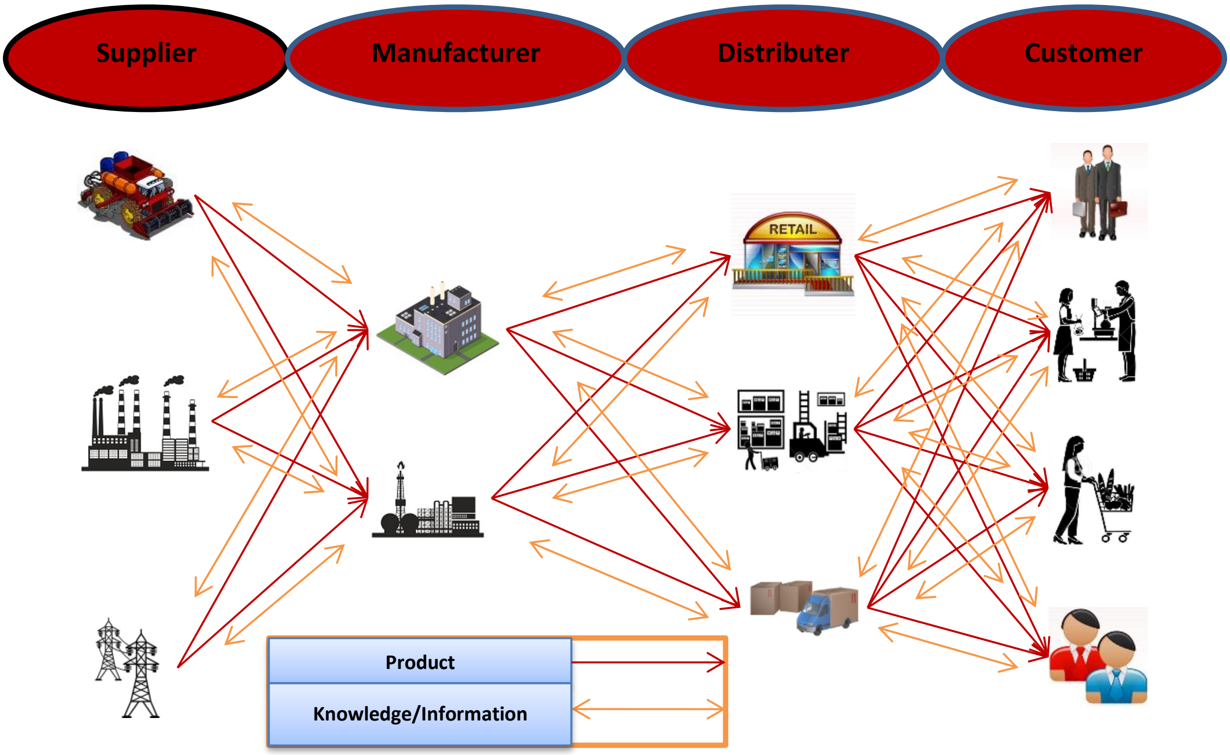

Figure 1.3: Modern SCM network

Figure 1.3 indicates that the product delivered through the supply chain is not limited only to manufactured goods. The supply chain is also involved in the distribution of services and knowledge/ information. While product flow has only a one way relationship between functional entities starting from suppliers and finishing by final customers, knowledge/ information flow is considered as a two-way relationship among all four functional entities. Although the term of SCM, stated by Oliver and Webbr (1982), in order to apply and promote integrated business strategies in 1980s, SCM has been used widely and became more popular after 2000s and has been adopted as an important approach in business and production strategies.

SCM is a systematic and strategic management network allowing different kinds of enterprise demands, including both tangible goods and services, in order to improve enterprise long term strategies and performance. Apart from different definitions of SCM, many researchers believed that SCM would be more operational when considered as a global network, not just a local network. Hence, the term 'global supply chain' has emerged recently. Global supply chain not only offers SMEs the ability to participate in a widespread geographical variety of markets, but also provides a well-organised business, by improving competitive advantages, time to market, inventory control, reputation and trust.

In addition, SMEs need to have an intelligent procurement strategy to reduce their raw materials or purchasing costs. Consequently, SMEs have an opportunity to bring lower cost products to market, which bring a competitive advantage and better profits. Weber *et al.,* (1991) stated that up to almost 80% of final product costs in manufacturing industries is because of material and services purchasing costs. As shown in Figure 1.4, suppliers are indicated as a beginning element of the whole SCM network, which have a great impact on other elements in network. In fact, an enterprise could not be successful and survive in a fierce competitive market unless they have an appropriate set of suppliers as a key function in SCM.

1.2.2 Agile Manufacturing

In the 1980s, industry leaders popularised the terms of 'world class manufacturing' and 'lean production' in order to enhance flexibility and quality of products and services, reduce time to make and delivery, and reduce high inventory costs in manufacturing industries (Sheridan, 1993). However, companies faced problems when adopting and implementing lean production concepts. In the early 1990s, a new manufacturing paradigm was formulated by a group of researchers at Iacocca Institute located in Lehigh University, related to the movement from mass production to new manufacturing paradigms (Nagel and Dove, 1991). Known as agile manufacturing, it enables collaborative and integrated relationships among enterprises, customers, suppliers, and was supported by newly emerged technologies in order to have a quick and agile response to changes in customer requirements. In order to bring agility to enterprises, improving ability to respond rapidly to unexpected customer changes and integrating the design and production information with their business partners is necessary (Cheng and Bateman, 2008).

Although there have been various definitions and important factors presented with regard to agile manufacturing after the initial work of the Iacocca Institute, Yusuf *et al.*, (1999) stated that AM mainly emphasised on factors such as:

- high quality and highly customised products;
- products and services with high information and value-adding content;
- mobilisation of core competencies;
- responsiveness to social and environmental issues;
- synthesis of diverse technologies;
- response to change and uncertainty; and
- intra-enterprise and inter-enterprise integration.

Enterprises willing to adopt agile manufacturing by providing an intelligent supply chain network from suppliers and manufacturers to final customers were able to negotiate new agreements with suppliers and retailers to facilitate a fast response to market and customer requirement changes.

1.2.3 Networked Manufacturing Based on Application Service Provider

Rudberg and Olhager (2003) defined NM as an aggregation and integration of factories placed in various, strategic, geographical places. NM not only offers various manufacturing services due to collaboration among enterprises, but also facilitates variety of shared resources in different stages such as information technology (IT), design, assembly, inventory, and management. Hence, NM, as an advanced manufacturing paradigm, was established and implemented by organisations in order to enhance the competitive abilities in global manufacturing, and to ensure quick response to unexpected customer requirement changes.

For the full implementation of networked manufacturing, an application service provider (ASP) approach as a useful solution was proposed. ASP is a web-based service approach which is capable of integrating various enterprise requirements such as hardware, software, and networks. NM by applying ASP could offer different kinds of service, such as customer relationship management (CRM) services, SCM services, and suppliers evaluation and selection services.

1.2.4 Manufacturing Grid

The MGrid has emerged to reach enterprise business objectives in terms of optimal resource utilisation through a manufacturing system network. Fan *et al.*, (2004) defined MGrid as

> '… *an integrated supporting environment both for the share and integration of resources in enterprise and social and for the cooperating operation and management of the enterprises'.*

MGrid is globally accepted and applied by researchers and manufacturers due to stressing on optimal resource selection and allocation by taking advantages of various technologies. These would include grid technologies, information technologies, and computer and advanced management technologies in order to unify effectively all kinds of resources located in various regions, SMEs, enterprises, organisations, and individual users.

According to Tao *et al.,* (2007), there are mainly two kinds of users in MGrid, namely resource enterprise or resource service provider (RSP), and user enterprise or resource service demander (RSD). Dealing with requirement changes in the system, RSP offers a manufacturing resource service by utilising idle resources, products, and various kinds of manufacturing capabilities such as production, design, analysis and engineering capabilities. In addition, in order to facilitate the virtual manufacturing network, RSD searches the optimised manufacturing resources, and chooses the best collaborative partners.

1.2.5 Computing-Based Cloud Manufacturing Systems

In the 1990s, such expenses, as floor space, power, cooling and operating, led organisations to adopt grid computing and virtualisation. Through grid computing, users could provide computing resources as a metered utility that can be turned on or off and the infrastructure shifted to virtualisation and shared with the customer. Hence, it was essential for service providers to change their business models to deliver remotely controlled services and lower costs. CC, then known as a novel phenomenon, indicates a main change in the way IT services are invented, developed, scaled, deployed, updated, maintained and funded. For the manufacturing industry, CC is emerging as one of the major enablers to alter the traditional manufacturing business model, helping it to align product innovation with business strategy, and generating intelligent factory networks which develop effective collaboration. There are two types of CC adoptions in the manufacturing sector (Xu, 2012):

- manufacturing with inspiration from various CC technologies; and
- CM - the manufacturing version of CC.

In terms of cloud computing adoption in the manufacturing sector, the key areas are around IT and new business models that cloud computing can readily support, such as pay-as-you-go, the convenience of scaling up and down per demand, and flexibility in deploying and customizing solutions. The adoption is typically centred on the business process management (BPM) applications, such as SCM, human resource management (HRM), CRM, and enterprise resource planning (ERP) functions with Salesforce and Model Metrics. Some manufacturing industries have started reaping the benefits of cloud adoption today, moving into an era of smart manufacturing with the new agile, scalable and efficient business practices, replacing traditional manufacturing business models. CC provides a hosted service which can be accessed over a network, normally through the Internet, intranet or local networks. These services typically categorised into three different sections, namely infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS).

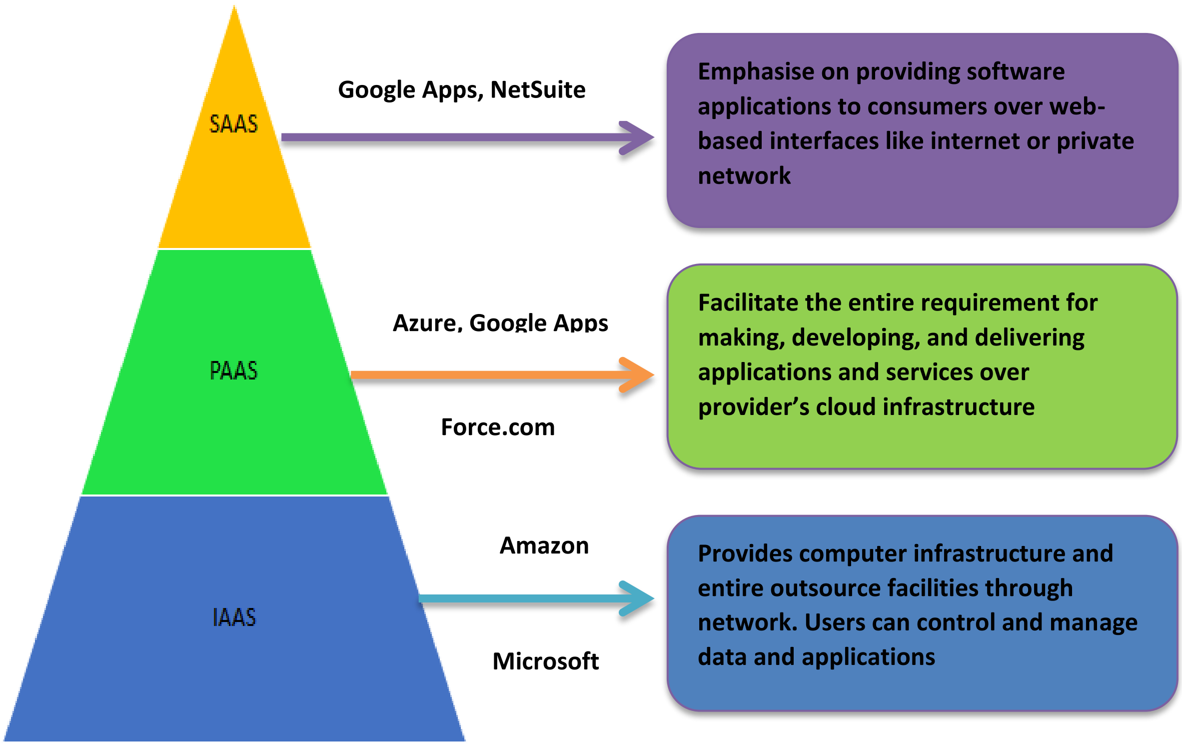

Figure 1.4: Cloud computing service models

According to Figure 1.4, IaaS consists of the entire infrastructure platform while PaaS (application development capabilities, various programming languages, and product development tools) set through IaaS. Furthermore, SaaS builds upon IaaS and PaaS (Marston *et al.*, 2011).

1.3 Emergence of Cloud Manufacturing

Table 1.1 presents the advantages and limitations of the aforementioned existing advanced manufacturing models, indicating the necessity of a new model to transform product-orientated manufacturing to a service-orientated manufacturing model. Hence, CM as a potential solution is suggested.

Table 1.1: Features of existing advanced manufacturing systems

	Advantage	**Disadvantage**
AM	Design innovation based on the customer`s requirement Respond quickly to emerging crisis Flexible organisation structure	Intensive planning and management of system Shortage of proper platform supporting for resource sharing
NM based on ASP	Provide leasing and management for software resource Realising the platform of the resource and information sharing	Lack of sharing the hard resources and manufacturing capabilities
MGrid	Sharing of distributed resources Workforce development	Lack of proper operating business model

Surviving in global manufacturing competition, manufacturing SMEs have to realise and deploy existing services, knowledge innovation, and scaling the customer requirement. However, different types of current manufacturing requirements cannot be covered and supported by existing advanced manufacturing models, such as AM, NM based on ASP, and MGrid.

Taking a CC approach, Xu (2012) defined CM as:

> *'a model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable manufacturing resources which can be rapidly provisioned and released with minimal management effort or service provider interaction'*.

Moreover, Meier (2010) described CM as:

> *'a service-oriented IT environment as a basis for the next level of manufacturing networks by enabling production-related inter- enterprise integration down to shop floor level'*.

One of the reasons regarding the wide use of CM recently is its common strategies and targets with different concepts such as SCM, ERP, SOA (Service-Orientated Architecture), and modelling systems.

Mainly, three layers of user participate in a CM platform, namely, manufacturing cloud, operator, and cloud customer (Figure 1.5). All manufacturing resources and capabilities are owned and provided by the manufacturing cloud. The operator facilitates the services for both the cloud customer and the manufacturing cloud through the CM platform. Hence, the cloud customer who is the subscriber of the services can take advantage of the 'on demand' or 'pay as you go' model.

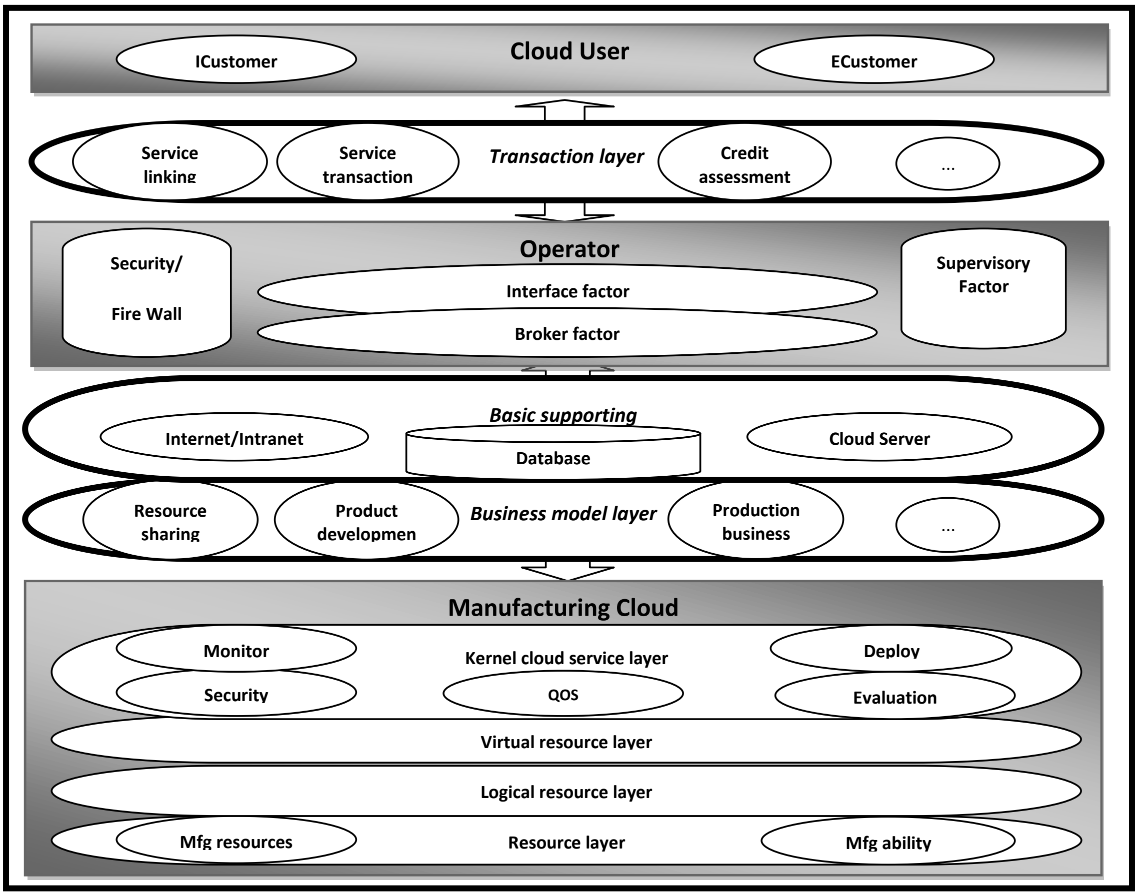

Figure 1.5: The framework and main layers of cloud manufacturing (Source: Hassanzadeh and Cheng, 2013)

As shown in Figure 1.5, the proposed architecture of the high value-added CM for SMEs is categorised into three main layers, cloud customer layer, operator layer, and manufacturing cloud Layer, in which each layer includes some sub-layers. Moreover, there are three intermediate layers among the main layers, namely, transaction layer, business model layer, and basic supporting layer.

Shared resource utilisation offered by various enterprises and collaborative relationship plays an important role for production development in CM systems. Hence, an intelligent supply chain network by using cloud technologies and IOT (Internet of Things) would decrease lead time, start-up costs, and response time for customer requirements (Shacklett, 2010). Moreover, the supply chain can act as an interface between cloud users and CM resources.

In order to provide effective and close collaboration between organisations, CM is able to encourage enterprises to re-evaluate their business strategies and redesign their SCM models. From the customer perspective, manufacturing supply chain collaboration is a customer centric aspect which allows them to demand key aspects of the desired tasks, such as cost, lead time, and quality. Hence, all customers have the opportunity to be linked to the manufacturers to specify, select, and order all their requirements such as cost, time, and quality.

The CM concept can offer some advantages to SMEs in terms of cost and time efficiency, management issues, agility, and customer centric issues. CM focuses on the importance of optimising resource utilisation and capacity in order to increasing manufacturing productivity. For instance, IT sources utilisation was less than 20 % through product-orientated manufacturing, while the service-orientated CM sector has improved the IT utilisation up to 40% (Rosenthal *et al.,* 2009). Moreover, CM allows globalisation which is the main aim of advanced manufacturing in the current era of communication. Easy access to virtualised and encapsulated manufacturing resources facilitates an agile environment via the Internet and networks for both user and manufacturer. CM not only provides more business opportunities and adequacy by mixing products as a special offer to consumers, but also estimates and evaluates the customer demand, thus, scaling the manufacturing according to the customer needs.

Besides all its advantages, it could also be argued that a CM platform faces certain challenges, for example,

(1) safety and security issues;

(2) shortage of certain standards;

(3) effective extension of management and optimisation; and

(4) existing unstructured data.

1.4 Research Motivation and Gaps

Providing an optimised supply chain network for SMEs is considered as one of the main aims of CM. In fact, on-demand cloud resources can lead manufacturers to improve their business processes and use an integrated and intelligent supply chain network. Globalisation and highly competitive markets have forced SMEs to outsource part of their manufacturing and business processes in terms of different management strategies, such as IT, raw materials, and sales. SMEs need to have a collaborative relationship with various suppliers locally and globally in order to survive in the globalised business market. In addition, providing customer requirements and a quick response to market changes would be performed by interacting and collaborating with other enterprises in the whole supply chain network.

Nowadays, the Internet plays a major role in accelerating communication between final customers and suppliers, managing industrial resources, providing on-line transactions (Cheng and Toussaint, 2002), and maintaining competitive advantages. SMEs have to find new ways to adopt and apply the Internet in their business and manufacturing strategies, and also create novel and efficient collaborative relationships with other enterprises. In order to increase productivity and provide customer satisfaction, organisations need to have close relationships with suppliers.

Whereas there has been some research in these areas, there is still a lack of proper cloud based solutions for the whole manufacturing supply chain network. In addition, of the research papers studied, only a few reviewed and implemented the cloud based supply chain from a decision-making point of view, especially in suppliers evaluation and selection studies. Most studies only focused on cloud-based supply chain definitions, architectures, applications, advantages and limitations which can be offered to SMEs.

Hence, a comprehensive research study to find an optimum set of suppliers for a number of goods and services required for a project within the CM context is necessary.

Suppliers selection is considered as a strategic procurement management system in the supply chain which needs an accurate decision making strategy in order to assure the long term feasibility and viability of an organisation. An efficient suppler selection network, by using cloud technologies and the Internet, would offer many opportunities, such as, providing various suppliers' information, flexible collaborative relationship with other partners, quick reconfiguration opportunities and fast respond to unexpected customer requirement changes (Shacklett, 2010).

1.5 Aims and Objectives of the Research

The main aim of this research is to provide and develop real and multi-way relationships through a supplier selection process based on an intelligent, cloud-based, manufacturing supply chain network, by using the Internet. The system will be subject to a number of criteria, such as, cost, quality, delivery time, delivery method, and reputation. The distinct objectives of this research are:

1. To develop a methodology framework that takes into account the characteristics of CM context, such as 'dynamic process', and 'global size';

2. To identify and develop an appropriate type of mathematical programming method suitable for 'multi-criteria decision making' problems;

3. To develop an intelligent web-based suppliers selection system under CM concept;

4. To identify and develop an appropriate set of criteria through conducting a literature review and an opinion survey; and

5. To define a typical CM setting as a case study with reference to nature and period of product ordered in different industries.

1.6 Scope of the Thesis

This thesis is an opportunity to make an original contribution to knowledge of methods of evaluating and selecting a best supplier, or group of suppliers, in various product life cycle stages of a manufacturing process, such as designing, purchasing, manufacturing, and assembly.

Essentially, the suppliers evaluation and selection methodology is going to be applied in a CM context, where the web-based global access, constant use and complexity of the function are critical.

Three different concepts are defined, analysed, integrated, and implemented in order to propose a cloud manufacturing based suppliers selection network, namely, a CM approach, suppliers evaluation and selection concepts, and project management and planning concepts.

Firstly, the proposed web-based system is able to offer the best set of suppliers for various manufacturing sectors, including oil and gas industries, automotive industries, and the computer and telecommunication industries. This means the web-based system would cover a range of manufacturing industries, and would not be limited to just one manufacturing sector.

Secondly, due to the integrating supplier selection concept with project management and planning, the web-based system could release optimised results according to different project networks sequences. All activities in different kinds of project network would have various kinds of relationships and sequence with each other, either in parallel or in series (Figure 1.6). For example, activities B and C have series relationships in 'series network' which means while activity B is not completed, activity C cannot start. On the other hand, activities B and C have parallel relationships in 'parallel network' which implies both activities can start at the same time, when activity A as a predecessor activity is completed.

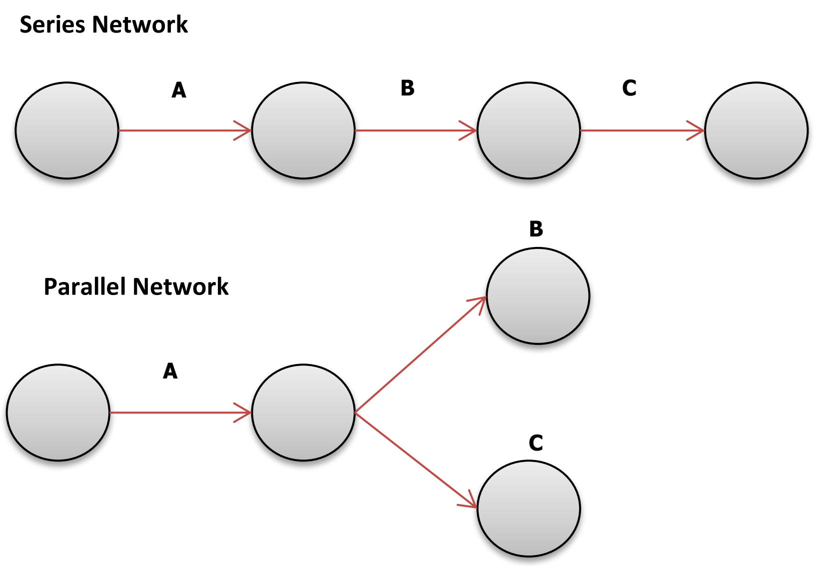

Figure 1.6: Different network sequence in project

These features provide flexibility to the system in order to offer the best set of suppliers in different stages of a supply chain life cycle. Moreover, predecessors of each activity are defined into the web based system. For example, to make a simple product including design, purchase, assembly, and delivery stage, the proposed system should offer the best suppliers for each process stage separately.

Thirdly, it is argued that there are four different kinds of relationship between suppliers and products (including goods and services) in whole project including:

- One supplier offers one product (1:1)
- One supplier offers N products (1:N)
- N suppliers offer one product (N:1)
- M suppliers offer N products (M:N)

Lastly, based on the evidence of the data collected, this research should support multi-criteria, over a single criterion approach for suppliers evaluation and selection. This provides strong competition among alternative service providers and various requirements of organisation. To find the best supplier(s), both qualitative and quantitative criteria are considered.

1.7 Thesis Outline

This thesis is presented as follows:

In this first chapter, the historical trend of the emergence of CM and the key concepts, such as, (SCM, AM, MGrid, NM, CC, CM) and the analysis of all these approaches were discussed. This was followed by a presentation of the research motivation, aims and objectives, and scope of the project.

In Chapter 2, extensive background information and the literature review on the concept of suppliers selection, different criteria for suppliers selection, and description of important criteria used in this thesis will be discussed. In addition, both individual and integrated suppliers selection development approaches which split into a number of aspects, such as, analytic hierarchy process (AHP), analytic network process (ANP), and mathematical programming (MP) including linear programming (LP), integer programming (IP), data envelopment analysis (DEA) and goal programming (GP) will be presented. This will be followed by considering project management and the project planning concept as essential parts of this research.

In Chapter 3, the proposed framework from a high-level perspective with some details of the framework as elements of the overall picture will be presented. This approach and the proposed framework constitute part of the original contribution to knowledge of this research. This chapter also includes consideration of the multi-criteria module, the bidding module, the optimisation module, and the learning module.

In Chapter 4, the results of the survey in relation to choosing suppliers selection criteria will be presented. Furthermore, there will be an overview and discussion of results obtained from the questionnaire in this chapter.

In Chapter 5, the development of mathematical programming (including both goal and mixed-integer programming) as a main methodology in research, will be discussed. In addition, objective function, and various restrictions with regard to pre-defined criteria in order to find the optimum suppliers will be presented.

In Chapter 6, validation of proposed methodology will be presented. The selected project is the 'Qeshm water and power co-generation plant' consists of making the compressed air systems by Havayar Co Group. All required information will be acquired and modelled based on the proposed optimisation model following by sensitivity analysis at the end of the chapter.

An extended conclusion and discussion on recommendations, limitations, and recommended future work will be presented in Chapter 7. Figure 1.7 provides an overview of the thesis with the chapters listed above.

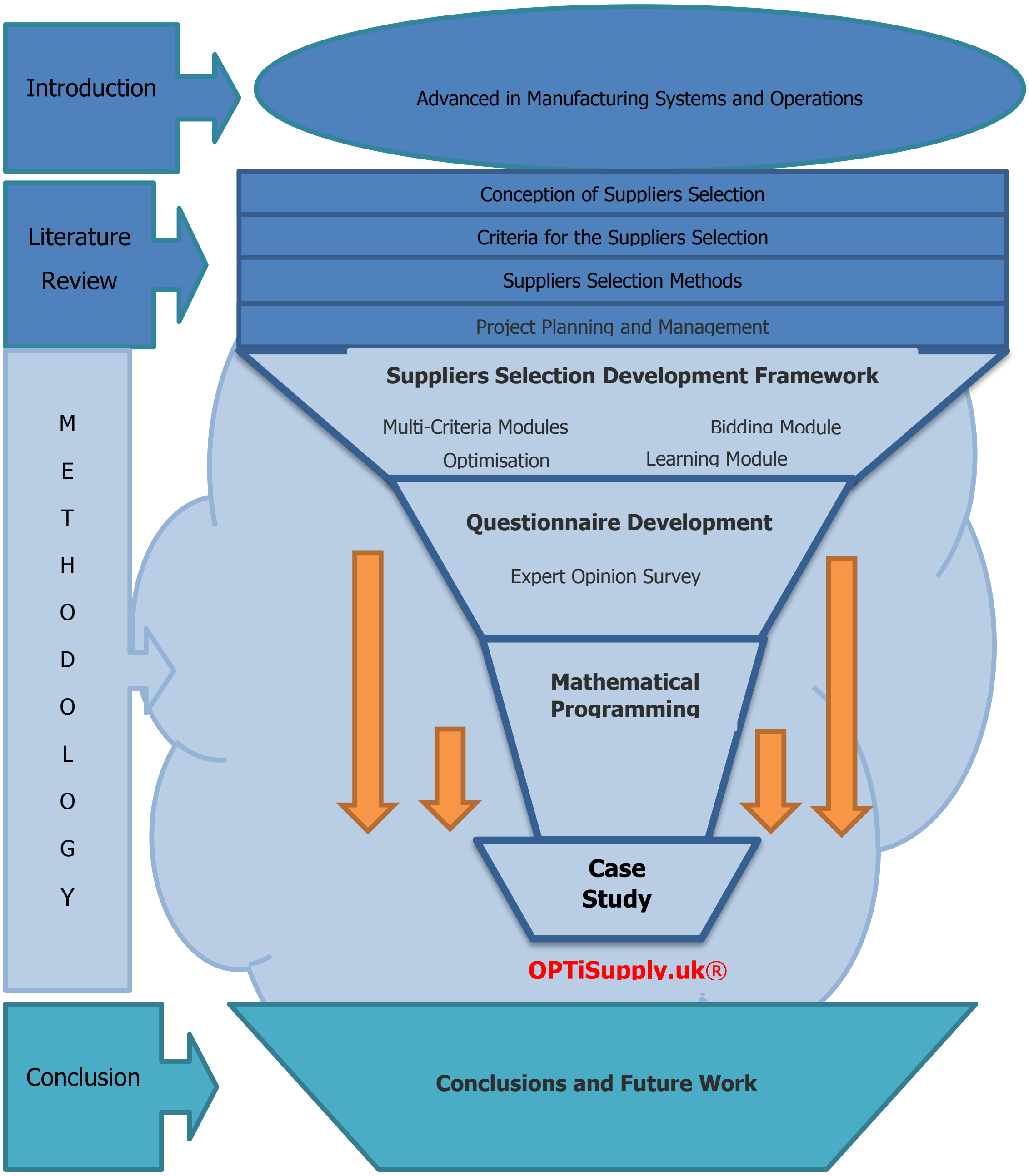

Figure 1.7: Overview of the thesis structure

CHAPTER 2 LITRETURE REVIEW

2.1 Introduction

Manufacturing companies are willing to outsource part of their manufacturing and business processes to be successful in current competition conditions. This outsourcing is happening in different sections such IT, raw materials, sales, logistics, and transportation in terms of various managements strategies. The result of a survey (Accenture Consulting, 2005) shows that 80% of correspondent companies are not only receiving services and parts from third party logistic providers, but also spending almost half of their budgets on outsourcing. Although, the traditional outsourcing emphasised on financial activities, many companies are also assessing multiple-criteria vendor selection in order to be more efficient (Talluri and Narasimhan, 2003). Moreover, reducing inventories, outsourcing costly manufacturing activities and collaborative relationships with other suppliers could reduce the competitive force of globalised business market. Hence, one of the main concepts for product realisation process from product design to final product delivery is selecting the best supplier and purchasing strategy (Fisher and Marshal, 1997; Hult *et al.*, 2004; Lee and Haul, 2004; and Wisner and Joel, 2003).

This chapter includes five sections. In Sections 2.2 and2.3, extensive background information and literature review on the concept of suppliers selection, different criteria for the suppliers selection, and description of important criteria used in this dissertation will be discussed respectively. In Section 2.4, both individual and integrated suppliers selection methods, which split into a number of aspects such as analytic hierarchy process (AHP), analytic network process (ANP), and mathematical programming (MP) including linear programming (LP), integer programming (IP), data envelopment analysis (DEA) and goal programming (GP), will be presented. Lastly, project management and project planning concepts, as an essential part of this thesis, will be described in Section 2.5.

2.2 Conception of Suppliers Selection

Suppliers selection is one of the main concepts of this research and is considered as strategic procurement management in the supply chain. Purchasing raw materials needs accurate decision making strategies to find the best suppliers to assure long term feasibility of an organisation (Thompson, 1990). Existing literature and suppliers selection problems identified by researchers will be discussed in this section based on various suppliers selection criteria. Based on Lagrangian relaxation, Benton (1991) proposed a model named as the 'discount model' for selecting appropriate suppliers based on multiple items and suppliers, resource constraints; and a quantity/cost discount model.

In his research, optimising the purchasing, inventory, and ordering costs were the main objective functions, followed by budget, stock level, and storage limitations as constraints. However, it was noted that quality and capacity were not included as constraints.

Dobler *et al.*, (1990) and Willis *et al.*, (1993) stated that the procurement department plays a significant role in enterprise as their managers are responsible for making critical decisions to select appropriate suppliers in order to reduce ordering/purchasing expenses.

To eliminate the complexity of suppliers selection as a multi-objective model, a broad approach to choose the best suppliers was proposed and launched by Weber and Current (1993). Their main aim was to reduce all expenses caused by purchasing the enterprise requirements from various suppliers each time. This model proposed a way to estimate changeable conditions of selected suppliers over time. Hence, management was able to undertake essential actions.

Although, there were only few articles emphasising decision making until Weber and Current (1993), Rosenblatt *et al.*, (1998) had a comprehensive articles review and stated another suppliers selection limitation, which was the amount and purchase time of products or services. By using *'kanban'* or 'just in time' (JIT) systems and specifying an exact quantity of requirements from an allocated suppliers, the limitation seems to have been overcome.

Chauhan and Proth (2003) proposed two different cases in an article. While various suppliers in the first case have contracts with one enterprise unit to supply their requirements, various suppliers provide services and products to several enterprises in the second case. In both cases, providers follow a predefined policy in inventory and procurement quantity. Their main aim was to choose the best supplier that is offering the lowest price. Hence, as a result, they proposed an optimal solution based on numerical algorithms for both cases.

How to buy a single product under fixed demand over various periods of time was the main problem in the Liao and Rittscher (2007) research. They proposed a stochastic, multi-objective suppliers selection model to estimate the total purchasing amount and delivery time by measuring suppliers flexibility. Moreover, they used a genetic algorithm (GA) to minimise the total logistic cost as an objective function, and such factors as total cost, quality rejection rate, delivery delay rate, and flexibility rate as constraints.

Providing a long term deal and a reasonable value to buyer, as well as removing possible risk for customer and retailer, are the final goal of suppliers selection as detailed by Keskin *et al.,* (2010). The authors believed that human decisions to assess and choose best suppliers are the reasons for making the suppliers selection area complicated and uncertain. They mentioned that the financial reasons were the main concern in traditional suppler selection issues. However, using algorithms, such as the Fuzzy Adaptive Resonance Theory (Fuzzy ART), as a multiple supplier selection method, can significantly resolve the existing problems.

As it mentioned, many authors have explored different problems and tried to solve them by using different techniques. However, the emphasis on time, cost and quality is common to all.

2.3 Criteria for the Suppliers Selection

Finding the appropriate suppliers is a difficult duty in procurement departments as suppliers have different strength and weakness. Although it might be easier to consider only a single criterion in final decision, multi-criteria decision making will be necessary in some cases. Many researchers analysed selection criteria and measured suppliers performance since 1960. There have been four comprehensive reviews, namely Dickson (1966), Weber *et al.*, (1991), Davidrajuh (2000), and Ho *et al.*, (2010), on suppliers selection criteria.

2.3.1 The Period Towards 1966

Dickson (1966) designed a questionnaire to identify important criteria in suppliers selection. He sent his survey to 273 procurement staff and managers, who were members of the National Association of Purchasing Managers, including agents and managers from the United States of America and Canada. As a result, he identified 23 criteria and the significance of each criterion based on five different scales, extreme, considerable, average, slight and, no importance. As shown in Table (2.1), the ability to meet quality standards, the ability to deliver the product on time, and performance history were the most significant performance measures among all 23 criteria in suppliers selection.

Table 2.1: Comparison of suppliers selection criteria rank

Rank	Dickson, (1966)	Weber, (1991)
1	Quality	Net Price
2	Delivery	Delivery
3	Performance History	Quality
4	Warranties	Production Facilities
5	Production Facilities	Geographical Location
6	Net Price	Technical Capability
7	Technical Capability	Management and Organisation
8	Financial Position	Reputation
9	Bidding Procedural Compliance	Financial Position
10	Communication System	Performance History
11	Reputation	Repair Service
12	Desire for Business	Attitude
13	Management and Organisation	Packaging Ability
14	Operational Controls	Operational Controls
15	Repair Service	Training Aids
16	Attitude	Bidding Procedural Compliance
17	Impression	Labour Relations Records
18	Packaging Ability	Communication System
19	Labour Relations Records	Reciprocal Arrangements
20	Geographical Location	Impression
21	Amount of Past Business	Desire for Business
22	Training Aids	Amount of Past Business
23	Reciprocal Arrangements	Warranties

2.3.2 Period of 1966-1991

Two decades after the Dickson research, Weber *et al.,* (1991) reprioritised 23 the Dickson criteria by reviewing 74 articles published in the manufacturing and retail sectors between 1966 and 1991. This comprehensive study showed that during almost 20 years, the priority and ranks of criteria has changed (see also Table 2.1). Net price, the ability to meet quality standards, and the ability to deliver the product on time are considered as the most important factors, following by production facilities, geographical location, and technical capability. Comparing criteria ranking in both the Weber and Dickson research shows factors such as quality, delivery, and net price are always considered as important factors. However, the surprise could be the rank changes of geographical location (from 20th stage to 5th stage) which, it is argued, is the result of economic globalisation (Mendoza *et al.,* 2008).

The top ten criteria ranked in the Weber research based on the number of articles published to address specific criterion presented 'quality' as the clear top being cited in 80% of all research papers (Table 2.2). Moreover, 'delivery' and 'quality' were cited in 58%, and 52% of research articles respectively. Zhang *et al.,* (2003) undertook a similar study as Weber by reviewing 49 articles based on the 23 Dickson criteria and presented almost the same result as Weber.

Table 2.2: Top 10 suppliers selection criteria
(Source: Weber, 1991)

Criteria	Articles	%
Net Price	61	80
Delivery	44	58
Quality	40	52
Production Facilities	23	30
Geographical Location	16	21
Technical Capability	15	20
Management and Organisation	10	13
Reputation	8	11
Financial Position	7	9
Performance History	7	9

2.3.3 Period of 1991-2001

Industrial organisations with good purchasing strategies are capable of having long-term viability and survival in highly competitive markets (Kinney, 2000). He divided his articles into two parts. He proposed outsourcing, global sourcing, supply chain optimisation, and supplier consolidation as four critical strategies for continuous improvement in industrial companies. Then, he allocated different weightings to each supplier selection criterion to show the importance of criteria in various industries.

Cheraghi *et al.,* (2001) published a paper in which the 23 Dickson criteria have been reviewed in almost 100 research articles between 1991 and 2001. He claimed that 'quality', 'delivery', and 'net price', with 79%, 77%, and 67% articles citation counts, to be the most important criteria. Criteria such as \`desire for businesses', \`amount of past businesses', and \`warranties' were not cited at all (see Table 2.3). Furthermore, the authors compared their findings with the Weber *et al.,* (1991) study which showed the significant variation in the relative importance of different critical success criteria. Table 2.3 below shows the important change of criteria ratings during 1966-1991 versus 1991-2001.

Table 2.3: Comparison of suppliers selection criteria rank

Rank	Weber, (1991)	Articles	%	Cheraghi *et al.,* (2001)	Articles	%
1	Net Price	61	80	Quality	31	79
2	Delivery	44	58	Delivery	30	77
3	Quality	40	52	Net Price	26	67
4	Production Facilities	23	30	Repair Service	11	28
5	Geographical Location	16	21	Technical Capability	11	28
6	Technical Capability	15	20	Production Facilities	10	26
7	Management and Organisation	10	13	Management and Organisation	7	18
8	Reputation	8	11	Financial Position	7	18
9	Financial Position	7	9	Attitude	5	13
10	Performance History	7	9	Performance History	4	10
11	Attitude	6	8	Communication System	4	10
12	Repair Service	6	8	Reputation	4	10
13	Operational Controls	5	7	Procedural Compliance	2	5
14	Packaging Ability	5	7	Geographical Location	2	5
15	Impression	4	5	Impression	2	5
16	Communication System	3	4	Reciprocal Arrangements	2	5
17	Reciprocal Arrangements	3	4	Labour Relations Records	1	3
18	Labour Relations Records	3	4	Training Aids	0	0
19	Training Aids	3	4	Operational Controls	0	0
20	Procedural Compliance	2	3	Packaging Ability	0	0
21	Desire for Business	2	3	Desire for Business	0	0
22	Amount of Past Business	1	1	Amount of Past Business	0	0
23	Warranties	1	1	Warranties	0	0

The authors' findings shows that in spite of traditional factors such 'quality' and 'price', non-traditional performance aspects such as 'just-in-time communication', 'continuously process development', and 'supply chain improvement' could be a reason for change in importance of suppliers selection criteria. Muralidharan *et al.,* (2002) argued that significant rank changes in different time periods are due to globalised and highly competitive markets using Internet based technologies. Meanwhile, new criteria in suppliers selection development could be presented over time. Changes in importance of criteria such as 'geographical location', 'repair service', and 'financial position' are shown in Figure 2.1 below.

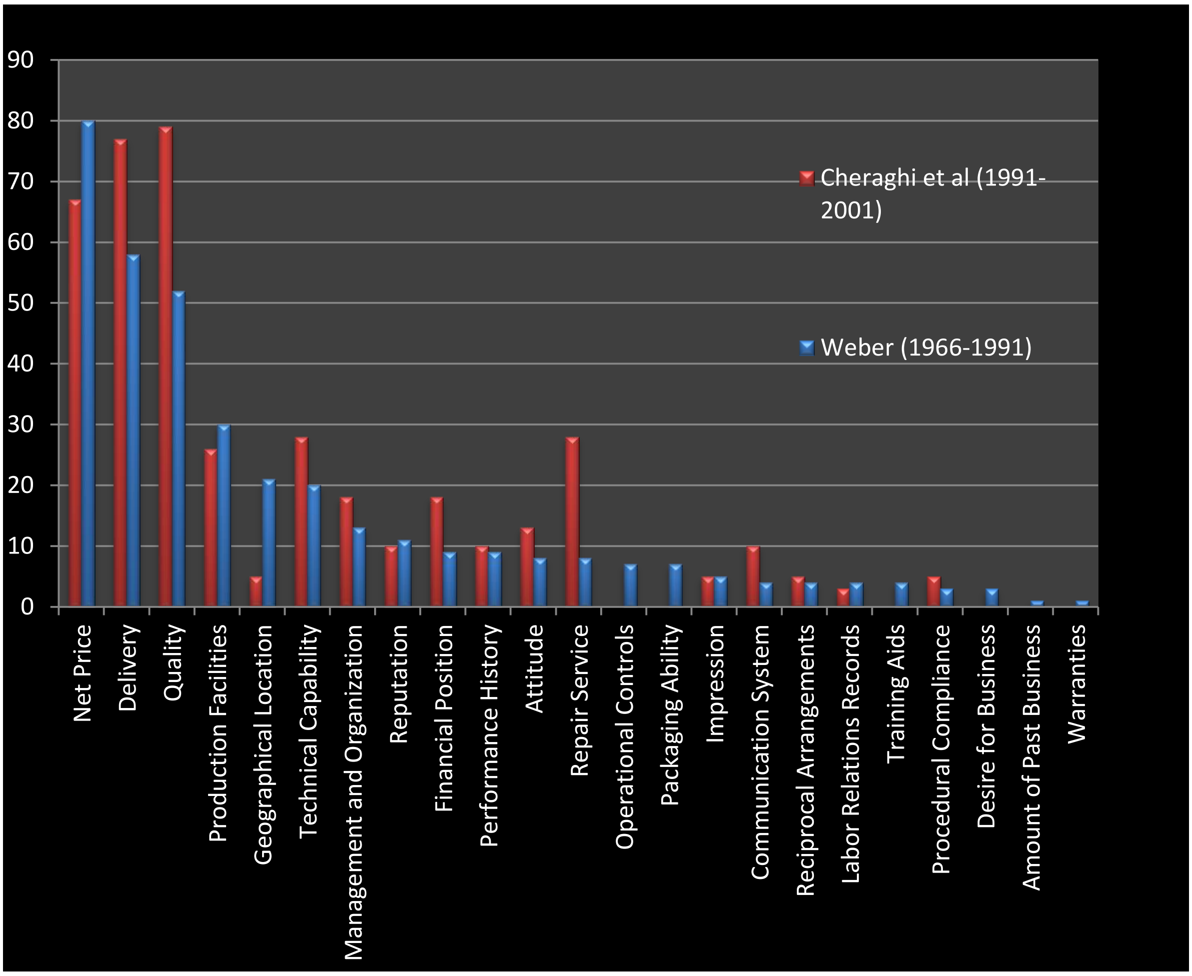

Figure 2.1: Comparison of factors (period of 1966-1991 and 1991-2001)

2.3.4 Duration of 2001 to Present

Weber *et al.*, (1991), Degraeve *et al.*, (2000), De Boer *et al.*, (2001), and Cheraghi *et al.*, (2001) were four papers reviewing the literature regarding suppliers selection development. Since these articles review the literature up to

2000, Ho *et al.,* (2010) published a comprehensive literature review based on 78 research articles searched and collected via Emerald, Ingenta, Meta- Press, ProQuest, and ScienceDirect on the multi-criteria decision making approaches for suppliers evaluation and selection models between 2000 and 2008. The main objective of their article was to identify the most popular criteria considered by the decision makers for assessing and choosing the best supplier.

Table 2.4: Suppliers selection criteria

(Source: Ho *et al.,* 2010)

Criteria	**Articles**	**%**
Quality	68	88
Delivery	64	82
Price/Cost	63	80
Manufacturing Capability	39	50
Service	35	45
Management	25	33
Technology	25	33
Research and Development	24	31
Finance	23	29
Flexibility	18	24
Reputation	15	20
Relationship	3	4
Risk	3	4
Safety and Environment	3	4

Among hundreds of criteria they supposed, Table (2.4) indicates that the 'quality', 'delivery', 'price/cost', and 'manufacturing capability' were the most popular criteria, as these criteria were sited in 88%, 82%, 80%, and 50% of the research papers, followed by 'service', 'management', 'technology', 'research and development', 'finance', 'flexibility', 'reputation', 'relationship', 'risk', and 'safety and environment'.

Pani and Kar (2011) identified the critical suppliers evaluation and selection criteria which are significant in manufacturing industries, and hence stated the significance of these criteria to the procurement activities. The authors identified ‘product quality’, ‘delivery compliance’, ‘price, production capability’, ‘technological capability’, ‘financial position’, and ‘e-transaction capability’ as important criteria of suppliers selection development.

2.4 Suppliers Selection Methods

Due to uniqueness of each problem, it is hard to introduce a specific solution for every problem. Different type of methods or combination of methods for suppliers evaluation and selection are available to help decision makers. In order to increase productivity and provide customer satisfaction, organisations need to have close relation with suppliers. In fact, to reduce cost and provide better services, organisations seek to outsource part of their product or services. Actually, they need to evaluate and monitor suppliers performance over time. Hence, organisations pay considerable attention to suppliers evaluation and selection methods. Agility and flexibility are basic requirements of a desirable model among different selection models. Finding the best supplier, who may have various weaknesses and strengths based on the enterprise short and long term goals, are considered as an uncertain task. In the simplest scenario, decision makers only consider a single criterion, for instance, either quality or price. However, it would be very optimistic to attempt to survive in highly competitive market if companies only consider one criterion instead of multiple criteria.

As explained in Section 2.3, different criteria should be considered in order to find the best supplier selection solution. Karimi and Rezaeinia (2014) defined supplier selection as a multiple criteria decision-making (MCDM) problem. Sarkis and Talluri (2002) and Chai *et al.*, (2013) stated that to enable the simplification of various criteria and obtain a best solution, MCDM is the most desired method for management. To deal with this problem, many authors proposed various individual supplier evaluation approaches, such as, AHP, ANP, MP, DEA, and GP. Moreover, some researchers proposed to use an integrated (mixed) approach of the aforementioned methods. Hence, individual approaches will be discussed in Section 2.4.1 following by integrated approaches in Section 2.4.2.

2.4.1 Individual Approaches

Based on the problems in different cases or industries, the researcher decided to use either individual approaches or integrated (mixed) approaches. Ho *et al.,* (2010) published a comprehensive literature review to show the popularity and capability of individual and integrated methods in different researches and industries. Among 46 journal articles, 23 papers (50%) formulated different types of mathematical programming individually as the most appropriate solution for various industries and organisations. These various MP models were applicable in different organisations, such as, bottling machines and packaging lines manufacturing, agricultural and construction equipment manufacturing, electronic components manufacturing, telecommunications industry, suppliers evaluation and management accounting, communications industry, nuclear power industry, consumer products manufacturing, pharmaceutical industry, aviation electronics manufacturing, hydraulic gear pump manufacturing, and hydraulic gear pump manufacturing. An AHP model was proposed individually in 15% (seven out of 46) of papers while ANP was proposed in almost seven percent of papers (three out of 46). Both AHP and ANP were applicable in manufacturing industries, such as, automobile castings, bicycles manufacturing, semiconductor assembly and equipment manufacturing industry, furniture industry, airline industry, printer manufacturing, electronic industry, and high technology metal-based manufacturing.

2.4.1.1 Analytic Hierarchy Process (AHP)

AHP is a modern MCDM approach proposed by Saaty (1980) which has been extensively using linear weighting techniques to analyse both quantitative and qualitative performance when multiples criteria and sub-criteria should be used. This method not only recommends a correct decision, but also enables decision makers to form a decomposition of complex problems into hierarchies which comprise different levels such as goal allocated criteria, for example, customer satisfaction, product/service, financial, human resource, and organisational effectiveness, , and the alternative solutions (Benyoucef, 2003). To categorise criteria in order to have a mathematically optimal solution, a matrix algebra and paired-wise comparison method is used.

Akarte *et al.,* (2001) proposed a web-based decision support system for casting suppliers evaluation by using AHP method. The authors specified 18 criteria, for example, quality, cost, and delivery, and categorised into four groups, namely, product development capability, manufacturing capability, quality capability, and cost and delivery. Customers need to sign up to their system first, and then choose the casting specification located in the portal. Chan (2003) designed a method called chain of interaction using AHP to create the overall weights for nominated suppliers based on the relative importance ratings. Recently, Kar (2014) proposed a fuzzy AHP approach for group decision making. To initialise and integrate the preferences of the group of decision makers, the author mixed fuzzy AHP with the geometric average method. Based on the numerical results from a case study, this article indicated that the applied mixed method in this research had more productivity and is more applicable in comparison with only using the AHP method. AHP has some advantages listed below:

- dealing with complex problems which cannot be solved by other methods;

- easy and straight forward to use;
- being flexible for different problems;
- combining both qualitative and quantitative criteria to choose the best solution; and
- ability to extend or mix with other methods (Muralidharan *et al.*, 2002).

However, having a long and slow process time is one of the main drawbacks of AHP method due to its reliance on a subjective, paired-wise, comparison method for assessing alternatives (Wang *et al.,* 2010). Moreover, to add a new criterion during a process, whole calculations must be repeated from the beginning.

2.4.1.2 Analytic Network Process (ANP)

As mentioned earlier, the first step of AHP begins with a strategic phase, and then a paired-wise algorithm must be developed. However, in order to offer the best solution, many authors used AHP and its extension ANP by integrating with mathematical programming (Ghodsypour and O'Brien (1998, 2001); Demirtas and Ustun, (2008, 2009); Gencer and Gurpinar, 2007; Ravindran *et al.*, 2010; Wang and Yang, 2007; Wu *et al.*, 2009). In all the mentioned studies, the authors proposed an approach to assess and rank the suppliers as the first part of their studies. Then, the optimal score of purchase as a part of methodology to each supplier is allocated.

The ANP is a generalisation of the AHP, solving complex decision problems. The main differences between these two models is in their structure, within which the hierarchy includes a goal, levels of criteria and connection between criteria and alternatives, while the latter one includes clusters, elements, and links(Saaty, 1996). In fact, Saaty (1996) introduced an extended model of AHP to solve the problem of interrelation among different criteria or alternatives.

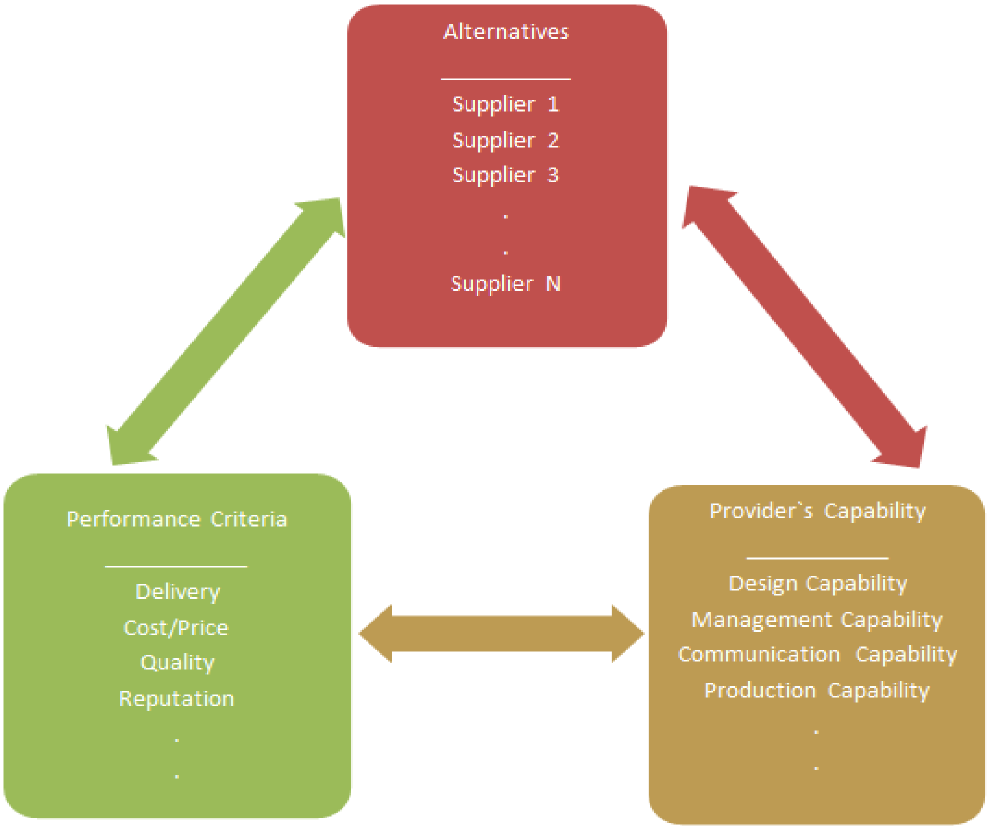

Figure 2.2: ANP model instance
(Source: Bayazit, 2006)

Similar to AHP and other methods, ANP proposes to select and optimise the best supplier. A simple cluster model with N suppliers and different decision attributes is shown in Figure 2.2. To clarify related alternatives, factors are provided in suppliers performance criteria and provider capabilities. Hence, this model consists of N clusters, alternatives, performance criteria, and provider capability (Bayazit, 2006). In contrast with AHP, which offers hierarchical and linear structure, ANP offers a nonlinear structure. Figure 2.3 below shows the structure differences in AHP and ANP.

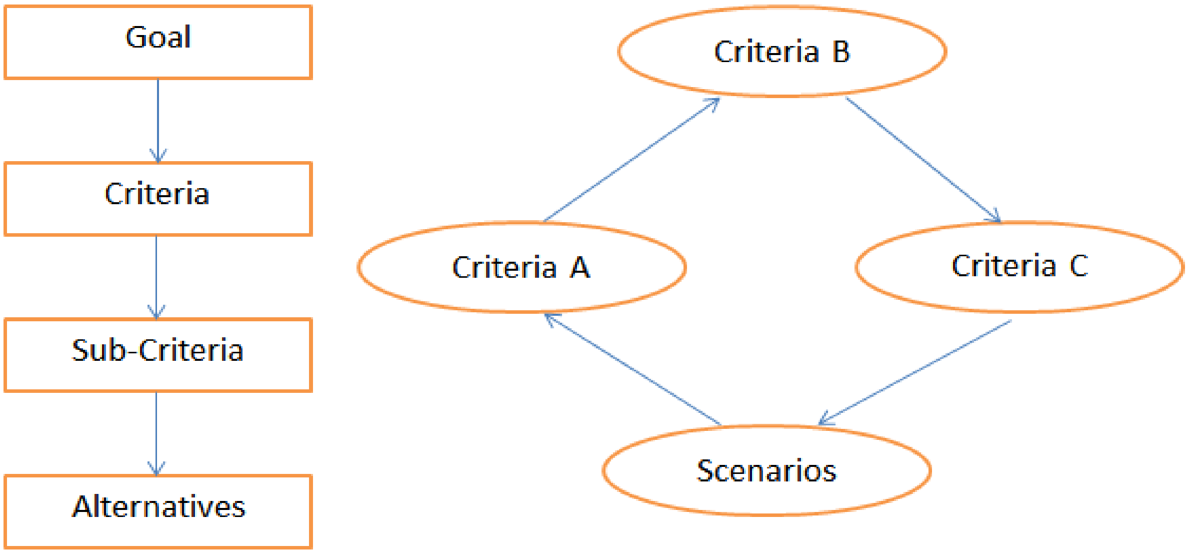

Figure 2.3: Hierarchal structure (left) against network structure (right)

The advantage of ANP in comparison with AHP is the former one is able to deal systematically with all kinds of dependence and feedback in a decision system (Bayazit, 2006). With respect to logistic factors and performance activities, Sarkis and Talluri (2002) proposed ANP to choose the best supplier in enterprises. They argued that not only internal interdependency needed to be considered in the evaluation process, but also that selection criteria would impact each other.

However, being suitable for only long term strategic decisions is one of the drawbacks of ANP method. Moreover, timely and complex pair-wise comparisons require considerable effort to obtain a best result, which still might lead into wrong results.

2.4.1.3 Mathematical Programming (MP)

MP or optimisation is an operation research (OR) technique allowing decision makers to generate the best solution and optimise the models. Liberti (2009) defined MP as:

'descriptive language used to formalise optimisation problems by means of parameters, decision variables, objective functions and constraints, while such diverse settings as combinatorial, integer, continuous, linear and nonlinear optimisation problems can be defined precisely by their corresponding formulations.'

The main methodology that has been used in this thesis is the MP model. The main advantage of this model is its capability of optimising results using both single and multiple objective models. In order to develop and implement a systematic MP model, there are four development stages shown in Figure 2.4:

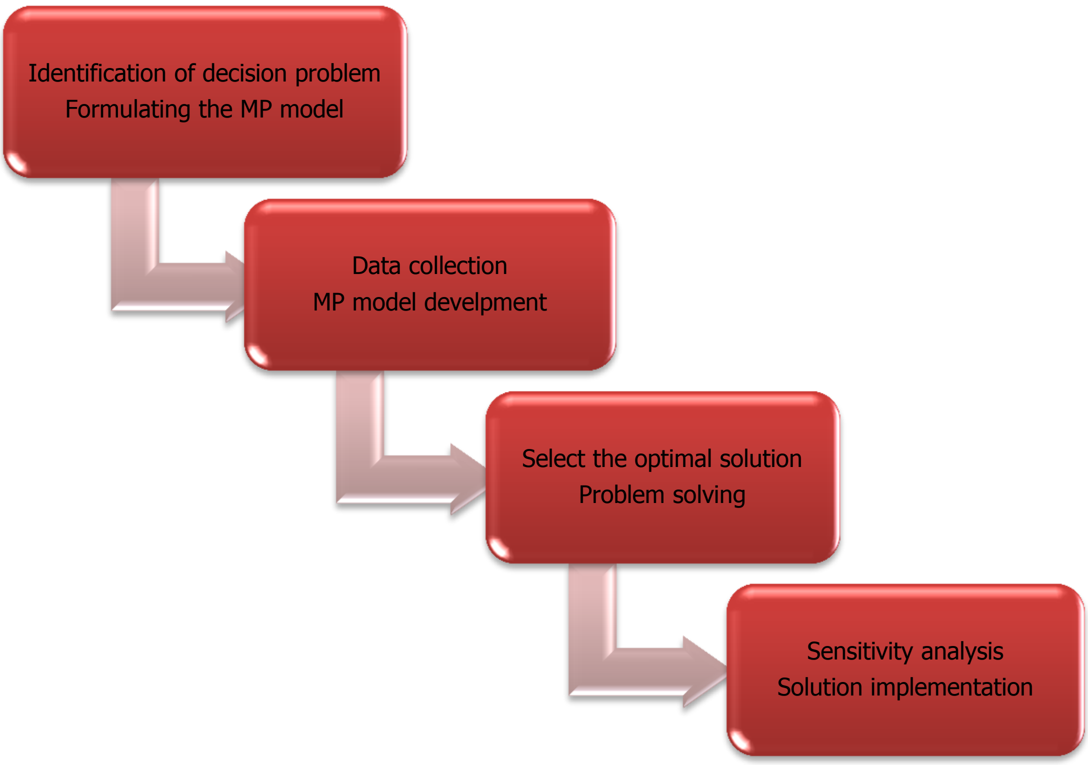

Figure 2.4: Mathematical programming development stages

According to Figure 2.4, the first stage is the identification of decision problems and formulation of the MP model. To formulate the MP models, there are three essential components, namely decision variables, objective function, and constraint.

1. Decision Variables: the variables within a model which are controlled by decision makers and could be varied over the practical set of alternatives. Decision variables usually are designated by X1, X2, X3…, Xn in order to help decision makers describe different solutions, and to increase or reduce the amount of main objective function.
2. Objective Function: A mathematical and real-valued function of decision variables which is desired to be maximised or minimised in order to indicate the quality of solutions over the set of feasible alternatives.
3. Constraints: The relationships among decision variables which influence on the optimal value of the main objective function.

After defining the essential components, the next stage is defining the parameters of the problem by the collection of required data. This stage, considered as the most time-consuming and costly step of whole process, includes objective-function coefficients, the constraint coefficients, and the right-hand side of the model.

In order to obtain an optimal solution, the MP model needs to be solved in the next stage. There are several methods to solve the problems, such as simplex method, dual simplex method, feasible solutions, and graphical solutions. However, by improvement in technologies and computing, over the past twenty years, new approaches have emerged. Small models could be solved by a typical spreadsheet such as the Excel Solver program, while specialised programs and packages such as 'Lindo', 'Lindo API', 'Lingo', and 'What'sBest©' (WB) are able to build large scale optimisation models. These programmes include different features and are suitable for linear programming, nonlinear programming, and integer programming, stochastic programming, and global optimisation. For example, WB is an Excel add-in, allowing spreadsheet users to solve optimisation models almost immediately. In addition, it is suitable to use in different areas such as business, marketing, industry, research, and government.

The last stage is a sensitivity analysis which provides a systematic review of results involving a categorisation of decisions. Moreover, sensitivity analysis would alert decision makers about errors and the results of errors introduced in the original formulation. In addition, sensitivity analysis helps decision makers to observe the new results when new variables or constraints are added into the problem.

Pyke and Cohen (1993) proposed a MP model in order to evaluate the values of different criteria in an integrated supply chain management system by considering a three-level supply chain. These levels include one product, one manufacturing facility, one warehousing facility, and one retailer. Minimising total cost was set as an objective function, while a service level, processing times and replenishment lead times were set as constraints.

Tzafestas and Kapsiotis (1994) designed a novel model by combining simulation techniques in a MP model in order to optimise a supply chain and analyse a numerical example of their optimisation model by setting total cost as an objective function. The authors accomplished their proposed model in different scenarios in order to compare and analyse different obtained results. These three scenarios consist of manufacturing facility optimisation, global supply chain optimisation, and decentralized optimisation. Despite three different scenarios, there were no significant differences in total costs reported in their research.

Narasimhan *et al.*, (2006) presented a MP model to identify best suppliers and suppliers bids when various products with various ranges of life cycles were being considered. Esfandiari and Seifbarghy (2013) presented a MP model by setting purchasing cost, rejected units, and late delivered units as constraints while maximising the quality was the main objective function. There are various types of MP categorised as:

Linear programming (LP)

LP is a MP model in which a linear function of a number of variables or criteria is selected in order to minimise or maximise. All variables are allocated to different kinds of constraints in the form of linear inequalities. Moore and Fearon (1973) and Pan (1989) used LP for selection evaluation based on criteria such as price, quality, and delivery. By minimising the total cost and setting quality of products and delivery time of final product as constraints, the authors optimised their model.

Talluri and Narasimhan (2003, 2005) presented a model in which customers have to set the target score. This model utilises two different LP models for maximising and minimising the supplier performance in order to provide a broad understanding of a supplier performance. Two years later, these researchers developed a DEA model for telecommunications companies to compare the new results with their previous results. Esfandiari and Seifbarghy (2013) proposed a multi-objective LP model in which the total scores from the suppliers selection procedure is maximised while purchasing cost, rejected units, and delayed delivered units were minimised.

Integer programming

Methods such as LP and Integer Linear Programming (ILP) (Talluri, 2002; Hong *et al.*, 2005), and GP have been applied to help decisions makers on suppliers selection evaluation.

Feng *et al.,* (2001) presented a stochastic integer programming (SIP) model for simultaneous selection of tolerances and suppliers based on the quality loss function and process capability index. The main philosophy used in the SIP model was inspired by concurrent engineering as it emphasised assimilability, quality, and cost, at the product design stage. The process capability index is considered as a relational link between manufacturing cost and the required level of manufacturing yield. In their proposed model, a combination of manufacturing cost and quality lost has been minimised as the objective function. The authors believed that their SIP model had advantages such as 1) removing the regression errors, 2) considering asymmetric and symmetric tolerance, and 3) applying the process capability level in both component level and the assembly level.

Hong *et al.,* (2005) proposed an integer programming model to optimise the number of suppliers and orders. This model optimises revenue and satisfies customer requirements by considering on suppliers experiences and purchaser requirements over a period in time. While minimising the total annual ordering, holding, and purchasing costs set as objective functions, quality and capacity were considered as constraints to the problem.

Amid *et al.,* (2009) formulated a mixed integer model to consider simultaneously the imprecision of information, and determine the quantities to each supplier based on price breaks. The proposed model set different objective functions by minimising the net cost, net rejected items, and the net late deliveries. Satisfying capacity and demand requirement are also set as two difference constraints.

Data envelopment analysis (DEA)

DEA is a non-parametric MP model developed by Charnes *et al.,* (1978) for measuring the relative efficiency of decision-making units (DMUs), which categorise into two units, multiple outputs and multiple inputs (Truong, 2010). The former one includes criteria such as quality, benefits, customer satisfaction, while the latter one includes criteria such as cost, material resources, and human resources. In the whole supply chain management network, DMUs consist of different organisations from manufacturers and suppliers to wholesalers and retailers.

Forker and Mendez (2001) suggested that DEA could be applied not only in suppliers evaluation, but also in the airline industry, banking, academic organisations, power plant, and health care. The authors introduced the 'best peer' supplier which refers to those suppliers who are not suitable for the organisation but, however, have the ability to improve their performance by minimum effort. Hence, the optimum ratio of a single input to multiple outputs needs to be calculated in order to filter the total results. Furthermore, Wu *et al.,* (2007) argued that one of the key advantages of DEA, which makes it a suitable method for evaluating and executing management decisions, is its capability to deliver a different range of critical decision models. Hence, managers have a variety of options in order to develop their operations.

However, the main practical problem in using DEA is the weights flexibility problem, (Kumar and Jain, 2010) due to offering a simple framework in order to convert decision maker judgments into the decision making process. The authors used the DEA approach for green environmental suppliers evaluation by encouraging suppliers to go with green and monitoring carbon footprints in order to survive in highly competitive markets.

Goal programming (GP)

Dealing with multi-criteria decision issues, where the predefined goals cannot concurrently be optimised, GP was proposed for the first time by Charnes and Cooper (1961) in order to provide a set of acceptable solutions. Many researchers and industries tend to use this model because GP can offer the most suitable solution to decision makers as well as its ease of use and adaptability. Wadhwa and Ravindran (2006) proposed a pricing model under quantity discounts to represent the purchasing cost by using the GP model, as they believed that GP model is more suitable for vendor selection process, based on a set of constraints and criteria. This model was designed to cope with one buyer and one product, and developed for more than one buyer and product to show the differences of results.

Kumar *et al.,* (2004) proposed a 'fuzzy mixed integer' GP based approach for vendor selection (f-MIGP-VSP) in order not only to handle realistic situations in a fuzzy environment, but also provide a better decision tool for the vendor selection decision in a supply chain. In their proposed model, minimising the net cost, net rejections, and net late deliveries were set as objective functions, while buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items were set as constraints. Any kind of commercial software such as LINDO or LINGO is able to solve the proposed f-MIGP-VSP formulation, which counts as one of the advantages of this model.

Khorramshahgol *et al.* (2014) proposed a GP model to cope with the swap problem of firms in oil industries. Three different GP-based scenarios were proposed where each scenario includes five objective functions and various constraints. The main aim of this research was to persuade managers to consider viable alternatives, preferences, 'trade- offs' and outcomes before making any decision for buying products.

Many authors proposed different types of MP models (LP, IP, GP, and DEA) in their researches as a more suitable method for vendor selection problems under various constraints and criteria in manufacturing industries. Specially, enterprises are able to evaluate and measure their performance when more than one criterion is defined in their purchasing policy. Hence, a multi-period buying policy could be derived by MP to minimise the total cost model (Degraeve and Roodhooft, 2000). Furthermore, MP provides an easier solution for decision makers when they need to supply the weightings for each of the objectives.

2.4.2 Integrated Approaches

In different scenarios, only applying an individual approach could not effectively solve the problems. Many authors proposed integrated approaches in order to use two or more models. Hence, decision makers were able to combine various approaches and get benefit from the advantages of different models. It is also essentially important in their implementation and application particularly in the e-manufacturing and e-business context (Cheng and Bateman, 2008).

Ramanathan (2007) introduced an integrated DEA with AHP model in order to evaluate suppliers performance by analysing information obtained from manufacturing cost. In this research, three different kinds of DEA, namely traditional, super-efficiency, and assurance region, combined with AHP to show which combined model can minimise the manufacturing cost. Sevkli *et al.,* (2007) developed a data envelopment analytic hierarchy process AHP (DEAHP) methodology in the TV manufacturing industry. Their finding shows that DEAHP can provide a better decision as its application is more suitable for high-value components where purchasing criteria are variables. To compare DEAHP with AHP, the authors defined the criteria for suppliers selection by designing an AHP tree, and then assigned different weightings for predefined criteria to specify an overall score for each supplier. The main manufacturing and business criteria they used in the research were reputation, price, technical capability, production capacity, and lead-time.

Cebi and Bayraktar (2003) proposed an integrated GP and AHP model including both quantitative and qualitative conflicting factors aims for the food manufacturing industry. The authors argued that food industries need to focus on an effective, systematic and scientific approach to suppliers management and suppliers selection in order to improve their competitive advantages. There were four main objective functions in the research, maximisation of quality, minimisation of delivery, minimisation of cost, and maximisation of utility function. The AHP method used in order to calculate the coefficients of the utility function (forth objective function) included qualitative criteria except quality, delivery and cost to prevent duplication in the model. Similar work was proposed by Wang *et al.,* (2004, 2005), by integrating AHP and GP based multi criteria decision making MCDM (methodology in automobile manufacturing industry. This research showed the combination of AHP weighting with GP (AHP-GP) is able to offer the best set of multiple suppliers while capacity was set as a constraint. Another research by using AHP-GP model in automobile industry has been proposed by Percin (2006). In order to evaluate the overall scores of alternatives suppliers and to measure the relative importance weightings of potential suppliers, the AHP model is applied emphasising 20 evaluation criteria. Moreover, all weightings, five objective functions (maximising suppliers' scores, maximising after-sales service levels, minimising suppliers' defects rate, minimising rate of late order delivery, minimising purchasing costs), and constraints are set by using the GP approach. One of the main advantages of this model is its flexibility to quickly respond to changing requirements in the automobile industry and to provide better solutions to decision makers and managers.

For sustainable manufacturing, Gupta *et al.,* 2010 developed a hybrid approach using an integrated AHP and fuzzy mathematical programming (AHP-FMP). In order to measure weightings of the various assets (liquid assets, high-yield assets, and less risky assets) within a cluster from the investor's points of view, and to determine suitability of different assets from a specific cluster for a given investor type, AHP has been used. Moreover, based on the results of the survey in their research and due to using mathematical programming, the authors specified five criteria (short term return, long term return, risk, liquidity and AHP weighted score of suitability). The main advantage of the proposed model is its capability and sustainability for each investor type in manufacturing organisations and also accommodating specific preferences within a given type.

To solve the multi-objective capacitated, multi-facility location problem in global manufacturing, and also to show the way to make better decisions and identify the results of wrong decisions when they received wrong data, Ozgen and Gulsun (2014) proposed an integrated linear programming approach and fuzzy analytical hierarchical process approach. The authors believe that the only way to deal with the imprecision of input data is to integrate two approaches. Minimising the total cost as well as maximising qualitative factor benefits (profit, customer satisfaction, and flexibility and robustness) in a four-stage supply chain network (suppliers, manufacturing plants, distribution centres, and customers) was set as the objective functions.

However, many researchers proposed mixed MP models in manufacturing organisations in order to take advantage of flexibility, control-oriented formulation, and ease of use of different MP models, such as the mixed linear-integer MP model, the integer-GP model, and the linear-GP model. In order to find an optimised solution for a parallel-machine scheduling problem with sequence-dependent setup times and release dates, Gharehgozli *et al.* (2009) presented a novel, mixed integer-goal programming (MIGP) model. Minimising the total weighted flow time and the total weighted tardiness simultaneously were set as the main two objective functions due to the complication of the model and uncertainty in real-world machinery scheduling. In addition, completion time of a real job assigned to the position in the sequence on any machine and the sequence-dependent set-up time were counted as two main constraints in MIGP model.

Ashouri *et al.* (2013) designed a mixed integer-linear programming (MILP) to optimise energy consumption in buildings. Moreover, authors designed and executed different building services such as thermal and electrical storages, heating and cooling systems, and renewable energy sources by using the proposed MILP model. The main problem in this research was to formalise the optimal selection and the making of modules while minimising the total costs. Hence, the main objective function includes minimising operating, investment, and discomfort objectives. While the operating objective represents the total consumption price of electricity and gas, the investment objective includes all purchasing, installation, maintenance cost. Furthermore, the limitation of annual CO_2 emissions and energy consumption per square meter of predefined area in building was set as two constraints.

As shown in Table 2.5, all methods have different advantages and limitations, and also have been used in different manufacturing sectors. MP models are able to offer a best solution to complex problems as well as optimising resource allocation within manufacturing sectors to establish desired goal. In addition, MP models are ideal for both single-objective models and multi-objective models because of ease of use, confidence in compromise solutions, and decision maker acceptance.

Table 2.5: Comparison of different decision-making methods

	Description	Advantages	Limitations	Applications
AHP	Powerful tool applying to make decisions when multiple and conflicting criteria are present, and both qualitative and quantitative aspects of a decision need to be considered	• Easy to implement • Robust • Ability to handle complex problems • Flexibility and intuitive appeal in different problems	• Requiring a large number of evaluations by the DM, especially for large problems • Having long and slow process time • Repetitive process in case of adding new criterion	Automobile castings, Bicycles manufacturing, Semiconductor manufacturing industry, Furniture industry, Airline industry, Printer manufacturing
ANP	Decision finding method and generalization of the analytic hierarchy process allowing for feedback connection and loops	• Ability to cope with non-linear structure • Dealing systematically with all kinds of dependence and feedback in a decision system	• In case of complex decisions, it needs complex methodology • Only suitable for long term strategic decision • Timely and complex pair-wise comparisons	High technology metal-based manufacturing, Electronic industry
DEA	Multi-criterial approach which capable of handling multiple inputs and outputs which are expressed in different measurement units	• Capable of handling multiple inputs and outputs • Useful in uncovering relationships that remain hidden for other methodologies	• Results are sensitive to the selection of inputs and outputs (Berg, 2010) • Incapable to provide a test for the best specification	Telecommunications industry, Supply chain management, Electronic components manufacturing, Nuclear power industry, Pharmaceutical industry
MP: **LP**, **IP**, **GP**	Multi-criterial approaches to find the best or optimal solution to a problem that requires a decision or set of decisions about how best to use a set of limited resources to achieve a state goal of objective	• Provide proper solution for complex problems • Capable of optimising results using both single and multiple objective model • Simplicity and easy way of understanding • Makes use of available resources efficient • Adaptive and flexibility to analyse the problem	• It depends on human judgment in some situation, such as given weights • Factors such as uncertainty and time are not taken into consideration	Pharmaceutical industry, Telecommunications industry, Personal computer manufacturing, Agriculture industry, Hydraulic gear pump manufacturing, Agricultural and construction equipment manufacturing

2.5 Project Management

Following the discussion of the supplier selection criteria and evaluation methods, it is necessary to describe the project management and project planning concepts. This is important where the suppliers selection function is applied to a set of interconnected services as a part of a project. Multi-service outsourcing has become an important business approach since it can significantly reduce service cost, shorten waiting time, improve customer satisfaction and enhance the firm's core competence (McCarthy and Anagnostou, 2004; Antelo and Bru, 2010). As for the process of multi-service outsourcing, a service process/product disaggregation is first conducted to pinpoint the SPEs that need to be outsourced. SPEs imply sub-services or products that combine to form a whole service process/product. A pool of appropriate suppliers is then selected for providing specific SPEs (Stratman, 2008). The outsourcing firm selects the most appropriate suppliers by considering service price, waiting time or service capacity, and builds long-term and profitable relationships with them (Wang and Yang, 2009).

A varied range of services from idea development to design, and others, such as, prototyping, part manufacturing, delivery, assembly, marketing, and sales, are outsourced by a number of suppliers. The key characteristic of such a project structure is 'Precedence'. Some services such as design and prototype need to be completed before other services, such as, part manufacturing, and assembly, are started. The precedence between the services is a key challenge for outsourcing.

As presented earlier in the scope of the current research, the project format of the services is going to be addressed. One of the first definitions of project management by Oiesen (1971) is:

> *'the application of a collection of tools and techniques (such*

as the CPM and matrix organisation) to direct the use of diverse resources toward the accomplishment of a unique, complex, one-time task within time, cost and quality constraints. Each task requires a particular mix of these tools and techniques structured to fit the task environment and life cycle (from conception to completion) of the task'.

The project management concept has been defined by The Project Management Institute (PMI) as 'the application of knowledge, skills, tools, and techniques to project requirements' (Murphy and Ledwith, 2006). Any kind of complex activities and systems in manufacturing processes within industries, like aviation and automotive or high technology machining, could result in more effective outcomes when decision makers apply different project management techniques (Theodosiou and Sapidis, 2003).

Efficient resource utilisation in both supplier selection and project management is one of the common goals (Kerzner, 2003). Hence, adopting a proper project management method in enterprises has a direct influence on improving performance, probability, and also survival in highly competitive markets. Project management applies in different sectors such as 'Transport and Infrastructure', 'Information Technology (IT)', 'Product Manufacturing', 'Supply Chain Management', 'Building and Construction', 'Oil and Gas', and 'Finance and Law'.

In addition, Precedence networks or critical path method (CPM) are useful graphical methods for displaying the project schedule in order to show the logical relationship among tasks. A precedence network is also known as a logic chart in which all activities are indicated as nodes while the relationship between nodes is represented by arrows. One of the advantages of this model is that when all tasks, tasks dependencies (predecessors) and tasks duration have been defined, CPM analysis would create the optimised project schedule.

Hence, it could be reviewed on the Gantt chart as a popular way of visualising the results of CPM analysis and the main tool for planning and scheduling projects.

According to British Standard in Project Management (2010), project management is defined as an approach to plan, organise, secure, and manage resources in order to achieve both short-term and long term goals and objectives of the project within defined time, budget, and resources .The main advantages of project management consist of:

- defining the main reason why a project should be done;
- identifying project needs, specifying timescales and resources;
- monitoring progress of project against a predefined plan;
- managing project costs;
- motivating the delivery team during project time; and
- providing good communication among stakeholders, contractors and consulting organisations.

2.5.1 Project Network Plan Development

Project planning is not only the simple planning tool, but also one of the main control approaches during the whole project in order to show whether the project has reached its goals, such as, cost and delivery time. A normal project network consists of factors such as budget, equipment, time estimation, start date, and finish date. As shown in Figure 2.5, each project network includes activities and events.

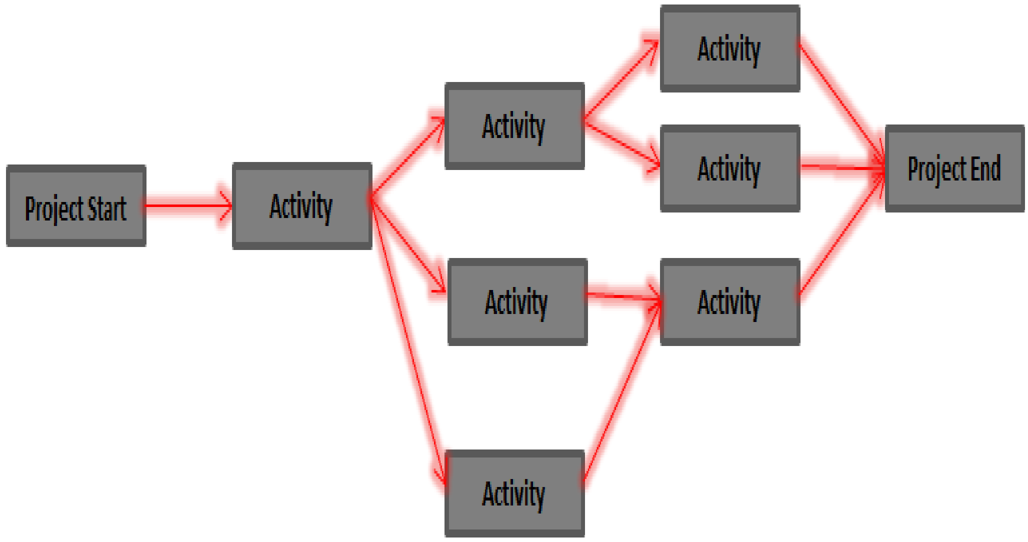

Figure 2.5: Project network plan sample

The main part of the project network is an 'activity' which has different characteristics such as those noted by Chang *et al.,* (1995):

- responsible for completing and meeting the goal of the project;
- always required time to be completed;
- includes resources like personnel, budget, and space ;
- have to be taken in order to progress from one event to the next;
- must be specific and clearly defined;
- should be assigned to a responsible manager; and
- must lead towards the final event, the planning goal.

However, sometimes more than one activity need to start simultaneously, called 'parallel activities', which provides a shorter finish time and enables managers to complete multiple stages at once. Another concept in project management is an 'event', which is defined generally as date, for instance start date, or the date by which the whole project is delivered. In order to provide a connection between depending activities, a' path' has been defined which does not have any duration and is only used to show the relationship between various activities. The shortest duration of project is the 'critical path', which is counted as one of the most significant outcomes of project network plan because if any delay happens on tasks in the critical path, the whole project will have a delay. However, if this delay happens in certain tasks, which are not in the critical path, the project might not have any delay. 'Precedence' of the network is indicated by arrows in order not only to identify a flow of the whole process, but also to indicate the sequence of each task or activities. Activity on network (AON) and activity on arrow (AOA) are mainly two network diagrams with different characteristics which are shown in Figure 2.6:

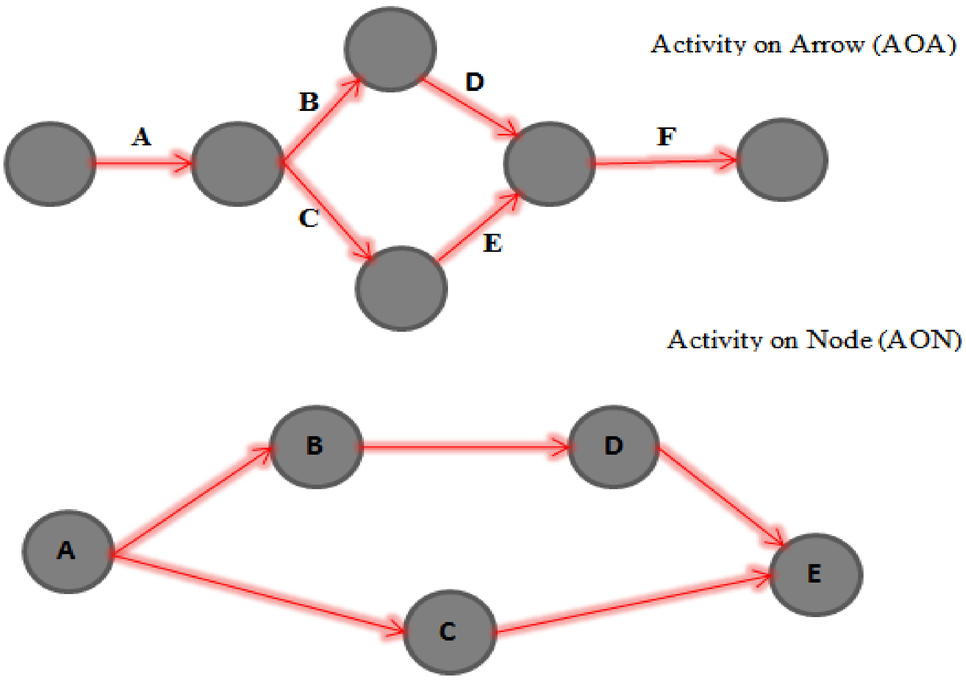

Figure 2.6: AOA and AON diagrams

AON is a flexible and powerful graphical technique in which each activity is represented as a node while the immediate predecessor activities and logical relation between to task is shown by arrows. Moreover, details such as duration and job code need to be located into the node. On the other hand, AOA method emphasises on events in which the arrow represents activities and node represents the events. Yang and Wang (2010) stated that AON is more suitable for large-scale systematic engineering and in technical restructuring engineering while AOA is better to use in construction engineering.

2.6Summary

In this chapter, a comprehensive and critical overview on the supplier evaluation and selection is presented and discussed, particularly for the whole manufacturing supply chains and product development life cycle, i.e. from the decision and procurement of the raw materials to the delivery of final goods to the customers.

Hence, approaches related to (1) suppliers selection concept and criteria, (2) suppliers selection methods, and (3) project planning were thoroughly reviewed. This chapter first presented the concept of supplier selection in manufacturing sectors followed by a critical analysis of various criteria selection over different periods of time. Different criteria have been ranked and considered during various periods. For instance , 'net price' was considered as the most important criterion between the period of 1966 and 1991, while 'quality' was noted as the most important criterion from the duration of 2001 to present. As presented earlier, among the many criteria that have been cited in the literature, criteria such as 'quality', 'delivery', 'price/cost', 'manufacturing capability', 'service', 'management', 'technology', 'research and development', 'finance', 'flexibility', 'reputation', 'relationship', 'risk', and 'safety and environment' were considered as the most applicable and common factors. However, according to the results obtained from the survey (Chapter 4), four criteria and sub-criteria will be used in this study. Different types of supplier selection methods, advantages and limitations have been discussed in detail in the second part of this chapter. Moreover, this literature review led this project to identify the most appropriate method. Individual methods such as AHP, ANP, MP, DEA, GP, LP, and IP were reviewed comprehensively followed by integrated (mixed) methods in a comparative analysis manner. The comparative study and analysis has also shaded the light for future development in the subject domain to some extent.

Lastly, the third part of this chapter includes the concept of project management and project network plan development. Mainly, different network diagrams activity on node and activity on arrow have been presented.

CHAPTER 3 DEVELOPMENT OF THE SUPPLIERS SELECTION FRAMEWORK AND ALGORITHMS

3.1 Introduction

The share of purchased components and services in the total cost of a product is increasing significantly. For instance, this share in high technology firms is estimated to account for up to 80% (Mendoza *et al.,* 2008; Weber *et al.,* 1991). Such a trend has put the suppliers selection decisions and models into a highly strategic position in industries. As a result the outsourcing market is expanding extraordinarily, leading to more efficient outcomes. In response, the modelling and solution approaches need to cope with the size of the market and increasing scale of the problem. More number of services and suppliers could be involved in the firm's decision making process.

This approach to the problem is a multifaceted one that brings different aspects of the problem into the big picture, the so-called 'framework'. The current chapter aims to look at the proposed framework from a high-level perspective with some details of the framework as the elements of the big picture. The proposed framework is characterised by three main features:

a) A *'holistic view'* to the supplier selection function in the context of cloud manufacturing, where all steps including criteria selection, bidding, optimisation and learning are covered.
b) General design: General approach and methodologies are designed. For instance, Dynamic Programming approach is selected to address multi-criteria decision-making aspect of the problem.
c) Process view: Interactions among various components of the framework and flow chart of the system are developed.

Further details of the methodologies of the research, namely 'criteria selection' and 'optimisation' are presented later in the Chapters 4 and 5. These are followed by a case study and the analysis of the data collected is presented in Chapter 6.

3.2 Contextual Considerations

What is clear about the suppliers selection problem is that it requires dealing with a number of criteria. Therefore, an appropriate multi-criteria decision-making approach needs to be adopted. This becomes challenging when criteria are conflicting. For example, as discussed in the last chapter, criteria such as 'cost' and 'quality' work in a conflicting fashion where optimising one criterion would compromise another. An appropriate solution approach needs to take care of this challenge, while addressing the priorities.

The context of cloud manufacturing (CM) also dictates some further requirements. It is a global platform; hence the size of the problem in terms of the number of suppliers could be massive. This feature requires an approach that can deal with the size of the problem.

A varied range of services from idea development to design, and others, such as, prototyping, part manufacturing, delivery, assembly, marketing, and sales, are outsourced by a number of suppliers. The key characteristic of such a project structure is 'Precedence'. Some services such as design and prototype need to be completed before other services, such as, part manufacturing, and assembly, are started. The precedence between the services is a key challenge for outsourcing. The problem addressed in this research takes a broad perspective; that is the services form a part of a project and the whole project needs to be outsourced. Therefore, a project-orientated approach is on demand, taking into account a number of services that might be outsourced in a parallel as well as sequential way. This contextual feature of the problem would have impacts on the framework and algorithms, making the development more challenging. For example, time calculations need to adopt project network scheduling, which involves time precedence. The integration of project network scheduling and the main supplier selection optimisation modelling constitutes one of the major contributions of this research.

3.3 Suppliers Selection Framework Based on Cloud Manufacturing

CM platform includes a number of services, such as Hardware-as-a-Service (HaaS), Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). In addition, there are some functions that provide service management for the users of the platform. Suppliers selection is one of the main service management functions of the CM platform. It is in direct link with the cloud clients and the service providers or so-called 'suppliers' (Figure 3.1).

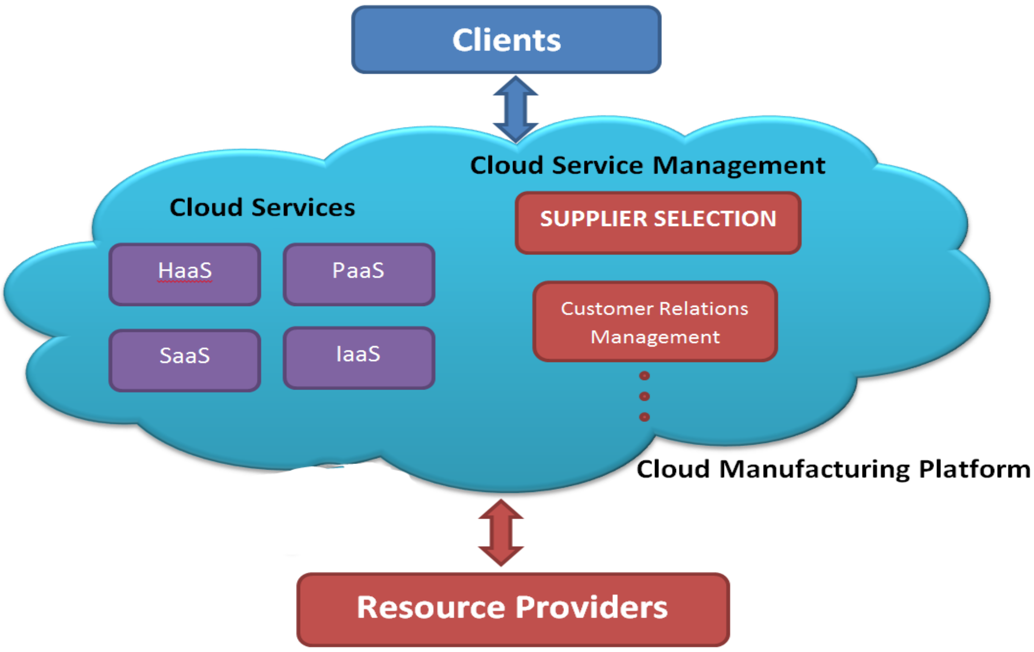

Figure 3.1: Cloud manufacturing services

The proposed framework aims to address the problem as presented earlier in Chapter 1. The main focus of this research is on 'Supplier Selection' function in the context of CM. The framework takes into account the contextual characteristics of the problem, as presented in the previous section.

The approach to the problem is a multifaceted one that brings different aspects of the problem into the picture. As a result, this framework consists of four modules, namely a) multi-criteria module, b) bidding module, c) optimisation module, and d) learning module (see Figure 2). This approach and the proposed framework constitute contributions to this research. Each module looks at a major aspect of the problem and presents algorithms to address that aspect. The next sections are going to describe the main functions and some details of these three modules. More details on the other main contributions of this research, namely 'Criteria Selection' and 'Optimisation' are presented later in Chapters 4 and 5.

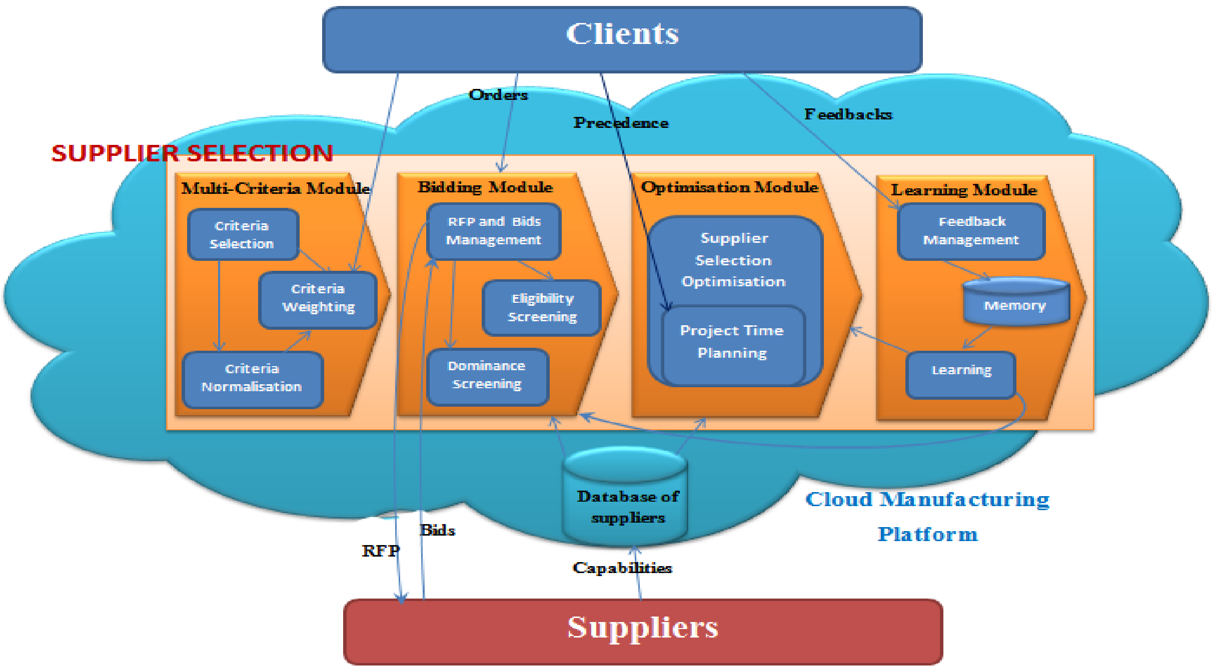

Figure 3.2: Proposed suppliers selection optimisation framework in the context of CM

3.3.1 Multi-Criteria Module

Suppliers selection is essentially a multi-criteria problem, involving a number of selection criteria that are mostly in conflict with each other, such as quality and price. A single decision on suppliers selection requires an algorithm that combines multi-criteria measures in a scientifically sound way. An approach that could handle such complexities is explained in this section.

3.3.1.1 Criteria Selection

The first step in solving such a problem is to identify a limited number of relevant criteria. As presented later in Chapter 4, the starting position is with 28 criteria cited in literature. An expert opinion survey followed by statistical analysis led to choosing four criteria that it is argued would be the most significant and relevant to the problem addressed in this research. The case study also contributes to this selection process as a final validation step, splitting one criteria 'delivery/time' into two 'delivery method' and 'time of delivery'. Therefore five criteria are finally proposed in this research, namely;

1. Cost/Price
2. Quality
3. Delivery method
4. Time of delivery
5. Reputation/Trust

3.3.1.2 Criteria Normalisation

When dealing with a multi-criteria decision making situation, it is essential to normalise different metric values if they are not in the same scale. All the criteria except for 'time' require normalisation in order to enable a conversion to single-criteria Linear Programming model. Time calculations involve a more complicated method and are dealt with in a different way, as explained later in the same section.

Two popular normalisation methods - assuming a maximisation objective is involved - as cited in Podviezko (2014) are;

1) Normalisation by comparison with the best value;

Equation 3.1: $\widetilde{r_{ij}} = \frac{r_{ij}}{max_j\, r_{ij}}$

2) Normalisation, which assigns zero to the worst value of a criterion, and 1 (or 100%) to the best value;

Equation 3.2: $\widetilde{r_{ij}} = \frac{r_{ij} - min_j\, r_{ij}}{max_j\, r_{ij} - min_j\, r_{ij}}$

The selection of a plausible normalisation method is highly dependent on the nature of the data. One important negative point about the second method is that it could magnify the small deviations between values disproportionally. For example, values 950, 960, 970, which are most probably perceived quite equally by a client, would be transformed to the large deviated values {0; 0.5; 1} as a result of normalisation (Podviezko, 2014).

It is understood that in the context of CM, where global competition is present and bids could be very close, such a shortcoming could result in a significant distortion of data. Therefore, the first method of normalisation is selected.

The first normalisation algorithm takes value 1 as being the target score. Therefore, normalisation algorithm requires a target value for each metric. The best value amongst the suppliers with regard to each criterion is used as the target value for normalisation calculations.

As for 'time', there is only one target value, which is the whole project's planned duration, rather than individual target times for each service.

Therefore, the whole project's completion time needs to be taken into account against the planned duration. This means that the normalisation of single services' time of delivery amongst different providers is not preferred in this context.

There exist two types of criteria, namely those that need to be minimised and those to be maximised. Below two formulae are presented for these two types of criteria, based on the first normalisation method as selected above:

1) Minimisation: Can be applied to the metric 'Total Cost'.

$$Normalised\ Score\ (i,j,k) = \frac{Min.\, criteria\ value\ amongst\ all\ the\ suppliers}{criteria\ value\ k\ of\ supplier\ i\ for\ service\ j}$$

2) Maximisation: Can be applied to the metrics 'Quality Pass Rate', 'Quality System Score', 'Delivery Method Score', 'Total value of orders received in CM' and 'No. of years of experience in the industry' .

$$Normalised\ Score\ (i,j,k) = \frac{criteria\ value\ k\ of\ supplier\ i\ for\ service\ j}{Max.\ criteria\ value\ amongst\ all\ the\ suppliers}$$

These two formulae ensure that - regardless of whether it is a minimisation or maximisation metric - all the metric values will be converted into a range [0,1] where '0' represents the poorest and '1' represents the best value.

3.3.1.3 Criteria Weighting

Criteria weighting is another mechanism that works in a multi-criteria decision making model in order to allow a numerical combination of multiple criteria. Numerical weights are assigned to define, for each criterion, the relative importance they have in the decision making process.

Simple Additive Weighting (SAW) is the oldest, most widely known and practically used method (Podvezko and Podviezko, 2010). The basic concept is to integrate the criteria values and their relative importance in a linear way in order to arrive at a single measure that will ultimately guide decision making, according to the following mathematical formulation.

Equation 3.3: $S_i = \sum_k w_k \times r_{ik}$

Where S_i denotes the weighted score of supplier i, and $w_k$denotes the weight figure in the range {0-1} assigned to the criteria k with value 1 being the best, and r_{ik} denotes the criteria k value of supplier i.

There are, however, two drawbacks associated with this method. First, SAW may be used if all the criteria are maximising only. A solution for this drawback is to adopt conversion formulae by which minimising criteria will be transformed to maximising ones. Another solution is a combined use of SAW and goal Programming (GP), where the objective is to minimise deviations from targets (either highest or lowest) rather than only to maximise a set of criteria values.

Another limitation of SAW is the requirement that all criteria values should be positive. Even though a similar conversion formula can resolve this, it will not be an issue where all criteria values are non-negative, which is the case in the problem addresses in this research. Therefore, SAW - in combination with GP model – is adopted in the current research as the preferred, streamlined weighting method.

3.3.2 Bidding Module

The global market for manufacturing products has become increasingly dynamic and customer-driven. This has led to rising rates of new product introduction and made-to-order productions. As a result, to face challenges, manufacturing enterprises need to be agile and responsive to cope with market changes (Lim and Zhang, 2012).

In line with the current atmosphere, a CM platform is not going to be used only for trading a limited number of standard services. At least the ultimate goal is to have a platform where made-to-order jobs match capabilities of service providers throughout the world.

The scope of this research does not put any restrictions on the type of manufacturing or support services. With this goal in mind, service variations exist and customisations might be the norm. This requires a 'Reverse Auction' model, where buyers submit the service specifications to the sellers, who compete to obtain business from the buyers. In the context of this research, the 'Online Reverse Auction' model is applicable where service specifications are submitted to the cloud before any service providers are identified. The cloud and the suppliers selection system in the cloud provide a platform through which the client and the suppliers are connected together and their information is shared.

3.3.2.1 Request for Proposal (RFP) and Bids Management

The suppliers selection process in the context of CM should start off with RFPs drawn by the clients, consisting of the service requirements, such as, technical characteristics and qualities, order quantities, time restrictions, and cost thresholds. The CM platform should support such a RFP generation process whereby clients would be able to capture all their requirements and pass them to the suppliers community in an efficient and effective fashion.

The RFPs will be reviewed by potential suppliers, who might respond to the RFPs via a bidding management mechanism. Such mechanism might take various forms. For example, there is a decision on transparency of the bids to all other bidders. The other format could be with regard to one-stage or multi-stage type of the bidding mechanism, which regulates the number of times bidding can be repeated or adjusted. All these technicalities are handled by 'RFP and Bids Management' element of the 'bidding module'. This research does not present particular recommendations on these technicalities.

The proposed framework suggests two screening mechanisms prior to an optimisation stage. These are explained in the next two sections.

3.3.2.2 Eligibility Screening

Some researchers (for example, Karpak *et al.*, 1999) suggest a manual process by clients to screen out those suppliers who are not eligible in terms of some of the basic requirements. Some others (for example, Feng *et al.*, 2001) present a model-based feasibility screening.

In the current research, a set of eligibility constraints is proposed to be tested against all the suppliers' proposals. Those proposals that do not meet any of these constraints will be filtered out prior to optimisation stage. It should, however, be noted that the optimisation model is also capable of accommodating the eligibility constraints. The benefit of prior screening, however, is that it would decrease the number of eligible proposals, hence reducing the size of the optimisation problem. The eligibility constraints can be defined against the following thresholds:

a) minimum acceptable level of quality;
b) minimum acceptable level of reputation;
c) maximum acceptable level of cost/price;
d) maximum acceptable level of delivery time; and
e) minimum acceptable level of delivery method score.

It should be noted that the Eligibility Screening mechanism uses information both from the current proposals and the historical performances of the suppliers, but not from normalisation process. (Further details on the historical performance part are presented later in Section 3.3.4). An Excel-based tool to conduct eligibility screening has been adopted.

3.3.2.3 Dominance Screening

'Dominance Screening' step is performed to filter out those suppliers who cannot match any of the other proposals from all the criteria's perspectives. For example, a proposal with 90% quality pass rate and price of £20k would be outbid by another proposal with 92% pass rate at the cost of £18k. Dominance screening would be able to reduce the size of the problem, before it is fed into the optimisation module. This could, in turn, lead to a more efficient solution approach especially where the size of the problem is an issue.

It is important to note that the dominance screening mechanism that has been developed uses information both from the current proposals and the historical performances of the suppliers. (Further details on the historical performance part are presented later in Section 3.3.4). Therefore, it is feasible that an inferior proposal could escape dominance screening and step up in the list due to the supplier's previous excellent performance. On the other hand, some mediocre proposals might get caught by the dominance screening, as a result of a very poor performance shown in the past.

3.3.3 Optimisation Module

The selection of best suppliers in the context of CM under the broad scope of this research, where a number of inter-connected services are involved, is a very complex problem, because:

a) the problem is of a multi-criteria nature, where the criteria are of different scale and mostly in conflict with each other;

b) CM assumes a global sourcing; hence the number of competing suppliers for each service could be huge;
c) the problem addressed in this research has a broad scope in a sense that it targets projects including a number of services, rather than a single service; hence the size of the problem could be very large; and
d) time calculations in such a project-oriented structure do not have a straightforward linear feature.

A rigorous solution approach to such a selection problem is required to tackle all these complexities. The integration of 'project time calculation' with the other parts of the methodology is crucial.

3.3.3.1 Integrated Suppliers Selection and Project Time Planning

Having performed an investigation of the literature on suppliers selection field, no studies were found that address the full-scale precedence relationships, both sequential and parallel relations in the form of a network, among services in a project-orientated context (Table 3.1). Quite a few of the articles (Mendoza *et al.*, 2008; Demirtas and Ustun, 2008; Wang and Yang, 2007; Venkatesan and Kumanan, 2012) model a single service/product, and that is the most straightforward approach in terms of the service inter-connections. Among those that model multi-service/product, only one (Wang *et al.*, 2010) addresses sequential relation among the services, and another one (Cebi and Bayraktar, 2003) addresses parallel relations among the services. None take both relations into account in the form of a project network structure, which is quite complicated when it comes to time calculations and its integration into the whole selection model. The rest either take the services as independent (Feng *et al.*, 2001; Wadhwa and Ravindran, 2006) or do not undertake delivery time calculations (Sawik, 2010).

From a time modelling perspective, some choose not to take delivery time as a selection criterion (Cebi and Bayraktar, 2003; Demirtas and Ustun, 2008) and use other criteria such as cost and quality. It is also noted that some others (Sawik, 2010; Venkatesan & Kumanan, 2012) use quasi-criteria such as 'on-time delivery rate' or 'delivery reliability index' instead of delivery time itself, which avoids complex time modelling.

Table 3.1: Comparison of articles on 'Suppliers Selection' from 'delivery time modelling' perspective

Article	Number of Services/Products	Time modelling?	Sequential Relations?	Parallel Relations?
Mendoza *et al.*, 2008	Single	√		
Wang *et al.*, 2010	Multi	√	√	
Feng *et al.*, 2001	Multi (independent)	√		
Cebi and Bayraktar, 2003	Multi			√
Demirtas and Ustun, 2008	Single			
Wang and Yang, 2007	Single	√		
Sawik, 2010	Multi	On-time delivery rate only		
Venkatesan & Kumanan, 2012	Single	Delivery reliability index only		
Wadhwa and Ravindran, 2007	Multi (independent)	√		

This current research presents an integrated methodology to solve such a complex problem. Optimisation methods in general and Mathematical Programming (MP) in particular form the major approach adopted in this research. It is argued that superior scientific robustness makes this approach an extremely attractive one. Considerable computational advancements have made these models even more appealing nowadays, especially in dealing with large-sized problems, as is the case with the one addressed in this research.

The most common form of MP models, called *'Linear Programming (LP)'* assumes that all parts of the model, including objective function and constraints, are in a linear format and decision variables can take real numbers. Under such assumptions, the optimisation model can be solved using a straightforward mathematical transformation algorithm called 'Simplex'. All parts of the model developed in this research follow linearity structure in essence, or are transformed to a valid linear structure. For example, in the case of project time planning part of our model, an innovative transformation is developed, in order to take advantage of LP models (see further details in Chapter 5).

Goal Programming (GP), one class of (MP) models, is a very popular optimisation model to solve multi-criteria problems. The Weighted or Non Pre-emptive GP method is used for optimising the multi-criteria aspect of the suppliers selection problem. The original problem is transformed into a minimisation one that aims to minimise total deviations from the target values of all criteria metrics. Normalisation and weighting algorithms, as explained earlier in Section 3.3.1, work to combine various criteria metrics into a single score associated with each supplier's proposal.

'Integer Programming (IP)' is a type of MP models in which some or all of the decision variables are restricted to be integers. IP does not meet one of the assumptions of LP models about decision variables and, hence, cannot be solved using Simplex transformation. IP models are amongst the very complex models called NP-Hard. A popular method to solve IP models is 'Branch and Bound' in which a systematic and efficient enumeration of candidate solutions is carried out to search for the optimum solution. *'0-1 Integer Programming'*, which is a special case of IP models, restricts some of the decision variables to be zero or one only. To address the selection nature of the problem in this research, the 0-1 integer programming model is used.

A *'Mixed Integer Linear Programming (MILP)'* is the term for a class of LP models in which some of the decision variables are restricted to take integer values only. In one way, MILP can be classified as a sub-group of both LP and IP models. Similar to the IP, MILP models are NP-Hard. A popular solution method for MILP is LP-based Branch and Bound, which is basically a combination of 'Simplex' and 'Branch and Bound' methods. A MILP model is ultimately used to take care of both linear aspects and integral characteristics of the suppliers selection problem. The integer part of the model pertains only to the suppliers selection decision variables that take a 0-1 format.

The details of the proposed mathematical programming model and its solution methods are described in Chapter 5.

3.3.4 Learning Module

The CM platform is a web-based system, through which the supplier selection service is provided in a continuous fashion for buyers. This feature allows the approach to take advantage of memory function and learning algorithms. An investigation of related evidence in the literature found only one article by Valluri and Croson (2005) that adopts a reward-punishment mechanism. The current research aims to adopt a similar basic concept in the context of CM, but with a punishment mechanism only. The reward mechanism within a multi-criteria model could distort the data beyond the normalised scale.

The purpose of this section is to describe algorithms used in this research in order to learn from the suppliers' past performance. The outputs of the learning algorithms are sent back to and are involved in the optimisation calculations.

3.3.4.1 Feedback Management

As presented earlier in Section 3.3.1, suppliers submit their proposals in response to the client's RFP. The information includes the suppliers' proposal on price, quality, delivery time, and delivery method. The post-contract assessment of the supplier's performance may not, however, match its initial claim in the proposal. This becomes important due to the fact that some of the initial claims are more of an estimate.

The assumption in this research is that the suppliers are more committed to the price quote, while it is accepted some deviations from initial claims especially on the quality and delivery time might occur. Having gone through case study validation and consultations with the procurement experts in the manufacturing industry, it was confirmed that suppliers may go beyond initial delivery date commitments in order to compensate for the quality defects.

Therefore, a feedback management system is designed in the platform to collect the client's post-contract views on two key criteria, which are 'quality' and 'delivery time'. This feedback is collected against each commissioned supplier through the following two performance measures;

a) *Quality Compliance Level (qc):* is calculated using this equation;

Equation 3.4: $$qc = \frac{real\ quality\ level\ delivered}{quality\ level\ claimed\ in\ the\ proposal}$$

b) Time Over-run Percentage (to): is defined as a positive real value, where 0 refers to no time over-runs. It is calculated using the following equation;

Equation 3.5: $$to = \frac{time\ overrun}{delivery\ time\ claimed\ in\ the\ proposal}$$

3.3.4.2 Memory Function

A learning mechanism that works based on the past experience requires a memory function that keeps record of the past performances. The feedbacks received from the clients are averaged on an on-going basis for each supplier. Furthermore, a fixed time window is defined, to which the averaging function is applied. A *'moving average'* mechanism is designed where the time window can be determined as the most recent T years, T being worked out in a separate study. Evidence suggests that shorter punishments improve learning speed of convergence to the best collective results. Inevitably, there is a trade-off between the number of candidate suppliers and the length of reward-punishment (Valluri and Croson, 2005). It is proposed, therefore, that with regard to T, in the first few years of the system establishment there might be fewer candidate suppliers involved. Hence, a longer learning period might be more appropriate. Once the system is stabilised and because the CM platform allows a crowd-sourcing capability with an increasing number of suppliers involved, this period could be shortened to speed-up the learning process. Such arrangement will ensure that the recent performances are taken into account rather than those in a longer period. It is argued that the reputation criterion in this study already accounts for the supplier's longer experience. The following equations are used to calculate the average performance measures, which are then stored in a *'dynamic memory'* element as linked to the suppliers' database.

Equation 3.6: $AQC_i = \frac{\sum_{t=1}^{T} \sum_j qc_{ijt}}{n}$

Equation 3.7: $ATO_i = \frac{\sum_{t=1}^{T} \sum_j to_{ijt}}{m}$

qc_{ijt} and to_{ijt} refer to *quality compliance level* ($\mathrm{qc_{ijt}} \in [0\,,1]$) *and time over-run percentage performance* ($\mathrm{to_{ijt}} \in [0\,,1]$) of supplier i with regard to service j at time t, respectively, AQC_i and ATO_i denote '*average quality compliance'* level and *'average time over-run'* percentage associated with supplier i over the last T period respectively, and n and m refer to the number of feedbacks received for supplier i on its quality compliance level and delivery time performance over the last T period, respectively. For instance, if the supplier 1 has manufactured three types of electromotors for three clients over the past year and its quality compliance levels of this supplier for manufacturing these electromotors have been 0.9, 1.1, and 0.8, then AQC associated with supplier 1 in the past year can be calculated as $\frac{0.9+1.1+0.8}{3} = 0.933$.

Before the very first feedback is received for a supplier, default values of 1.0 and 0.0 are used for AQC_i and ATO_i, respectively. This default initialisation works as a primary motivation for suppliers to take part in the CM club.

3.3.4.3 Learning Algorithm

Every time a new proposal is received from a supplier, information about its past performance is retrieved from the memory and the proposal is affected accordingly. The effect is in the form of mathematical transformations, as presented below, which revise the original metric values.

Equation 3.8: $Q'_{ij} = \tilde{Q}_{ij} \times AQC_i$

Equation 3.9: $t'_{ij} = t_{ij} \times (1 + ATO_i)$

$\tilde{Q}_{ij}$ and Q'_{ij} refer to *original* quality metric value and *revised* quality metric normalised value associated with the proposal of supplier i for service j, respectively, and t_{ij} and t'_{ij} denote *original* delivery time and *revised* delivery time associated with the proposal of supplier i for service j, respectively. The results of these two transformation equations will be used in screening algorithms as well as optimisation models, as presented earlier in sections 3.3.2 and 3.3.3.

3.4 Process Flowchart

The whole process of supplier selection in the form of a flowchart is shown in Figure 3.3. The process is instigated, within the CM platform, by a user client through generating an RFP that includes all the information necessary for a valid bidding. This function is carried out using the 'RFP and bid management' component of the platform.

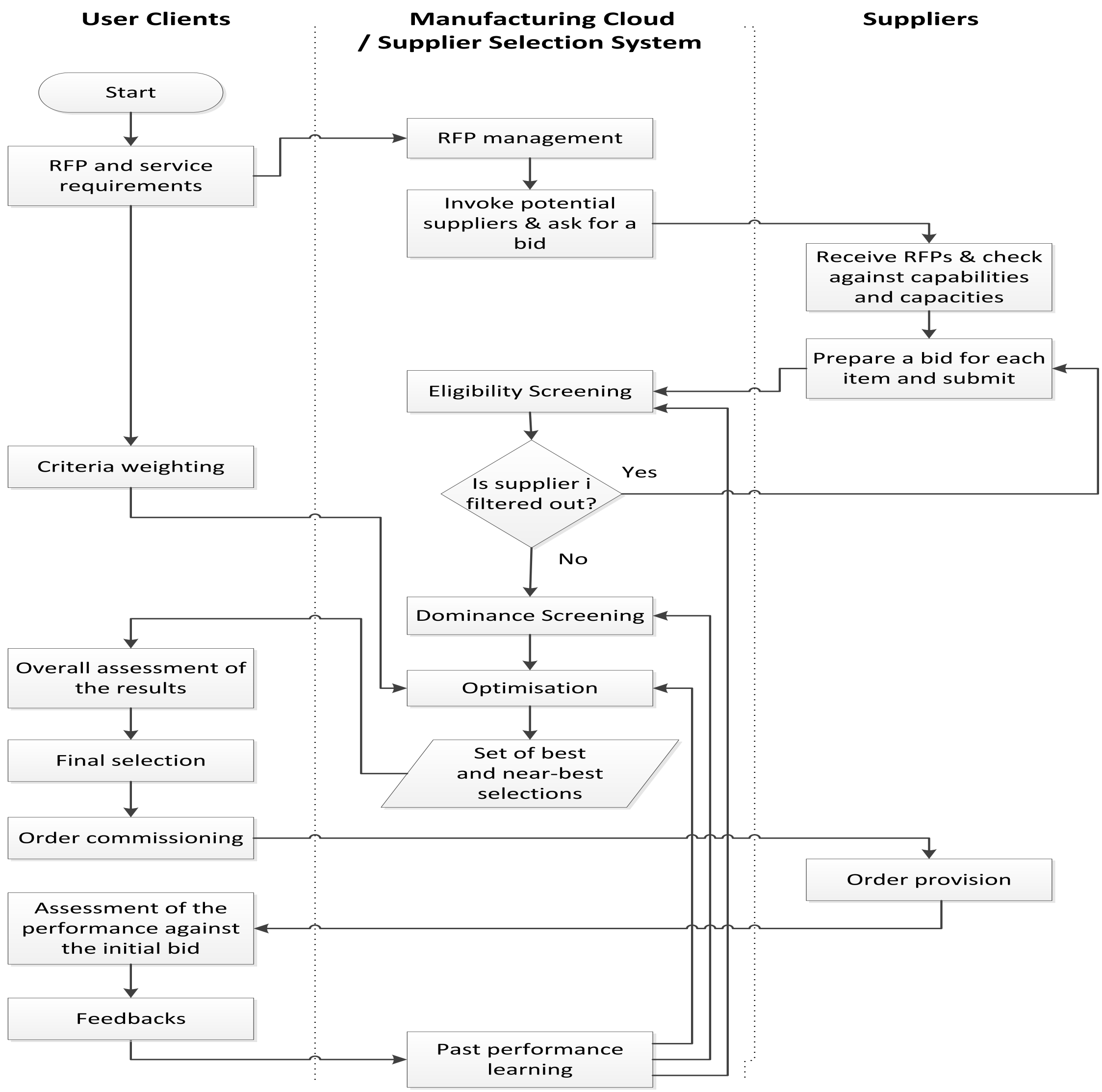

Figure 3.3: Proposed suppliers selection process flow chart

Potential suppliers who are already members of the club are invoked by the platform and asked for a bid. Those suppliers who find themselves fit submit their bids through the platform.

The bids are checked for eligibility against the minimum requirements (eligibility screening) and for dominancy against each other (dominance screening). Those that fail these checks will be filtered out and the rest will pass to optimisation, where an integrated mathematical model is solved and problem solution(s) is (are) found. However, before that is completed, the user client needs to determine criteria weightings.

The user client can choose to carry out a final evaluation of the solution(s) and make the final selection before the job is commissioned to the selected supplier(s). Upon the provision of service(s) by supplier(s), the user client makes an assessment of the supplier's performance. Feedbacks are sent back to the platform and averaged over a fixed period of time to inform the screening and optimisation algorithms about the supplier(s) past performances.

3.5 Summary

This chapter aimed to look at the proposed framework from a high-level perspective. The multiple, conflicting criteria nature of the suppliers selection is one of the solution challenges. To add to this, the global size of the CM environment as well as the complexity of a project-oriented view to the problem is involved.

An integrated approach to solve both project scheduling and supplier selection functions simultaneously within a single mathematical programming platform constitutes the main novelty of the proposed framework. The other novelty associated with the framework is in its holistic view to the problem addressed containing four modules, which has not been previously presented in the literature.

The proposed framework consists of four modules, namely a) multi-criteria module, b) bidding module, c) optimisation module, and d) learning module. This approach and the proposed framework constitute parts of the original contribution to knowledge that this research makes.

As a part of the multi-criteria module, five criteria and seven metrics are identified, a normalisation method based on comparison with the best value is adopted to convert the metric values into a unified scale, and the SAW method is adopted to combine various metrics together.

In the bidding module, 'Online Reverse Auction' model is adopted in line with the ultimate goal of CM towards a global made-to-order crowdsourcing platform. RFPs and proposals are managed by the platform. Furthermore, two primary processes, namely eligibility screening and dominance screening, are developed to filter out those proposals that can be shown from the start not to be able to meet eligibility requirements or to compete with others.

The optimisation module, which works as the heart of the whole framework, faces big challenges, such as complex time calculations in a full-scale project network structure. The novel approach presented is to develop an integrated mathematical model for supplier selection optimisation and project time planning. The general format of the optimisation model follows GP structure to deal with multi-criteria nature of the problem. More specifically, a Mixed Integer (0-1) Linear Programming model is developed to address the other characteristics of the problem.

Lastly, a learning module allows the model to learn about the suppliers' past performance over the course of the system's life. A feedback management system is designed in the platform to collect the client's views on two key criteria, namely ‘quality’ and ‘delivery time’. Average performance measures are then calculated over a moving fixed period, results of which are stored in a *‘dynamic memory’* element as linked to the suppliers’ database. At last, the averages past performance measures are retrieved from the memory and are applied to the optimisation and screening algorithms through two proposed mathematical transformation formulations.

More details on ‘criteria selection’ and ‘optimisation’ modules are presented later in Chapters 4 and 5, respectively.

CHAPTER 4 FORMULATION OF THE SUPPLIERS SELECTION CRITERIA – EXPERT OPINIONS SURVEY

4.1 Background and Theoretical Framework

Suppliers selection decisions are complicated by the fact that a number of conflicting criteria are involved in the decision making process. The suppliers selection function is affected by the contextual characteristics of cloud manufacturing (CM) in such dimensions as market size and dynamic process. On the other hand, research evidence on the suppliers selection criteria within the context of CM is rare. Therefore, an attempt was made to identify related articles in a wider literature.

As presented earlier in Chapter 2, 29 criteria on suppliers selection have been cited throughout the literature (Table 4.1). The frequency of their use in the literature is, however, varied. The current research requires a small number of criteria that will be used in the optimisation module. The number of criteria has a direct and significant effect on both the optimisation complexity and the research implementation. The number of criteria is directly linked to the number of decision variables and optimisation model constraints, both of which are key factors that determine the problem size and its solution complexity. Furthermore, each criterion involves data collection and a judgemental process to rank it against other criteria.

Table 4.1: Criteria for suppliers selection cited in the literature

Net Price/Cost	Reputation	Impression	Amount of Past Business
Delivery	Financial Position	Communication System	Warranties
Quality	Performance History	Reciprocal Arrangements	Research and Development
Production Facilities/ Manufacturing Capability	Attitude	Labour Relations Records	Flexibility
Geographical Location	Repair Service	Training Aids	Relationship
Technical Capability/ Technology	Operational Controls	Procedural Compliance	Risk
Management and Organisation	Packaging Ability	Desire for Business	Safety and Environment

A range of 'four to five' criteria could arguably be the best number that would represent the main characteristics of suppliers selection function in the context of CM. Furthermore, this range of criteria would allow both the complexity and implementation challenges of the research to be managed.

What can be implied from the review of literature in Chapter 2 is that there are three criteria - namely 1) Cost/Price, 2) Quality, and 3) Delivery - that are virtually dominant in the top of almost all the lists. Looking further into the rest of the lists, it was noted that some of them such as 'Reputation', 'Attitude', and 'Impression' are inter-related and could all come under one group, called 'Reputation/Trust'. Even some others such as 'Production Facilities', 'Technical Capability', 'Management and Organisation', and 'Financial Position' could be measured by 'Reputation/Trust', when suppliers come forward to the bidding stage. In fact, many of the claims made by the suppliers can be better evaluated by their level of reputation or trustworthiness. For example, it is assumed that when a supplier submits a proposal, it has made a claim that it is capable in term of production facilities, technical capability, and financial position. Thus, further judgements about their capabilities can be done by using a measure of their 'Reputation/Trust'. Interestingly, the measurement of Reputation/Trust could be facilitated through online, global platforms such as a CM platform.

Therefore, four criteria are identified as initial candidates for further investigation, namely;

1) cost/price;
2) quality;
3) delivery; and
4) reputation/trust.

Below, more details and descriptions on these four criteria are presented.

4.1.1 Cost/Price

Cost/price is an obvious consideration for any purchase. Many authors noted cost/price as one of the significant factors in suppliers evaluation and selection criteria.

According to Talluri (2002), activities related to cost/price are presented as:

- total cost : evaluating a supplier's cost structure involves providing detailed cost data by the supplier;
- quantity discount: suitability of discount scheme implemented on payment of invoices within a time frame;
- payment terms: suitability of terms and conditions regarding payment of invoices, open accounts, sight drafts, credit letter and payment schedule; and
- payment procedures: understanding the competitive prices which suppliers could be offer to final users.

Stanley and Gregory (2001) reported the purchase price as the most common cost related element. Moreover, they believe operational cost such as transaction processing and cost of rejects should be considered during the choosing of the right suppliers. Ho *et al.*, (2010) present some related attributes of cost/price including 'appropriateness of the materials price to the market price', 'competitiveness of cost', 'cost reduction capability', 'cost reduction effort', 'cost reduction performance', 'direct cost', 'fluctuation on costs', 'indirect-coordination cost', 'logistics cost', 'manufacturing cost', 'unit cost', 'ordering cost', 'parts price', 'product price', and 'total cost of shipments'.

4.1.2 Quality

Nowadays, quality is considered in both products and services in all aspects of the supplier-manufacturer collaboration (Keskar, 1999). IBM (Weele, 2010) defines quality as:

'the degree in which customer requirements are met.
We speak of a quality product or quality service when
Both supplier and customer agree on requirements and
These requirements are met.'

Effective performance by a supplier realises the success of the buying organisation, which means both suppliers and customers should have some common point of view about the concept of quality. According to APICS (1999), quality is divided into quality of conformance and quality of design. The former one is defined by the lack of defects, while the latter one is defined with client satisfaction.

Ellram and Seiferd (1993) specified the following activities as being related to quality:

- select and approve suppliers;

- assess supplier performance;
- understand suppliers processes;
- maintain supplier relations;
- acquire parts for rework;
- return rejected part;
- inspect incoming materials; and
- dispose of scrap

Most of the quantitative methods use metric 'defect rate' or 'quality pass rate' as the common way of measuring quality of products (Sanayei *et al.*, 2008; Wang and Gu, 2007; and Kokangul and Susuz, 2009), while some of them believe that defect rate cannot represent the quality adequately and quality is of a systematic and process-orientated capability rather than a final product characteristic. The challenge, however, is how to quantify these qualitative aspects of 'Quality'.

4.1.3 Delivery/Time

Along with quality and cost, another factor that is considered a key criterion for suppliers evaluation and selection is 'Delivery/Time'. Customer satisfaction is the main advantage of providing a proper delivery service to customer.

Johansson and Stensson (2007) noted some factors in performance delivery:

- order lead-time showing the time period necessary for an order to be placed to guarantee a given delivery date;
- delivery reliability showing the reliability of the exact delivery time;
- delivery certainty indicates the delivery of the right product;
- customer adaptation shows the ability to provide to customer demand;
- information showing the right information exchange between customer and retailer; and

- flexibility shows agility when conditions change.

Ho *et al.*, (2010) specified a number of attributes that can be classified under three groups; a) delivery date, b) delivery methods (including insurance and tracking facilities), and c) delivery compliance. While 'delivery date' and to some extent 'delivery compliance' can be quantified, using delivery methods in a quantitative model creates some challenges.

4.1.4 Reputation/Trust

An enterprise reputation usually aids its sales. For instance, a poor reputation leads to a lack of willingness on the part of the customer to buy a product or service from the supplier. Making a reputation model is an essential way to measure trust in today's highly competitive markets. Reputation indicates the customer's point of view about a supplier and its capabilities. Especially in industrial market, these opinions are formed and changed by information which is made available by other customers about past experience (Josang *et al.*, 2007).

Roehrich *et al.*, (2014) argued that the value of enterprise reputation has a direct relation with the organisation's financial performance, favourable stakeholder behaviour, and customer trust and purchase intentions.

To assess a firm's corporate reputation, Lin *et al.,* (2003) proposed an appropriate trust model helping an enterprise to evaluate partner trustworthiness and allowing the decision makers to enable a complete rank ordering of the supplier on supplier reputation. The authors define ability, benevolence and integrity functions as trust factors.

The Internet has a major role to play in helping enterprises to improve their reputation and trust, since it is easy to receive evaluation on specific suppliers from other clients. Therefore, it is proposed that CM allows a better consideration of reputation/trust criterion in the suppliers selection function.

4.2 Criteria Metrics

The next step in the investigation of the criteria for suppliers selection is to identify adequate metrics to measure each criterion. This is essential due to the fact that this research is adopting a quantitative approach to the problem. This quantification becomes challenging with those criteria that are of a qualitative nature, such as quality and reputation. One very important principle on metrics is about the ease of access to the metric's information. This principle might even result in choosing a proxy measure.

Based on the literature and the fact that this research will develop an improved approach to suppliers selection, it will identify two or three candidate metrics for each criterion - except for cost/price criteria that is a straightforward decision to go for 'total cost including delivery costs' as the best metric. Then expert consultations are sought for the selection of the best one(s). With respect to the other three groups of criteria, a list of candidate metrics was worked out from the literature (Table 4.2). This list establishes a proposed hypothesis, which is subject to expert opinions.

Table 4.2: Preliminary list of candidate metrics and their descriptions

Criteria Group		Metric	Description
Quality		Defect rate or Pass rate	Percentage of defect or passed services against an agreed service quality level
		Quality system score	A relative score representing the quality systems established in the company, e.g. standard quality certificates awarded
Delivery/Time		Lead time	Time duration to provide and deliver a service
		Delivery method score	A relative score representing 'delivery insurance' and 'tracking facilities'
Supplier Trust/Reputation	Suppliers experience in the Cloud Manufacturing	No of orders received in Cloud Manufacturing	Total number of orders received by the company in the Cloud Manufacturing platform so far
		Total value of orders received in Cloud Manufacturing	Total monetary value of orders received by the company in the Cloud Manufacturing platform so far
		No. of years of experience in cloud manufacturing	Number of years since the company joined the Cloud Manufacturing platform
	Suppliers profile in the industry	No. of years of experience in the industry	Number of years since the company started business in the industry
		Years from first establishment	Number of years since the company established
		Annual turnover	The company's last year turnover

Preliminary research based on the evidence in the literature showed that 'defect rate or pass rate' and 'lead time' are clearly one key metric for 'Quality' and 'Delivery' criteria respectively. Apart from those, another metric – such as ‘quality system score’ and ‘delivery method score’ – was found for each of these two criteria. Therefore, a streamlined question for each of these two criteria would be whether to pick the first key metric only, or to make a combination with the second metric.

The literature as well as a subjective initial assessment on ‘Reputation/Trust’ highlights a number of its contributing factors that can be grouped into two subsets, namely:

a) suppliers profile in the industry: Represents the company’s profile and history in the related industry such as machining, marketing, and product design. Three most streamlined metrics to measure this sub-criterion are suggested in Table 4.2 and can be treated as interchangeable. Therefore, only one metric out of these three candidates can ultimately be selected. While ‘years from establishment’ refers to the company’s total experience from establishment, ‘no. of years of experience in the industry’ refers only to its experience in the related industry. The information for all three suggested metrics can be easily collected from the public domain or the CM platform itself.
b) suppliers experience in the CM: A CM club, like any other club, establishes rules, regulations and mechanisms that are required to be conformed to by all members. This factor represents the company’s experience in the CM club as a measure of its familiarity to the rules/regulations and its endeavor to build up its reputation in the club over the years. The information for all three metrics suggested for this sub-criterion can be easily captured from the CM platform.

The literature lacks an expert-opinion based investigation of the suppliers selection criteria in general and its applicability in CM in particular. Therefore, this study aims to conduct an expert opinion survey to inform the research. In the next sections, the details of the expert opinion survey are described.

4.3 Objective of the Survey

The objective of the survey is to elicit domain experts' opinions, which works as a means to test hypotheses about the suppliers selection criteria on two aspects:

a) the importance of three major candidate criteria groups – such as: i) Quality, ii) Delivery/Time, and iii) Reputation/Trust - in the context of CM; and
b) the importance of individual candidate metrics (or quantitative measures) in the context of CM.

4.4 Participants

The target population aimed at is domain experts having knowledge and/or experience of involvement in CM research or practice and those in closely related areas including networked manufacturing. Two search methods were selected that helped to identify 150 potential experts. These methods were: (a) search of literature for people involved in CM and networked manufacturing, and b) previous network of contacts.

4.5 Questionnaire Development

Using SurveyMonkey®, an online survey development software and data collection tool, a questionnaire was developed that consisted of three sections as follows (see the questionnaire in Appendix 1).

a) Introduction: This section of the questionnaire included information about the survey, the study objectives, information on confidentiality, and introduction of the research team and their contact details.

b) About You: This section comprised two questions that asked information about the respondent's type of organisation and contact details (as optional).
c) Main topic of the survey: This section was the main part of the survey where experts were asked for their opinions about the criteria and the metrics that would represent the criteria. This section included eight questions. A balanced five-point Likert-type scale format ('strongly agree', 'agree', 'neutral', 'disagree', 'strongly disagree') plus a 'don't know' option was used to capture respondents' opinions. In addition, open-ended spaces were provided to allow respondents to express their suggestions on any other metrics on a more freely basis.

4.5.1 Piloting

The questionnaire was pilot tested and checked for clarity and consistency by five experts in the domain. Suggestions about better articulation of criteria and questions and also about allowing respondents to express their opinions in an open-ended format were received and incorporated in the questionnaire.

4.5.2 Implementation of the Survey

The survey was launched in January 2015 for a period of two weeks. The experts were invited to the survey by an initial email and two further reminders. Consent from the experts for participating in the study was not sought; however, the return of completed questionnaire was considered as a valid consent of the individual participant.

4.5.3 Results and Analysis

Forty-four people responded to the survey, though four of them were removed because they did not answer the main questions. So, the response rate was 26.6% (= 40/150), which is acceptable for such expert opinion surveys. More responses were from academia (27 out of 40), mainly because the main source of search was the literature (see Figure 4.1).

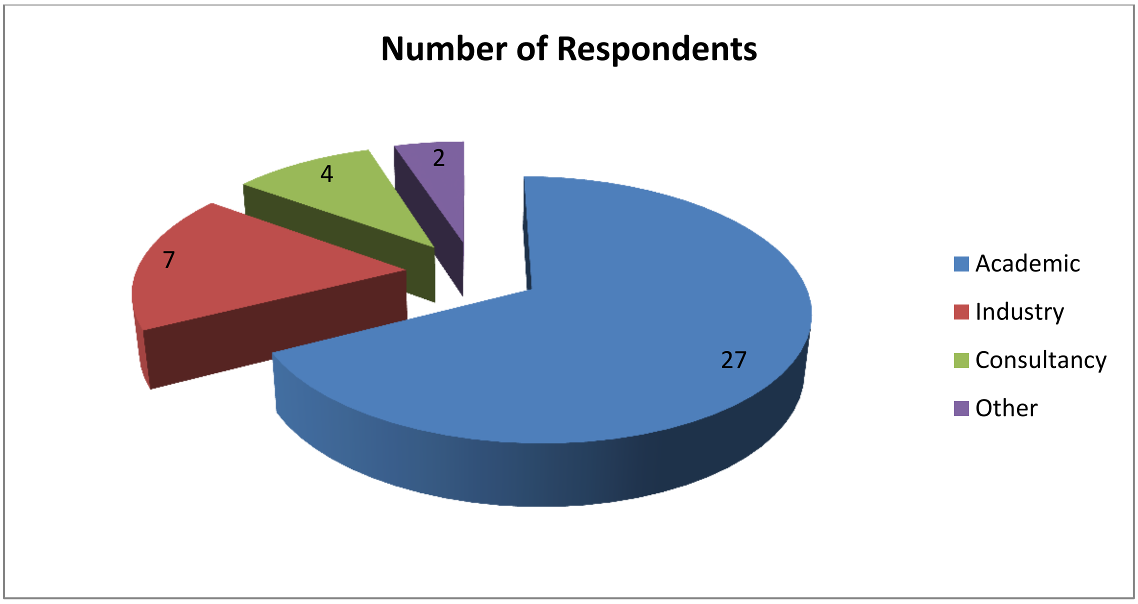

Figure 4.1: Number of respondents by category

4.5.4 Importance of Major Criteria Groups in Suppliers Selection

What can be implied in terms of importance of the major criteria groups, as seen from Figure 4.2, is that:

a) All three criteria received agreements (Strongly Agree and Agree combined) from at least 87% of the respondents. This supports the previous assumption on the selection of these three criteria alongside 'Cost/Price'.

b) 'Delivery/Time' received the highest votes from the respondents followed by 'Quality of Service' and 'Reputation of the Supplier', respectively.

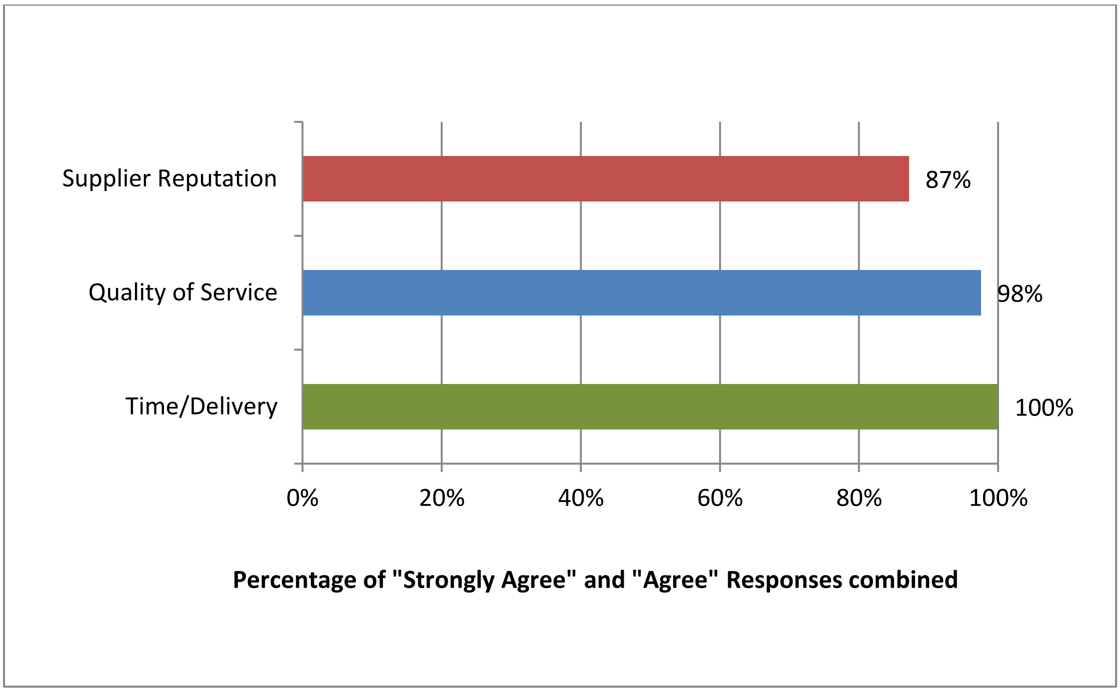

Figure 4.2: Importance of major criteria groups in suppliers selection

4.5.5 Metrics to Evaluate Criterion 'Quality of Service'

As seen in Figure 4.3, Combined Quality Score received a significantly high vote (90%) compared to the other metrics. This could be because quality cannot be measured only by 'Defect Rate' and other factors such as 'Quality System' are also important. Therefore, two metrics such as a) defect (or quality pass) rate, and b) quality system score, were selected to represent the criterion 'quality of service'.

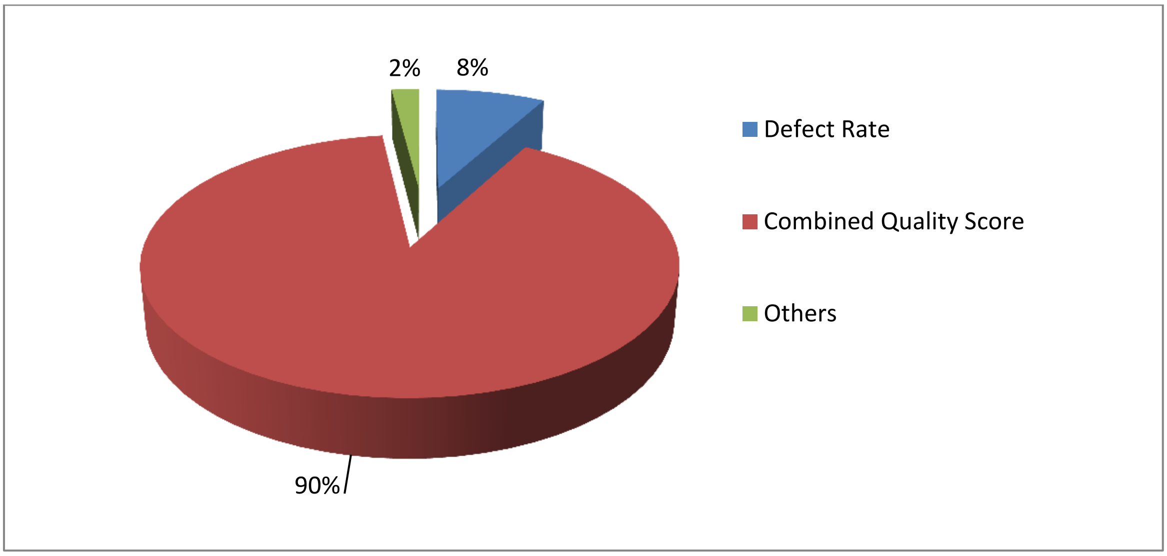

Figure 4.3: 'Quality of service' metrics

4.5.6 Metrics to Evaluate Criterion 'Delivery/Time'

As seen in Figure 4.4, both Delivery Time and Combined Delivery/Time Score received the same level of votes (50% each). As the vote to the single metric 'delivery time' is not significantly superior, a combination of two metrics, i.e. a) delivery time, and b) delivery method, was selected to represent the criterion 'Delivery/Time'.

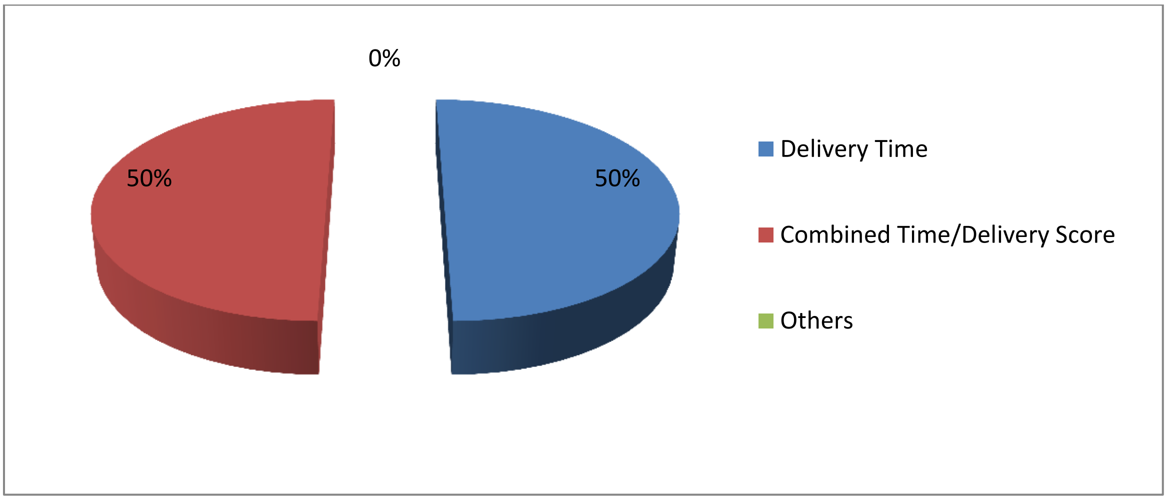

Figure 4.4: 'Delivery/Time' metrics

4.5.7 Criterion on 'Suppliers Reputation'

Because the supplier reputation is a less established criterion compared to the other three, we need to get more information about it in order to measure its contribution. Therefore, we first break it down further into two sub-criteria (called as factors), i.e. a) 'suppliers experience in CM', and b) 'suppliers profile in the industry'. Then metric(s) will be suggested for each factor.

4.5.8 Factors to Represent Criterion 'Suppliers Reputation'

As seen from Figure 4.5, a combination of both 'suppliers experience in the CM' and 'suppliers profile in the industry' received the highest vote (69%) from the respondents, which means both factors need to be taken into account in a combined way.

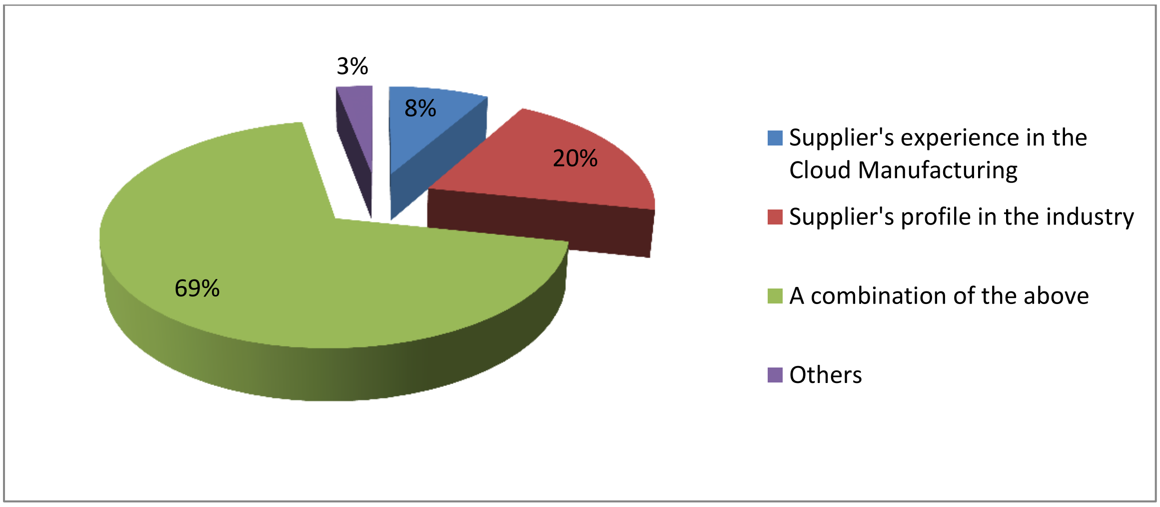

Figure 4.5: 'Suppliers Reputation' factors

4.5.9 Metrics to Evaluate the Factor 'Suppliers Experience in CM'

As seen from Figure 4.6, 'Total Value of Orders Received' showed the highest vote (40%) compared to the other choices. As 'Total Value' is directly related to the 'No. of Orders Received', it can also highlight this metric as the second best option (28%).

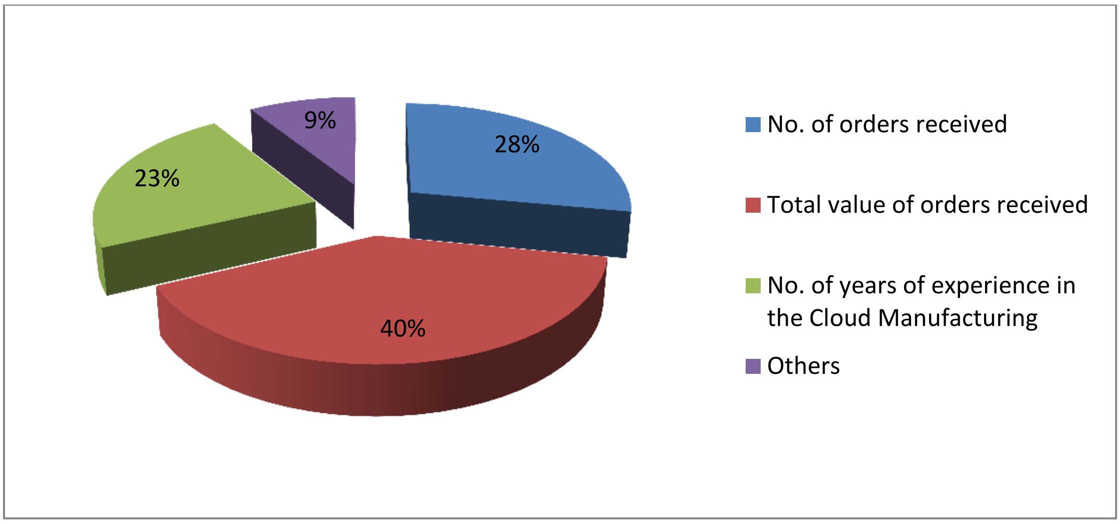

Figure 4.6: 'Suppliers Experience in CM' metrics

4.5.10 Metrics to Evaluate the Factor 'Suppliers Profile in the Industry'

As seen from Figure 4.7, 'No. of Years of Experience in the Industry' received the highest vote (55%), which is also easier to identify and verify compared to the second best option, namely 'Annual Turnover'.

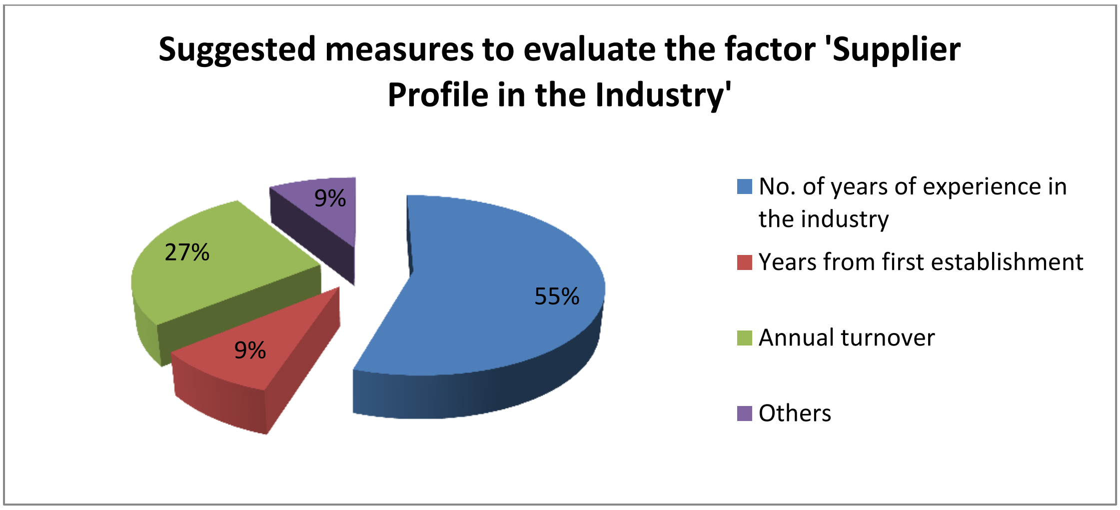

Figure 4.7: 'Suppliers profile in the industry' metrics

4.5.11 Further Validation via Case Studies

One further step via the case study was taken to validate the results of the expert opinion survey. Consultations with industry experts through a real-life case study (as explained in Chapter 6) resulted in a number of recommendations, one of which was about having 'Time' and 'Delivery' as two separate major criteria groups that look at 'time of delivery' and 'method of delivery' respectively. This became apparent due to the fact that they could have quite different weights (client priorities) when a multi-criteria decision making is to be performed.

4.5.12 Final Results

Table 4.3 presents the final results of our survey and case study consultations.

Table 4.3: Final list of metrics

MAJOR GROUP	**Cost**	**Quality of Service**	**Time of Delivery**	**Method of Delivery**	**Supplier Trust/Reputation**
METRICS	Total cost (inc. delivery)	Defect rate or Quality pass rate	Delivery time	Delivery method score	Total value of orders received in Cloud Manufacturing
		Quality system score			No. of years of experience in the industry

4.6 Summary

Research evidence on the suppliers selection criteria within the context of CM is rare. Based on a search within a wider literature, 29 criteria were identified that could contribute to the suppliers selection function in general. The first assessment of the literature identified four commonly used criteria, namely Cost/Price, Quality, Delivery, and Reputation/Trust.

In line with the quantitative nature of this research, two to three candidate metrics were suggested for each criterion, except for cost/price criteria that was associated with one metric. A survey was designed and administered online for two weeks to elicit domain experts' opinions on the candidate criteria and metrics. Forty people responded to the survey.

What can be implied from the survey results, in terms of the importance of major criteria groups, is that all criteria received significant agreements from at least 87% of the respondents. After the industrial consultations, as a part of the case study investigation, one of the criteria (Time/Delivery) was divided into two, making a list of five criteria at the end. It was noted that seven metrics were suggested by the experts to measure those five criteria in the model.

These results were used as elements of the optimisation model, whose details are presented in the next chapter.

CHAPTER 5 DEVELOPMENT OF THE OPTIMISATION-BASED MODELING ON SUPPLIERS SELECTION FOR A SET OF SERVICES

5.1 Introduction

Suppliers selection function is essentially a search process for the best supplier(s) amongst a group of suppliers. Such a search process becomes extremely complex if the size of the search set becomes large. Problem size is characterised by a number of parameters, including:

1) number of suppliers;
2) number of services;
3) number of criteria and sub-criteria; and
4) nature of relation between services.

Within the scope of this research, as depicted earlier in Chapter 1, there are reasons to believe that the problem size could be large. First, the problem is going to be addressed in the cloud manufacturing (CM) context where a global platform is designed for suppliers from around the world to take part. Therefore, a large number of suppliers would potentially submit proposals to the system. Secondly, this research is not supposed to find the best supplier for one single service. Rather it is going to suggest the best supplier(s) for a set of interconnected services. This requires a simultaneous problem-solving approach for all the services. Thirdly, the current research aims to take several key criteria and sub-criteria into account. As a matter of fact, this research suggests considering seven criteria and sub-criteria in the process of supplier selection, as presented earlier in Chapter 4. Such a multi-criteria approach makes decision-making a quite complicated task. Lastly, this research assumes that precedence relationships exist between services as a part of a project network structure. Such a structure further complicates the problem-solving.

Problem characteristics and structure of this type have not been addressed earlier by previous studies. The current approach to face these complexity challenges is to apply Optimisation (or Analytical) models. In this chapter, the formulation of the mathematical model (MP) to solve the suppliers selection problem is developed.

5.2 Assumptions

The problem addressed in this research has a broad scope, as presented earlier in Chapter 1. The only restricting assumption that is crucial to the development of the model is as follows:

Each service is bought from only one supplier.

In other words, splitting a service or an order between more than one supplier is not allowed.

This assumption could be justified when the service cannot be split, or when the quality of service might be sacrificed as a result of splitting the service among several suppliers.

5.3 Criteria Metrics Normalisation Re-visited

As concluded from the expert opinion survey described earlier in Chapter 4, five criteria were found significant in the context of this research, two of which, namely quality and reputation, having two metrics each (Table 5.1). The non-pre-emptive goal programming method requires a weighted transformation of all the criteria metrics into a single normalised score. Therefore, a further transformation with regards to these two criteria is necessary.

Table 5.1: Final list of metrics

MAJOR GROUP	**Cost**	**Quality of Service**	**Time of Delivery**	**Method of Delivery**	**Supplier Trust/Reputation**
METRICS	Total cost (inc. delivery) (C_{ij})	Defect rate or Quality pass rate (q_{ij1})	Delivery time (t_{ij})	Delivery method score (D_{ij})	Total value of orders received in Cloud Manufacturing (r_{ij1})
		Quality system score (q_{ij2})			No. of years of experience in the industry (r_{ij2})

Following presents normalisation as well as weighting-based transformations required for four of the criteria. As explained earlier in section 3.3.1, 'Time' criterion does not need a normalisation transformation.

i) Cost criterion:

Equation 5.1: $\tilde{C}_{ij} = \frac{Min_i \, C_{ij}}{C_{ij}} \qquad \forall j$

Where $\tilde{C}_{ij}$ refers to normalised cost score of supplier i for service j ($\tilde{C}_{ij} \in [0\,,1]$ with 1 being the lowest cost).

ii) Quality criterion:

Equation 5.2: $Q_{ij} = qw_1 \times \frac{q_{ij1}}{Max_i q_{ij1}} + \; qw_2 \times \frac{q_{ij2}}{Max_i q_{ij2}} \qquad \forall j$

Equation 5.3: $\tilde{Q}_{ij} = \frac{Q_{ij}}{Max_i Q_{ij}} \qquad \forall j$

Where $\mathrm{Q_{ij}}$ refers to quality score of supplier i for service j, $\widetilde{\mathrm{Q}}_{\mathrm{ij}}$ refers to normalised quality score of supplier i for service j ($\tilde{Q}_{ij} \in [0\,,1]$ with 1 being the highest quality), q_{ij1} refers to the quality pass rate of supplier i for service j, q_{ij2} refers to the quality system score of supplier i who has offered a proposal for service j, qw_1refers to the relative weight associated with quality pass rate, and qw_2refers to the relative weight associated with the quality system score ($qw_1 \in [1, 10], qw_2 \in [1, 10]$).

iii) Delivery method criterion:

Equation 5.4: $\widetilde{D}_{ij} = \frac{Min_i\, D_{ij}}{D_{ij}}$ $\forall j$

Where $\widetilde{D}_{ij}$ refers to normalised delivery method score of supplier i for service j ($\widetilde{D}_{ij} \in [0\,,1]$ with 1 being the highest delivery method score).

iv) Reputation criterion:

Equation 5.5: $R_{ij} = \ rw_1 \times \frac{r_{ij1}}{Max_i r_{ij1}} + rw_2 \times \frac{r_{ij2}}{Max_i r_{ij2}}$ $\forall j$

Equation 5.6: $\tilde{R}_{ij} = \frac{R_{ij}}{Max_i R_{ij}}$ $\forall j$

Where R_{ij} refers to reputation score of supplier i for service j, $\tilde{R}_{ij}$ refers to normalised reputation score of supplier i for service j ($\tilde{R}_{ij} \in [0\,,1]$ with 1 being the highest reputation score), r_{ij1} refers to the total value of orders received in CM by supplier i who has offered a proposal for service j, r_{ij2} refers to the number of years of experience in the industry by supplier i who has offered a proposal for service j, rw_1refers to the relative weight associated with 'total value of orders received in cloud manufacturing system', and rw_2refers to the relative weight associated with 'number of years of experience' ($rw_1 \in [1, 10], rw_2 \in [1, 10]$).

5.4 Mathematical Programming Model

Analytical models in general and MP models in particular, have proved very effective in finding the optimum solutions. Under this category, the problem is represented completely in mathematical terms composed of a criterion or objective, which the study maximises or minimises, subject to a set of mathematical constraints that depict the conditions under which the decisions have to be made. The model computes an optimal solution, that is, one that satisfies all the constraints and gives the best possible value of the objective function (Bradley *et al.,* 1977).

As explained earlier in Chapter 3, the proposed model is based on *'Goal Integer 0-1 Programming'* method for the supplier selection part and *'Linear Programming' (LP)* method for the project planning part. Non-Pre-emptive Goal Programming takes care of the multi-criteria objective aspect of the problem, while decision variables take binary values 0 or 1 to represent 'selection or no-selection' status for each supplier. The Project Planning part of the problem is essentially of a 'Network Model' type. This study, however, uses an innovative approach in order to convert the network model structure into a LP model.

The standard form of a MP is composed of four main components, as illustrated in Table 5.2:

Table 5.2: Standard form of a mathematical model

Decision Variables Defined	$x_i: defined\ as\ \ i = 1, \dots, n$
Objective	$Maximise\ or\ Minimise\ \ z = f(x_1, x_2, \dots, x_n)$
Constraints	$g_1(x_1, x_2, \dots, x_n) \begin{cases} \le \\ \ge RHS_1 \\ = \end{cases}$ $g_2(x_1, x_2, \dots, x_n) \begin{cases} \le \\ \ge RHS_2 \\ = \end{cases}$ $\dots$ $g_m(x_1, x_2, \dots, x_n) \begin{cases} \le \\ \ge RHS_m \\ = \end{cases}$
Non-Negativity and Variable Types	$x_i \ge 0 \quad \forall i = 1, \dots, n$ $x_k:\ Integer\ or\ Non-Integer$

Here in the next sections, the formulation of the proposed model based on this standard format will be presented. The formulation, however, is displayed in two parts, one for the supplier selection function and the other for the project planning function, as follows:

5.5 Modelling of the Suppliers Selection Component

5.5.1 Decision Variables

The first step in formulating a mathematical model is to define the decision variables, whose values determine the solution of the model. In fact, the purpose of the modelling is to find the best set of values for these variables.

Three sets of decision variables are used in this research:

i) Supplier selection variables;
ii) Goal Programming deviation variables; and
iii) Project planning variables.

Decision variables can be defined in different ways. For instance, two possible definitions of decision variables for a supplier selection problem could be:

a) y_{ij}: equals to 1 if supplier i for service j is selected and 0 if otherwise (so-called binary variables);
b) y_j: equals to i if supplier i for service j is selected.

It can be proved that the second option above faces at least two major issues; one to restrict the model to select y_j values from those suppliers who have actually submitted quotes for service j; and second to restrict the model to select one and only one supplier for each service. These issues, however, can be handled easily by using the first type of decision variables, namely binary ones.

The majority of the previous studies, such as Wadhwa and Ravindran, 2007; Wang *et al.,* 2010; Cebi and Bayraktar, 2003) use the binary variables for suppliers selection problems. Generally speaking, the binary structure is typically a good representation scheme for decision problems where there are only two modes of decisions, namely, 'Yes' or 'No'.

In another study, however, Sawik (2012) chooses decision variables taking any fractional values between 0 and 1, merely because a combination of more than one supplier for one order is allowed.

In this current research, binary decision variables for supplier selection problem are used, as follows:

y_{ij}: *Equals to 1 if supplier* i *for service* j *is selected and 0 if otherwise*

Such a variable structure turns the mathematical model into a 0-1 Integer Programming type that can be solved by using a specific class of solution methods, known as 'Branch and Bound'.

The next set of decision variables are concerned with the GP method in which 'deviations from goal values' are defined as variables for each criterion. These variables simply represent the deviation from each criterion goal value. For example, if it is assumed that the quality goal value is 100% pass rate and a supplier is offering a quality pass rate of 98%, then the deviation from goal value for this supplier is 2% (= 100% - 98%). Goal values need to be determined for each criterion, which will be discussed later in the next section.

There are generally two types of GP deviation variables, namely negative (d^-) and positive (d^+). The negative variables take care of underachievement and the positive ones take care of overachievement. However, in this research, overachievement does not occur. First, in terms of 'Time' criterion, project time planning calculations make sure that project slack times are allocated to the services so that the project is not finished early. Secondly, in terms of the other criteria, the normalisation method does not allow overachievement; because:

i) the normalisation method proposed in this research uses the best value among the supplier proposals as the goal value.
ii) the normalisation method converts all the criteria (both minimisation and maximisation ones) into a uni-directional similar scale [0, 1] where 1 represent the best score.

In other words, the goal values are set to 1, and no metrics will take values beyond 1. Therefore, positive deviation variables can be removed, which results in a major reduction on the number of decision variables, and saving computation times. This can be seen as an original contribution to knowledge of this current research.

Accordingly, the deviation variables are set out in the current research as follows:

d_{jk}: *Negative deviation from goal on criteria* k *with regards to the* j *th service*

$\ddot{d}_T$*: Negative deviation from goal on criteria 'Time' with regards to the whole project*

The deviation variable with respect to the criterion 'Time' takes a different type of variable in this research, due to a different nature of the criterion 'Time' compared to that of other criteria, as explained in the next section.

The deviation variables are used in a minimisation objective function in order to guide the search process towards a solution set as close as possible to the goal values. The objective function is presented in the next section.

Lastly, the Project Planning decision variables are explained later in section 5.4.

5.5.2 Objective Function

In a GP model, the objective is set to minimise total deviations from Goals. This ensures that the model will find the best possible solution considering the relative weightings given to the criteria. Therefore, the objective function in this research is set out as follows:

Equation 5.7: $$Min.\ Z = \sum_{j=1}^{J} \sum_{k=1}^{K-1} (w_{jk} \times d_{jk}) + \frac{J \times \ddot{w}_T \times \ddot{d}_T}{T}$$

where w_{jk} refers to the relative weight assigned by the client to the criterion k (all criteria except for 'Time') with regards to the jth service, $\ddot{w}_T$ refers to the relative weight assigned by the client to the criterion 'Time'.

The weight values w_{jk}, are defined to be determined by the clients within the range [0, 1]. No values outside this range will be allowed.

Furthermore, the goal deviation values, d_{jk}, are also managed to be set within the range [0, 1] by the set of constraints called 'Goal Constraints' – as explained in the next section. This ensures that all the terms $(w_{jk} \times d_{jk})$ take values within the range [0, 1], as well.

The nature of the 'Time' criterion, however, is different from that of other criteria. While the deviation values, d_{jk}, for all the criteria except for 'Time' are defined for each service j, the deviation value for criterion 'Time' can only be defined and meaningful for the whole project rather than for each individual service. This is due to two reasons: a) the whole project finishing time, rather than the individual service times, is assumed to be of prime importance for the clients, are, and b) the project services have a network structure and therefore the finishing time of the whole project cannot be obtained simply by adding up all service times.

In order to accommodate this characteristic of the 'Time' criterion, a special algorithm is designed, as follows:

i) A separate weight factor, $\ddot{w}_T$, and a separate deviation variable, $\ddot{d}_T$, for the whole project are defined.

ii) Because the terms $(w_{jk} \times d_{jk})$ with regards to criterion k (except for 'Time') for all the services are added up in the objective function (in the form $\sum_{j=1}^{J}(w_{jk} \times d_{jk})$), the single term $(\ddot{w}_T \times \ddot{d}_T)$ also needs to be multiplied by J in order to normalise the effects of criterion 'Time' in the objective function.

iii) Because the deviation value $\ddot{d}_T$ cannot be set by the model constraints in the range [0, 1], another normalisation process in the form $\frac{(\ddot{w}_T \times \ddot{d}_T)}{T}$ is proposed. This will ensure that the normalised term is set in the range [0, 1].

In conclusion, a different term $\frac{J \times \ddot{w}_T \times \ddot{d}_T}{T}$ for criterion 'Time' is added to the objective function, as shown earlier in main objective function.

5.5.3 Demand Constraints

As mentioned earlier, as an assumption of this research, the demand for a service provision is assumed to be met by one and only one supplier. Demand constraints ensure that this assumption is met for each service. As a result, a set of J demand constraints for J services are formulated as follows:

$$\sum_{i=1}^{I} y_{ij} = 1 \qquad\qquad \forall\ j = 1, \dots, J$$

The above formulation ensures that all y_{ij} values would set to zero except for the best supplier option, which will take a value 1.

5.5.4 Goal Constraints

Each goal in GP is implemented as a 'goal constraint' which is in the form;

solution value + shortfall = Goal value

This ensures that goal values are targeted in the model. Due to the fact that a multi-criteria problem is being addressed in this research, however, reaching a goal value might not be possible. Therefore, some 'shortfall' from the goal value would appear. The objective would be to minimise the shortfalls, or so called 'deviations', as explained earlier in the previous section.

The goal constraints need to be formulated for each supplier selection criterion separately. Therefore, five sets of goal constraints are developed in this research for five criteria, one set for each criterion namely cost, quality, reputation, delivery and time. The formulations are explained in the next sections.

5.5.4.1 Quality Goal Constraints

The following presents the formulation of J goal constraints for the quality criterion.

Equation 5.8: $\sum_{i=1}^{I}(\tilde{Q}_{ij} \times AQC_i \times y_{ij}) + d_{j1} = 1 \qquad \forall\, j = 1, \dots, J$

Where AQC_i refers to 'Average Quality Compliance' level associated with supplier i so far.

5.5.4.2 Reputation Goal Constraints

The following presents the formulation of J goal constraints for the reputation criterion.

Equation 5.9: $\sum_{i=1}^{I} \tilde{R}_{ij} y_{ij} + d_{j2} = 1 \qquad \forall\, j = 1, \dots, J$

Where $\tilde{R}_{ij}$ refers to the Reputation score of supplier i for service j after normalisation ($R_{ij} \in [0\,, 1]$).

5.5.4.3 Cost Method Goal Constraints

The following presents the formulation of J goal constraints for the cost criterion.

Equation 5.10: $\sum_{i=1}^{I} \tilde{C}_{ij} y_{ij} + d_{j3} = 1 \qquad \forall\, j = 1, \dots, J$

Where $\tilde{C}_{ij}$ refers to the normalised cost score of supplier i for service j ($\tilde{C}_{ij} \in [0\,, 1]$ with 1 being the lowest cost) and d_{j1} refers to the cost deviation variable for service J.

5.5.4.4 Delivery Goal Constraints

The following presents the formulation of J goal constraints for the delivery method criterion.

Equation 5.11: $\sum_{i=1}^{I} \widetilde{D}_{ij} y_{ij} + d_{j4} = 1 \qquad \forall\, j = 1, \dots, J$

Where $\widetilde{D}_{ij}$ refers to the Delivery method score of supplier *i* for service *j* after normalisation ($D_{ij} \in [0\,,1]$).

5.5.4.5 Non-negativity and Variable Types

Deviation variables, d_{jk} and $\ddot{d}_T$, are set to be non-negative, while supplier selection decision variables, y_{ij}, are set to be either zero or one.

$d_{jk} \geq 0 \qquad \forall\, j, k$

$\ddot{d}_T \geq 0$

$y_{ij} = 0\ or\ 1 \quad \forall\, i, j$

5.6 Modelling of the Project Planning Segment

All projects consist of a number of activities that need to be carried out in a particular sequence. Activities might have parallel or sequential relationships with each other. Parallel activities can be performed simultaneously, while those with sequential relationship can only be performed on a sequential basis. Such activity relationships represent a 'Network Structure', which requires a specific type of approach for analysis, called 'Network Analysis'. 'Critical Path Method (CPM)' is a Network Analysis approach to conduct project planning and time calculations. Network analysis in general and CPM in particular, require graphical analysis, which makes it difficult for computerisation. An illustration of graphical analysis using CPM can be seen in Figure 5.1.

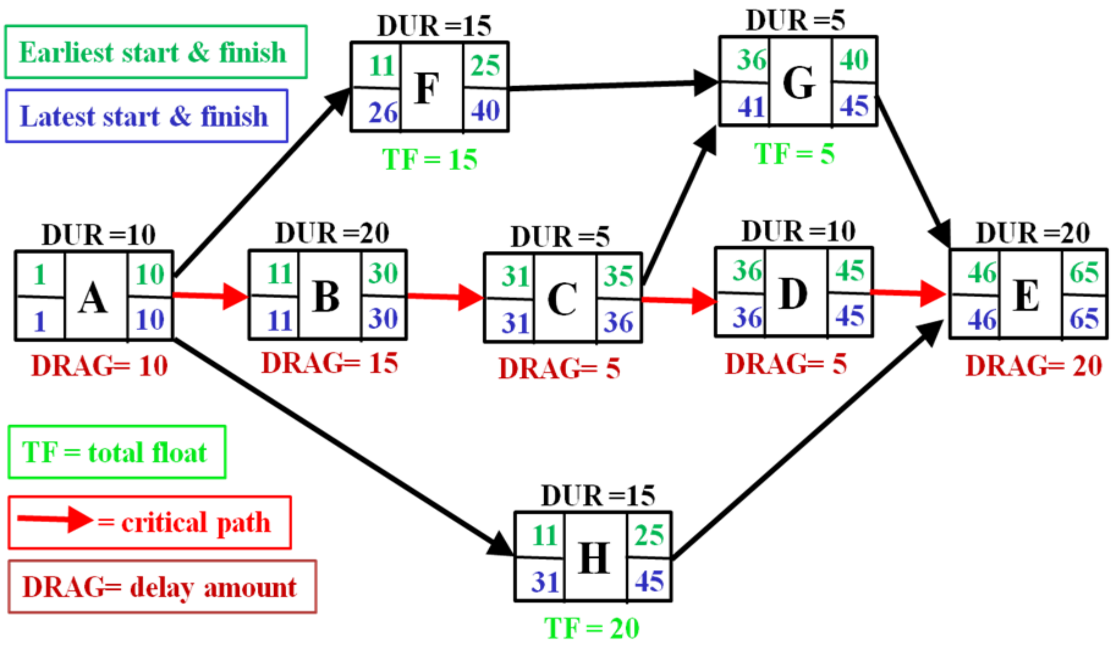

Figure 5.1: An example of a classic graphical-based CPM analysis

The integration of multi-criteria decision making and network analysis makes the solution approach even more complicated. In the current research, a LP model is developed to solve a project planning problem. This model, then, is integrated with the core segment of the model, namely suppliers selection, which is a mixed 0-1 Integer Goal Programming model. Therefore, the proposed approach adopts an integrated mathematical programming model, which deals with both suppliers selection and project planning. This constitutes one of the major contributions of this research.

5.6.1 Decision Variables

One of the aims of the project planning problem is to find the shortest possible time at which the project can finish. The project finishing time is, in turn, built based on the finishing time of activities (services) and the precedence relationships among the services.

Therefore, this research adopts a decision variable that represents activity starting times. In a project network structure, however, two or more activities could have a single starting time, as seen in Figure 5.2. In such network structure, called 'Activity on Node (AON)', nodes represent the 'activities'.

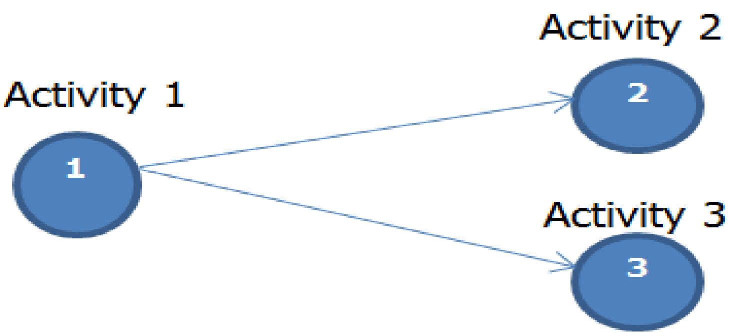

Figure 5.2: An illustration of two parallel activities with the same finishing time

Therefore, what is proposed in this research as decision variable is the starting time of services, as follows:

S_e *: refers to the starting time of service e in the project*

The starting time of activities with no precedence is assumed to be 'Zero'. Furthermore, one extra dummy activity is defined in the end of the project, called 'project end'. This is essential to define precedence relationship between final activities, especially those in parallel, and the project end. Figure 5.3 illustrates this situation.

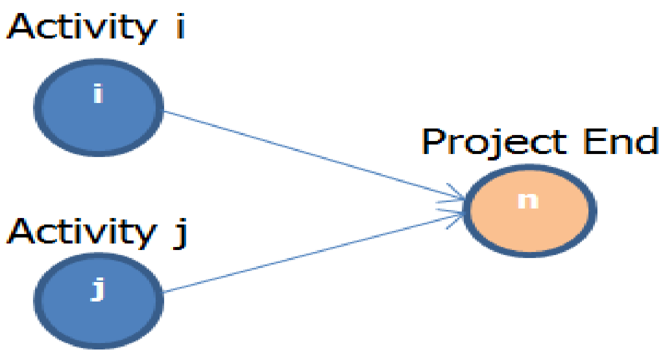

Figure 5.3: Dummy activity defined at the end of a project for project planning purposes

5.6.2Objective Function

Project time is treated in this research only as one of the several supplier selection criteria. The objective function defined earlier in section 5.5.2 includes a term, $\frac{J \times \ddot{w}_T \times \ddot{d}_T}{T}$, that represents the 'project time deviation from goal' and minimises the deviation. No further changes are required.

5.6.3 Constraints

Two types of constraints are required for project planning sub-model, as explained in the next three sections.

5.6.3.1 Project Planning Precedence Constraints

The first and perhaps the most fundamental set of constraints in a project planning model are those that represent 'precedence' relationships in a project.

One constraint is defined for each immediate precedence, as presented in the following:

Equation 5.12: $S_j + t_{ij} \times (1 + ATO_i) \times y_{ij} \leq S_{j'} \qquad \forall\, i, j \quad \forall j' \in J$

Where S_j refers to the starting point of service j, t_{ij} refers to the delivery time quoted by supplier i to perform service j, ATO_i denotes *'Average Time Over-run'* percentage associated with supplier i, $S_{j'}$ refers to the starting point of service j', which is the immediate successor of service j, and J represents all services that are the immediate successor of service j. Figure 5.4 illustrates the graphical representation of these precedence relationships.

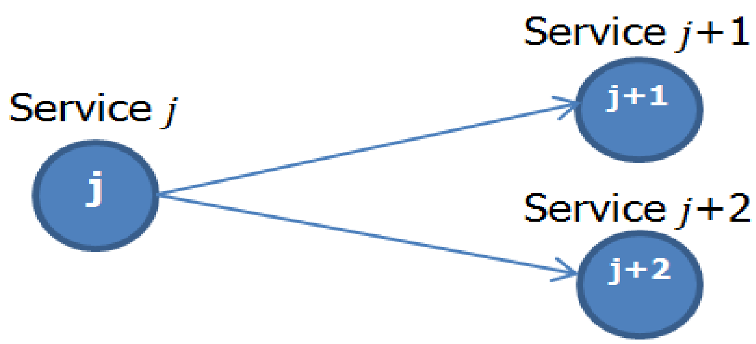

Figure 5.4: Graphical representation of precedence relationships in this research

5.6.3.2 Delivery Time Goal Constraint

As explained earlier in section 5.5.1, overachievement does not occur with the criteria 'Time'. This means that the project finishing time could be greater or equal to the time goal (deadline). The following presents the formulation of goal constraint for delivery time criterion.

Equation 5.13: $S_n - \ddot{d}_T = T$

Where S_n refers to the actual project's end (the dummy activity) time, T refers to the delivery time goal of the whole project (project deadline), and $\ddot{d}_T$ refers to the deviation from this goal.

5.6.4 Non-negativity

Occurrence time of nodes in a project, S_e, are obviously non-negative; hence a set of non-negativity constraints are added to the model, as follows:

$$S_e \geq 0 \qquad \forall\, e$$

5.7 Numerical Example

The mathematical model developed for a small example including three services as part of a project is presented in this section.

5.7.1 Input Data

The project network structure is shown in Figure 5.5. Project deadline is $T = 36$.

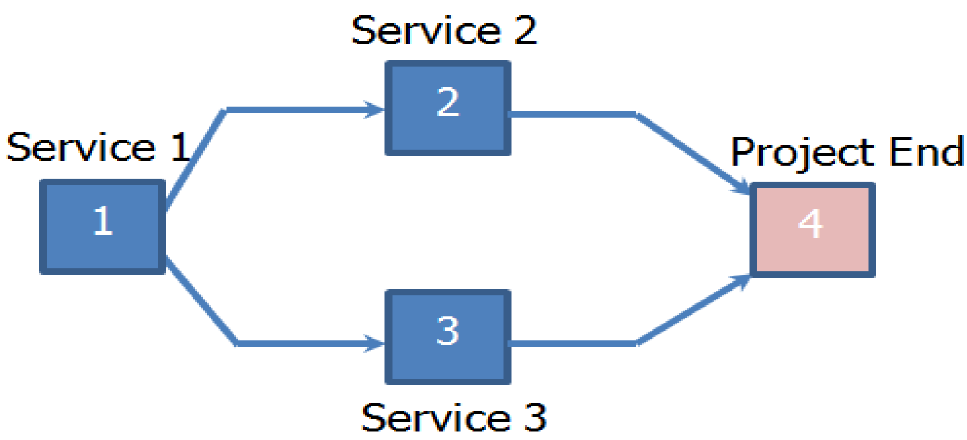

Figure 5.5: Graphical representation of the project example

The criteria weights are shown in table 5.3:

Table 5.3: Criteria weights

Criteria	Quality	Reputation	Cost	Delivery method	Delivery Time
Weighting	3	1	2	1	3

The metric weights associated with criteria 'Quality' and 'Reputation' are shown in Table 5.4.

Table 5.4: Metric weights associated with criteria 'Quality' and 'Reputation'

Criteria	**Quality**		**Reputation**	
Metrics	Defect rate or Quality pass rate	Quality system score	Total value of orders received in cloud manufacturing	No. of years of experience in the industry
Weighting	5	3	3	5

Eight suppliers have submitted proposals for these three services. The suppliers' fixed information as well as the proposal data and their normalised values are presented in Tables 5.5, 5.6, 5.7, and 5.8.

Table 5.5: Suppliers fixed information

Supplier	Quality System Score	Total value of orders received in cloud manufacturing (£)	No. of years of experience in the industry	Average Quality Compliance' level Coefficient	Average Time Over-run Coefficient
1	4	250	12	0.70	0.20
2	6	30	34	0.75	0.30
3	8	70	36	0.85	0.25
4	3	120	8	0.95	0.40
5	4	300	10	0.90	0.50
6	2	45	20	0.85	0.35
7	6	60	40	1.00	0.25
8	9	160	15	0.90	0.15

Table 5.6: Suppliers proposals (Service1)

Service 1 (Original Proposal)

Supplier	Quality Pass Rate	Cost (£)	Delivery Method Score	Time
1	97	350	2	21
2	98	400	4	23
3	99	380	4	22
4	96	300	8	20
5	95	390	4	24
6	94	400	6	23
7	92	330	10	25
8	98	320	2	22

Service 1 (Normalised)

Quality	Reputation	Cost (£)	Delivery Method
0.79	0.71	0.86	0.20
0.87	0.81	0.75	0.40
0.96	0.93	0.79	0.40
0.74	0.40	1.00	0.80
0.77	0.76	0.77	0.40
0.68	0.53	0.75	0.60
0.84	1.00	0.91	1.00
1.00	0.62	0.94	0.20

Time (Learned from History)
25.2
29.9
27.5
28
36
31.05
31.25
25.3

Table 5.7: Suppliers proposals (Service2)

Service 2 (Original Proposal)

Supplier	Quality Pass Rate	Cost (£)	Delivery Method Score	Time
1	94	500	4	12
2	95	440	6	13
3	91	400	10	11
4	93	380	2	13
5	99	520	8	13
6	96	480	10	15
7	93	440	8	12
8	96	480	8	14

Service 2 (Normalised)

Quality	Reputation	Cost (£)	Delivery Method	Time (Learned from History)
0.77	0.71	0.76	0.40	14.40
0.87	0.81	0.86	0.60	16.90
0.93	0.93	0.95	1.00	13.75
0.73	0.40	1.00	0.20	18.20
0.81	0.76	0.73	0.80	19.50
0.72	0.53	0.79	1.00	20.25
0.86	1.00	0.86	0.80	15.00
1.00	0.62	0.79	0.80	16.10

Table 5.8: Suppliers proposals (Service3)

Service 3 (Original Proposal)

Supplier	Quality Pass Rate	Cost (£)	Delivery Method Score	Time
1	89	200	10	11
2	85	230	8	13
3	90	180	2	14
4	93	210	8	12
5	90	220	6	12
6	89	190	6	15
7	92	240	4	14
8	97	180	8	13

Service 3 (Normalised)

Quality	Reputation	Cost (£)	Delivery Method	Time (Learned from History)
0.74	0.71	0.90	1.0	13.20
0.80	0.81	0.78	0.8	16.90
0.91	0.93	1.00	0.2	17.50
0.72	0.40	0.86	0.8	16.80
0.75	0.76	0.82	0.6	18.00
0.66	0.53	0.95	0.6	20.25
0.84	1.00	0.75	0.4	17.50
1.00	0.62	1.00	0.8	14.95

5.7.2 Mathematical Model

Decision Variables:

y_{ij}: *Equals to 1 if supplier* i *for service* j *is selected and 0 if otherwise* $i = 1, \ldots, 8$ and $j = 1, \ldots, 3$

d_{jk}: *Negative deviation from goal on criteria* k *with regards to the* j*th service* $j = 1, \ldots, 3$ & $k = 1, \ldots, 4$

$\ddot{d}_T$*: Negative deviation from goal on criterion 'Time' with regards to the whole project*

S_e *: starting time of service e in the project* $e = 1, \ldots, 4$

Objective Function:

Equation 5.14: $\boldsymbol{Min.z = (3d_{1,1} + 3d_{2,1} + 3d_{3,1}) + (1d_{1,2} + 1d_{2,2} + 1d_{3,2}) + (2d_{1,3} + 2d_{2,3} + 2d_{3,3}) + (1d_{1,4} + 1d_{2,4} + 1d_{3,4}) + \frac{3 \times 3 \times \ddot{d}_T}{36}}$

Demand Constraints

Equation 5.15: Service 1 $y_{1,1} + y_{2,1} + y_{3,1} + y_{4,1} + y_{5,1} + y_{6,1} + y_{7,1} + y_{8,1} = 1.0$

Equation 5.16: Service 2 $y_{1,2} + y_{2,2} + y_{3,2} + y_{4,2} + y_{5,2} + y_{6,2} + y_{7,2} + y_{8,2} = 1.0$

Equation 5.17: Service 3 $y_{1,3} + y_{2,3} + y_{3,3} + y_{4,3} + y_{5,3} + y_{6,3} + y_{7,3} + y_{8,3} = 1.0$

Goal Constraints:

Service 1

Equation 5.18: Quality: $0.55y_{1,1} + 0.66y_{2,1} + 0.82y_{3,1} + 0.70y_{4,1} + 0.69y_{5,1} + 0.58y_{6,1} + 0.84y_{7,1} + 0.9y_{8,1} + d_{1,1} = 1.0$

Equation 5.19: Reputation: $0.71y_{1,1} + 0.81y_{2,1} + 0.93y_{3,1} + 0.4y_{4,1} + 0.76y_{5,1} + 0.53y_{6,1} + 1y_{7,1} + 0.62y_{8,1} + d_{1,2} = 1.0$

Equation 5.20: Cost: $0.86y_{1,1} + 0.75y_{2,1} + 0.79y_{3,1} + 1y_{4,1} + 0.77y_{5,1} + 0.75y_{6,1} + 0.91y_{7,1} + 0.94y_{8,1} + d_{1,3} = 1.0$

Equation 5.21: Delivery Method: $0.2y_{1,1} + 0.4y_{2,1} + 0.4y_{3,1} + 0.8y_{4,1} + 0.4y_{5,1} + 0.6_{6,1} + 1y_{7,1} + 0.2y_{8,1} + d_{1,4} = 1.0$

Service 2

Equation 5.22: Quality: $0.54y_{1,2} + 0.65y_{2,2} + 0.79y_{3,2} + 0.69y_{4,2} + 0.73y_{5,2} + 0.6y_{6,2} + 0.85y_{7,2} + 0.9y_{8,2} + d_{2,1} = 1.0$

Equation 5.23: Reputation: $0.71y_{1,2} + 0.81y_{2,2} + 0.93y_{3,2} + 0.4y_{4,2} + 0.76y_{5,2} + 0.53y_{6,2} + 1y_{7,2} + 0.62y_{8,2} + d_{2,2} = 1.0$

Equation 5.24: Cost: $0.78y_{1,2} + 0.87y_{2,2} + 0.93y_{3,2} + 0.73y_{4,2} + 0.81y_{5,2} + 0.70y_{6,2} + 0.85y_{7,2} + 1y_{8,2} + d_{2,3} = 1.0$

Equation 5.25: Delivery Method: $0.4y_{1,2} + 0.6y_{2,2} + 1y_{3,2} + 0.2y_{4,2} + 0.8y_{5,2} + 1y_{6,2} + 0.8y_{7,2} + 0.8y_{8,2} + d_{2,4} = 1.0$

Service 3

Equation 5.26: Quality: $0.52y_{1,3} + 0.60y_{2,3} + 0.78y_{3,3} + 0.69y_{4,3} + 0.67y_{5,3} + 0.56y_{6,3} + 0.84y_{7,3} + 0.9y_{8,3} + d_{3,1} = 1.0$

Equation 5.27: Reputation: $0.71y_{1,3} + 0.81y_{2,3} + 0.93y_{3,3} + 0.4y_{4,3} + 0.76y_{5,3} + 0.53y_{6,3} + 1y_{7,3} + 0.62y_{8,3} + d_{3,2} = 1.0$

Equation 5.28: Cost: $0.9y_{1,3} + 0.78y_{2,3} + 1y_{3,3} + 0.86y_{4,3} + 0.82y_{5,3} + 0.95y_{6,3} + 0.75y_{7,3} + 1y_{8,3} + d_{3,3} = 1.0$

Equation 5.29: Delivery Method: $1y_{1,3} + 0.8y_{2,3} + 0.2y_{3,3} + 0.8y_{4,3} + 0.6y_{5,3} + 0.6y_{6,3} + 0.4y_{7,3} + 0.88y_{8,3} + d_{3,4} = 1.0$

Project Planning Precedence Constraints:

Equation 5.30: $S_1 + 25.2y_{1,1} \leq S_2$

Equation 5.31: $S_1 + 29.9y_{2,1} \leq S_2$

Equation 5.32: $S_1 + 27.5y_{3,1} \leq S_2$

Equation 5.33: $S_1 + 28y_{4,1} \leq S_2$

Equation 5.34: $S_1 + 36y_{5,1} \leq S_2$

Equation 5.35: $S_1 + 31.05y_{6,1} \leq S_2$

Equation 5.36: $S_1 + 31.25y_{7,1} \leq S_2$

Equation 5.37: $S_1 + 25.3y_{8,1} \leq S_2$

Equation 5.38: $S_1 + 25.2y_{1,1} \leq S_3$

Equation 5.39: $S_1 + 29.9y_{2,1} \leq S_3$

Equation 5.40: $S_1 + 27.5y_{3,1} \leq S_3$

Equation 5.41: $S_1 + 28y_{4,1} \leq S_3$

Equation 5.42: $S_1 + 36y_{5,1} \leq S_3$

Equation 5.43: $S_1 + 31.05y_{6,1} \leq S_3$

Equation 5.44: $S_1 + 31.25y_{7,1} \leq S_3$

Equation 5.45: $S_1 + 25.3y_{8,1} \leq S_3$

Equation 5.46: $S_2 + 14.4y_{1,2} \leq S_4$

Equation 5.47: $S_2 + 16.9y_{2,2} \leq S_4$

Equation 5.48: $S_2 + 13.75y_{3,2} \leq S_4$

Equation 5.49: $S_2 + 18.2y_{4,2} \leq S_4$

Equation 5.50: $S_2 + 19.5y_{5,2} \leq S_4$

Equation 5.51: $S_2 + 20.25y_{6,2} \leq S_4$

Equation 5.52: $S_2 + 15y_{7,2} \leq S_4$

Equation 5.53: $S_2 + 16.1y_{8,2} \leq S_4$

Equation 5.54: $S_3 + 13.2y_{1,3} \leq S_4$

Equation 5.55: $S_3 + 16.9y_{2,3} \leq S_4$

Equation 5.56: $S_3 + 17.5y_{3,3} \leq S_4$

Equation 5.57: $S_3 + 16.8y_{4,3} \leq S_4$

Equation 5.58: $S_3 + 18y_{5,3} \leq S_4$

Equation 5.59: $S_3 + 20.25y_{6,3} \leq S_4$

Equation 5.60: $S_3 + 17.5y_{7,3} \leq S_4$

Equation 5.61: $S_3 + 14.95y_{8,3} \leq S_4$

Equation 5.62: Whole Project Time: $S_4 - \ddot{d}_T = 36$

Non-negativity and Variable Types:

$d_{jk} \geq 0 \quad \forall \; j = 1, \dots, 3 \;\&\; k = 1, \dots, 4$

$\ddot{d}_T \geq 0$

$y_{ij} = 0 \; or \; 1 \quad \forall \; i = 1, \dots, 8 \;\&\; j = 1, \dots, 3$

5.7.3 Results

The model was run using What'sBest© software and the results were generated, as shown in Table 5.9.

Table 5.9: Model results for the numerical example

	Service1	Service2	Service3	Project Total
Selected Supplier	7	3	8	-
Cost (£)	330	400	180	910 (Total)
Time (Days)	31.25	13.75	14.95	46.2 (Total)
Quality	0.84	0.79	0.9	0.84 (Average)
Reputation	1	0.93	0.62	0.85 (Average)
Delivery Methods	1	1	0.8	0.93 (Average)

5.8 Summary

The size of the problem addressed in this research in terms of the number of suppliers, number of services, nature of relationship between services, and number of criteria, could be potentially massive. This makes the optimisation task very complex. In this chapter, the formulation of the mathematical model to solve the supplier selection problem was developed.

First, it is assumed that each service is bought from only one supplier. In other words, splitting a service or an order into more than a supplier is not allowed. The proposed model is based on 'Goal Integer 0-1 Programming' method for the supplier selection part and 'Linear Programming' method for the project planning part. Non-Preemptive Goal Programming takes care of the multi-criteria objective aspect of the problem, while decision variables take binary values 0 or 1 to represent 'selection or no-selection' status for each supplier.

The model developed consists of four key components, namely a) decision variables, b) objective function, c) constraints, and d) non-negativity and variable type formatting. Three types of decision variables were defined. Objective function was set to minimise total deviations from Goals. Also, three sets of constraints were considered. General formulation of the model was provided, before a small numerical example was solved by the model.

CHAPTER 6 CASE STUDY IN THE OIL AND GAS INDUSTRY

6.1 Introduction

To validate the proposed methodology, finding an appropriate case study to cover all aspects aforementioned in previous chapters is vital. There are some major factors which must be considered in order to choose the suitable case study organisation.

First of all, this research deals with a multi-criteria decision making situation involving a number of selection criteria such as 'Quality', 'Cost', 'Delivery method', 'Time of delivery', and 'Reputation/trust'. A case study organisation needs to consider these criteria in their purchasing strategies and policies.

Secondly, multi-service outsourcing is the next aspect of this research which needs to be considered. A case study organisation needs outsourcing through varied stages in manufacturing processes such as design, part manufacturing, procurements, assembly, and final delivery.

Lastly, a set of inter-connected services in the form of a project is necessary in order to evaluate the precedence of services in a form of parallel or sequential relationships.

6.2 Case Study Setting

Darya Pala Co. consists of a group of professional expert engineers for the purpose of serving the state, public, communities, and individuals, by performing consultancy of all kinds of engineering, such as, construction, supervision, advising, and managing different projects, especially in the fields of oil and gas, petrochemical refining transfer and utilisation, and power generation transmission and distribution. One of the recent projects for Darya Pala Co. is the Qeshm water and power co-generation plant.

Qeshm water and power co-generation plant is designed to produce 18,000 m3 /day portable water for local consumption which utilises heat recovered from 50(MW) gas turbines, in Qeshm Island, Hormozgan Province, Iran (see Figure 6.1). The main aim of this project is to increase production of drinking water, thereby helping to bridge the gap between supply and growing demand of potable water in the project area. In addition, the project will reduce greenhouse gas emissions by using waste heat in Heat Recovery Steam Generators (HRSGs) instead of heat generated by combustion of fossil fuels.

Darya Pala Co. is responsible for engineering services, design, and procurement for different parts such as control system, control value, gasket, fitting station, pipeline, piping station, pump, safety, and HVAC (heating, ventilating, and air conditioning). In order to provide HVAC systems for use in the site buildings, an industrial compressed air system is required. The whole package of the compressed air system was supposed to be supplied by Havayar CO Group.

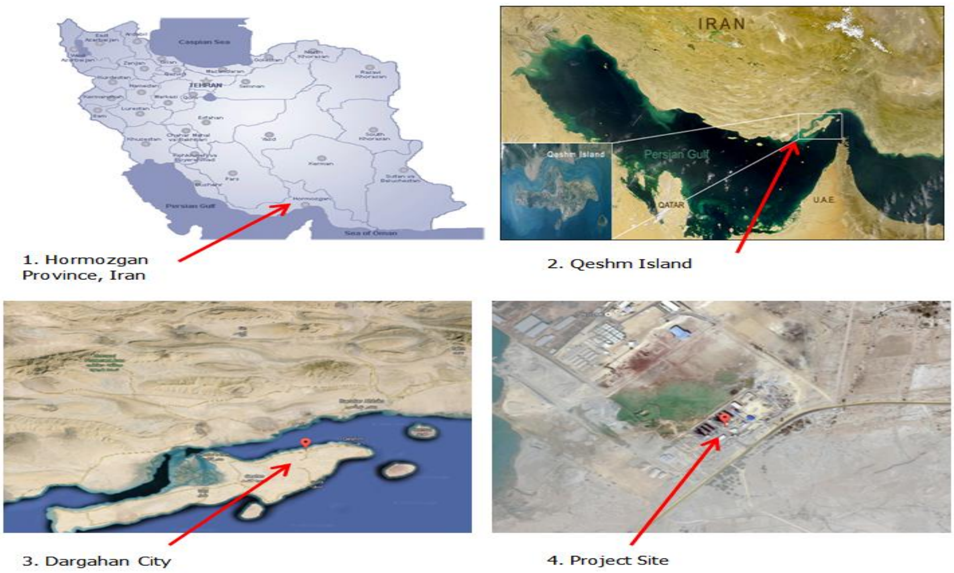

Figure 6.1: The geographical location of the project size

6.2.1 Objectives and Scope

The optimum selection of suppliers for different activities involving the manufacture of compressed air system for the purpose of the Qeshm water and power co-generation plant constitutes one of the objectives of this case study. Furthermore, it aims to validate the proposed general framework of the methodology, as described earlier in chapter three, as well as the detailed methodology, as described through chapters four and five.

Compressed air systems are designed not only to operate within a fixed pressure range, but also to deliver a volume of air which changes under system demand. A package of compressed air comprises of four main devices, namely 'Air Compressor', 'Air Receiver', 'Air Filter', and 'Air Drier' which are linked together. In addition, each device consists of various parts which are either made in the firm or purchased from third party sources. Hence, Havayar Co Group has contracted out some activities rather than providing them internally. These activities consisted of

1) 'design services';
2) 'part sourcing'; and
3) 'delivery services' to deliver the air compressed package (Figure 6.2).

It should be noted that assembly/manufacturing stage of the process was planned to be carried out internally.

The whole process of making a compressed air system starts with receiving various designs and plans by different suppliers. After approving the plans by Havayar, part sourcing (purchasing) stage starts by specifying which parts need to be purchased from various suppliers. After receiving parts from various suppliers, assembly and manufacturing stage starts, which is not considered in the current research because this stage is performed by skilled people within the firm. Lastly, the transportation stage is responsible for delivering the compressed air system package to the main site.

6.2.2 Recommendations on the Criteria

As implied from the literature, four important criteria were first identified, namely quality, cost, delivery and reputation. However, consultations with the company's staff in procurement department provided us with some reflections on the structure of criteria. More specifically, there were comments on the fact that suppliers might need more time to meet their quality commitments in a way to compensate for the rejected parts. Therefore, it became clear that a distinction and stress on the 'Time' as an independent criterion rather than a sub-factor of 'Delivery' criterion is vital. This led to the suggestion of having 'Time' and 'Delivery' as two separate major criteria groups that represent 'time of delivery' and 'method of delivery' respectively. Such a distinction allowed the possibility to define different weights (client's priorities) for each of these criteria.

6.3 Services and Suppliers Proposals

There are totally 29 services in the project including 27 purchased goods and two service requests. All 29 services are shown in Figure 6.2 as below:

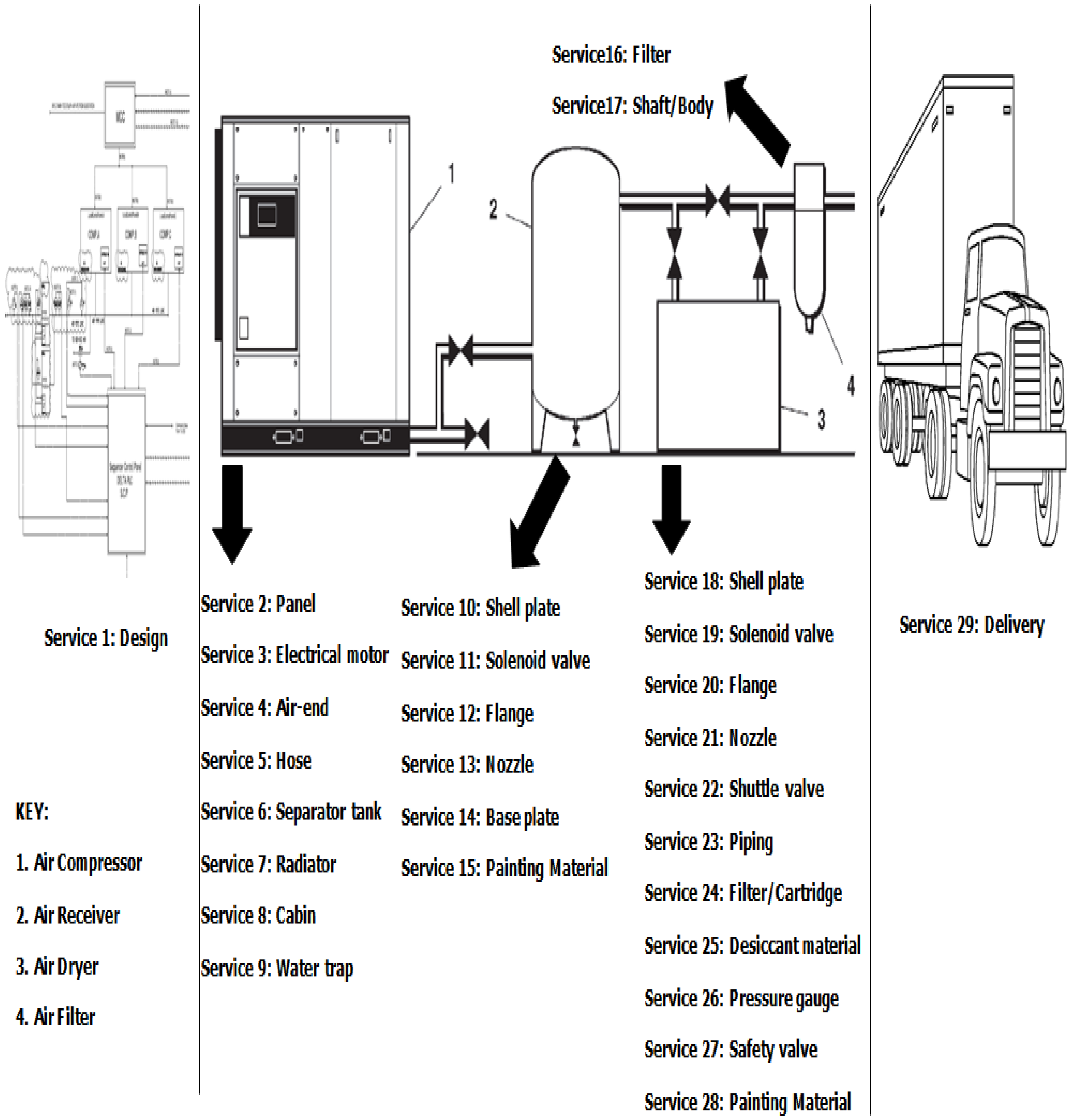

Figure 6.2: List of all 29 services associated with the project

Figure 6.2 indicates that Service 1 is related to design services. Services 2,3,4,5,6,7,8 and 9 include different parts used in the Air Compressor, namely, panel, electrical motor, air-end, hose, separator tank, radiator, cabin, and water trap respectively, which need to be purchased from various suppliers. Services 10, 11, 12, 13, 14, and 15 are allocated to purchase different parts used in the air receiver, namely, shell plate, solenoid valve, flange, nozzle, base plate, and painting materials respectively. Services 16 and 17 include purchasing two main parts used in the air filter such as filter and shaft/body respectively. Services 18 to 28 consists of purchasing different parts of air dryer, namely, shell plate, solenoid valve, flange, nozzle, shuttle valve, piping, filter/cartridge, desiccant material, pressure gauge, safety valve, and painting material respectively. Lastly, service 29 is related to the delivery of the complete package to the site building in Qeshm Island. In addition, there are common parts and materials used in these devices such as shell plate, solenoid valve, flange, nozzles, and painting materials which count as common services in both the air receiver and the air dryer.

108 suppliers are found interested in providing these 29 services. While some of these suppliers provide only one service, some of them supply more than one service. Hence, these suppliers offer a varied range of proposals for services including sales quotes and information regarding delivery time, delivery methods, and product quality pass rates. In order to assign delivery method scores, the main factors are considered, such as

a) delivery tracking option, either available or not available, and
b) insurance options, either not-insured, half-insured, and fully-insured.

As a result, six different delivery methods are suggested, which can be rated as follows:

0: no tracking, not insured;

2: tracking, not insured;

4: no tracking, half insured;

6: tracking, half insured;

8: no tracking, fully insured; and

10: tracking, fully insured.

6.3.1 Design Service (Service 1)

In order to design the compressed air package, Havayar Co Group have been working with three companies whose responsibility was to design all four devices within the air compressed system package. These three suppliers have the duty of designing, drawing, piping, and part modelling the air compressor, air receiver, air filter, and air dryer by using various software and applications such as Catia, Autocad, Autodesk Inventor, and pro/ENGINEER. Table 6.1 shows suppliers proposal for the following service.

Table 6.1: Suppliers proposal for Service 1

Service 1: Design				
Supplier	Quality Pass Rate	Cost (£)	Time(days)	Delivery Method
1	94	18,000	55	10
2	98	21,000	50	10
3	96	20,000	60	10

According to Table 6.1, all three suppliers have a rate of ten for delivery method part. As explained earlier, Service 1 is a design service which contain various drawing and design files with different formats such as Catia and Autocad. After finishing the designing service, suppliers have the option of sending the files by Email, or using file housing services such as Dropbox or Google Drive. Hence, equal rates are considered for all three suppliers which could be from one to ten.

6.3.2 Part Sourcing (Services 2 to 28)

As stated earlier, various parts are need to be purchased in order to make the air compressor, air receiver, air filter, and air drier:

6.3.2.1 Air Compressor (Services 2 to 9)

The air compressor consisted of eight parts which required to be purchased, namely, panel (Service 2), electrical motor (Service 3), air-end (Service 4), hose (Service 5), separator tank (Service 6), radiator (Service 7), cabin (Service 8), and water trap (Service 9). In total, 43 suppliers offered their proposal. Table 6.2 shows suppliers proposals for Service 2, which is base plate. Suppliers proposals for Services 3 to 9 are available in Appendix 2.

Table 6.2: Suppliers proposal for Service 2

Service 2: Panel				
Supplier	Quality Pass Rate	Cost (£)	Time (days)	Delivery Method
4	97	500	10	8
5	98	800	7	10
6	95	360	6	6
7	99	1,000	14	8
8	95	600	8	8

6.3.2.2 Air Receiver (Services 10 to 15)

The shell plate (Service 10), solenoid valve (Service 11), flange (Service 12), nozzle (Service 13), base plate (Service 14), and painting materials (Service 15) are parts that need to be purchased in order to make an air receiver. Table 6.3 shows suppliers proposals for Service 10 which is the base plate. Suppliers proposals for Services 11 to 15 are available in Appendix 2.

Table 6.3: Suppliers proposal for Service 10

Service 10: Shell Plate				
Supplier	Quality Pass Rate	Cost (£)	Time (days)	Delivery Method
47	93	200	8	8
48	90	240	6	8
49	91	180	10	6
50	94	240	8	8
51	91	120	7	4

6.3.2.3 Air Filter (Services 16 and 17)

The air filter consisted of two parts which were required to be purchased, namely, the filter (Service 16) and the shaft/body (Service 17). Table 6.4 shows suppliers proposals for both services.

Table 6.4: Suppliers proposal for Service 16 and Service 17

	Supplier	Quality Pass Rate	Cost (£)	Time (days)	Delivery Method
Service 16: Filter	77	94	300	18	8
	78	98	280	18	8
Service 17: Shaft/Body	79	91	260	19	4
	80	92	220	21	6
	81	93	80	10	6
	82	94	100	13	8

6.3.2.4 Air Drier (Services 18 and 28)

Services 18 to 28 consisted of purchasing different parts of the air dryer, namely, shell plate (Service 18), solenoid valve (Service 19), flange (Service 20), nozzle (Service 21), shuttle valve (Service 22), piping (Service 23), filter/cartridge (Service 24), desiccant material (Service 25), pressure gauge (Service 26), safety valve (Service 27), and painting material (Service 28) respectively. As stated earlier, there are common parts and materials used in the air receiver and air drier. Suppliers proposals for Services 18 to 27 are available in Appendix 2.

6.3.3 Transportation Service (Services 29)

Service 29 is related to the delivery of the compressed air system from Karaj City to Qeshm Island. There are three transportation companies which submitted their proposals (see table 6.5). The distance between two sites is almost 1437km.

Table 6.5: Suppliers proposal for Service 29

Service 29: Delivery				
Supplier	Quality Pass Rate	Cost (£)	Time	Delivery Method
108	97	1,300	15	8
109	98	1,200	18	6
110	96	1,500	19	10

6.4 Suppliers Information and Normalisation

As discussed in Chapters 3 and 4, the ‘Quality’ criterion cannot be measured only by quality pass rate (defect rate) as other factors, such as, quality management system, are also important. Therefore, apart from the proposed ‘quality pass rate’ information provided by various suppliers regarding the existing 29 services, quality system scores based on quality management system certifications (QMSC) are required such as ISO 9001 , Six Sigma, and Chartered Quality Institute (CQI). Accordingly, the quality system scores are worked out in a scale 0 to 10. An example of these scores for 23 suppliers is presented in Table 6.6. The remaining data are available in Appendix 3.

The 'Reputation' score consisted of two sets of metric data, namely 'total value of orders allocated to each supplier in CM (TVOA)' and 'number of years of experience in the industry or year established (YE)'. Therefore, it is required to provide suppliers information (Table 6.6) in order to calculate 'Quality' and 'Reputation' scores.

Table 6.6 shows 23 suppliers profile information for Services 1 to 5. Suppliers profile information for Services 6 to 29 are available in Appendix 3.

Table 6.6: Suppliers profile information for services 1 to 5

	Suppliers Profile Information			
	Suppliers	TVOA* (£)	Year Established (YE)	Quality System Score
Service 1 Design	1	43,000	2005	7
	2	36,000	2000	8
	3	22,000	2011	9
Service 2 Panel	4	12,500	2001	6
	5	12,000	1994	8
	6	14,000	1995	7
	7	10,000	2006	9
	8	10,800	1984	9
Service 3 Electrical Motor	9	27,000	1990	8
	10	30,000	1982	5
	11	34,500	2010	8
	12	39,000	2007	7
	13	21,000	2002	9
Service 4 Air-end	14	75,000	2008	8
	15	61,000	2000	7
	16	66,000	2003	7
Service 5 Hose	17	17,600	1995	7
	18	14,000	1998	6
	19	10,800	2003	7
	20	1,344	2011	8
	21	1,480	2007	6
	22	1,820	2001	7
	23	1,200	1999	9

* As there is no historical data on the CM experience, assumptions were made.

6.4.1 Criteria Weighting

Criteria weights are regarded as the degree of relative importance associated with each criterion in suppliers selection. These weights can be within a scale of 1 to 10 where 10 represent the most important. It should be noted that 10 is twice as important as 5, and 3 is three times as important as 1. Table 6.7 shows the numerical weights associated with each of five criteria as well as the quality and reputation sub-criteria, allocated by the Procurement Department (PD) in Havayar Co Group.

Table 6.7: Preferred criteria and sub-criteria weights proposed by PD

Criteria Weights				
Quality	Reputation	Cost	Delivery method	Time
3	1	3	1	3

Sub-criteria Weights			
Quality		Reputation	
Quality Pass Rate Weight	Quality Management Systems in the Company Weight	Past Experience of Working with the Supplier Weight	Profile in the industry Weight
3	2	3	2

'Quality' scores for each supplier are calculated according to formulations below:

1) Quality criterion:

Equation 6.1: $$Q_{ij} = qw_1 \times \frac{q_{ij1}}{Max_i q_{ij1}} + qw_2 \times \frac{q_{ij2}}{Max_i q_{ij2}} \qquad \forall j$$

Where Q_{ij} refers to quality score of supplier i for service j, q_{ij1} refers to the quality pass rate of supplier i for service j, q_{ij2} refers to the quality system score of supplier i who has offered a proposal for service j, qw_1refers to the relative weight associated with quality pass rate, and qw_2refers to the relative weight associated with the quality system score ($qw_1 \in [1, 10], qw_2 \in [1, 10]$).

For example, quality scores for design service (Service 1) which is proposed by Suppliers 1 to 3 are:

Equation 6.2: $$Q_{11} = 3\ \frac{94}{max_{(94,98,96)}} + 2\frac{7}{9} = 4.43$$

Equation 6.3: $$Q_{21} = 3\ \frac{98}{max_{(94,98,96)}} + 2\frac{8}{9} = 4.78$$

Equation 6.4: $$Q_{31} = 3\ \frac{96}{max_{(94,98,96)}} + 2\frac{9}{9} = 4.94$$

Table 6.8 shows the quality scores for Services 1 to 3 while the rest of the scores are presented in Appendix 4.

Table 6.8: Quality scores for services 1 to 5

Quality Scores					
Suppliers	Service 1: Design	Service 2: Panel	Service 3: Electric Motor	Service 4: Air-end	Service 5: Hose
1	4.43	-	-	-	-
2	4.78	-	-	-	-
3	4.94	-	-	-	-
4	-	4.28	-	-	-
5	-	4.75	-	-	-
6	-	4.44	-	-	-
7	-	5.00	-	-	-
8	-	4.88	-	-	-
9	-	-	4.69	-	-
10	-	-	3.87	-	-
11	-	-	4.60	-	-
12	-	-	4.44	-	-
13	-	-	5.00	-	-
14	-	-	-	4.75	-
15	-	-	-	4.40	-
16	-	-	-	4.56	-
17	-	-	-	-	4.49
18	-	-	-	-	4.24
19	-	-	-	-	4.36
20	-	-	-	-	4.75
21	-	-	-	-	4.21
22	-	-	-	-	4.56
23	-	-	-	-	4.94

‘Reputation’ scores for each supplier are calculated according to formulation below:

2) Reputation criterion:

Equation 6.5: $$R_{ij} = rw_1 \times \frac{r_{ij1}}{Max_i r_{ij1}} + rw_2 \times \frac{r_{ij2}}{Max_i r_{ij2}} \qquad \forall j$$

Where R_{ij} refers to reputation score of supplier i for service j ($R_{ij} \in [0, 1]$ with 1 being the highest reputation score), r_{ij1} refers to the total value of orders received in CM by supplier i who has offered a proposal for service j, r_{ij2} refers to the number of years of experience in the industry by supplier i who has offered a proposal for service j, rw_1refers to the relative weight associated with 'total value of orders received in total', and rw_2refers to the relative weight associated with 'number of years of experience in industry' ($rw_1 \in [1, 10], rw_2 \in [1, 10]$).

For example, reputation scores for design service (Service 1) which is proposed by suppliers 1 to 3 is:

Equation 6.6: $$R_{11} = 3\ \frac{43{,}000}{75{,}000} + 2\frac{2015-2005}{2015-1975} = 2.22$$

Equation 6.7: $$R_{21} = 3\ \frac{36{,}000}{75000} + 2\frac{2015-2000}{2015-1975} = 2.19$$

Equation 6.8: $$R_{31} = 3\ \frac{22{,}000}{75000} + 2\frac{2015-2011}{2015-1975} = 1.08$$

Table 6.9 shows the reputation scores for Suppliers 1 to 30, while the rest of the scores are presented in Appendix 4.

Table 6.9: Reputation scores for suppliers 1 to 30

Reputation Scores					
Suppliers	Reputation score	Suppliers	Reputation score	Suppliers	Reputation score
1	2.22	11	1.61	21	0.46
2	2.19	12	1.96	22	0.78
3	1.08	13	1.49	23	0.85
4	1.20	14	3.35	24	0.39
5	1.53	15	3.19	25	0.80
6	1.56	16	3.24	26	0.56
7	0.85	17	1.71	27	0.55
8	1.99	18	1.41	28	0.93
9	2.33	19	1.03	29	0.94
10	2.85	20	0.26	30	1.02

6.4.2 Normalisation

When dealing with multi-criteria decision making problems, it is vital to normalise different metric values if they are not in the same scale. All the criteria, except for 'Time', require normalisation in order to enable a conversion to single-criteria Linear Programming model. Therefore, normalisation based on comparison with the best value is selected. As discussed in Chapter 3, 'Total Cost' metric is required to be minimised, while 'Quality', 'Delivery Method', and 'Reputation' metrics are maximised.

1. Minimisation

Equation 6.9: $$Normalised\ Score\ (i,j) = \frac{Min.criteria\ value\ amongst\ all\ the\ suppliers}{criteria\ value\ of\ supplier\ i\ for\ service\ j}$$

This is applied to the cost criterion, where the objective is to minimise the total cost alongside other criteria. Calculations for normalised cost of proposals from 3 suppliers for Service 1 are shown below followed by Table 6.10 which shows both initial raw scores and normalised scores. Additionally, all criteria normalised scores are available in Appendix 5.

Total Cost:

Equation 6.10: $$\tilde{C}_{11} = \frac{18{,}000}{18{,}000} = 1$$

Equation 6.11: $$\tilde{C}_{21} = \frac{18{,}000}{21{,}000} = 0.8571$$

Equation 6.12: $$\tilde{C}_{31} = \frac{18{,}000}{20{,}000} = 0.9$$

2. Maximisation

Equation 6.13: $$Normalised\ Score\ = \frac{criteria\ value\ k\ of\ supplier\ i\ for\ service\ j}{Max.\ criteria\ value\ amongst\ all\ the\ suppliers}$$

This formula is applied to the quality, reputation, and delivery method criteria, where the objective is to maximise their metric values alongside other criteria. Calculations for normalised quality and delivery method of proposals from 3 suppliers for Service 1 as well as the reputation scores of suppliers 1 to 3 are shown below followed by Table 6.11 which shows both initial raw scores and normalised scores. Additionally, all criteria normalised scores are available in Appendix 5.

Quality:

Equation 6.14: $\tilde{Q}_{11} = \frac{4.43}{4.94} = 0.8976$

Equation 615: $\tilde{Q}_{21} = \frac{4.78}{4.94} = 0.9674$

Equation 6.16: $\tilde{Q}_{31} = \frac{4.94}{4.94} = 1$

Delivery Method:

Equation 6.17: $\widetilde{D}_{11} = \frac{10}{10} = 1$

Equation 6.18: $\widetilde{D}_{12} = \frac{10}{10} = 1$

Equation 6.19: $\widetilde{D}_{13} = \frac{10}{10} = 1$

Reputation:

Equation 6.20: $\tilde{R}_{11} = \frac{2.22}{2.22} = 1$

Equation 6.21: $\tilde{R}_{12} = \frac{2.19}{2.22} = 0.9864$

Equation 6.22: $\tilde{R}_{13} = \frac{1.08}{2.22} = 0.486$

Table 6.10: Service 1 (design) before and after normalisation

Service 1: Design (Before Normalisation)				
Supplier	Quality	Cost (£)	Reputation	Delivery Method
1	4.43	18,000	2.22	10
2	4.78	21,000	2.19	10
3	4.94	20,000	1.08	10
Service 1: Design (After Normalisation)				
Supplier	Quality	Cost (£)	Reputation	Delivery Method
1	0.8976	1.00	1.00	1.00
2	0.9674	0.8571	0.9864	1.00
3	1.00	0.90	0.4864	1.00

6.4.3 Suppliers Historical Dynamic Data

As explained in Chapter 3, a learning module is one of the major aspects of the proposed framework to help the system to learn from the suppliers' past performance. After submitting proposals for criteria, such as quality, cost, time and delivery method, the memory function and learning algorithms provide the post-contract assessment of the supplier's performance. This management system requires 'Average Quality Compliance (AQC)' level and 'Average Time Over-run' (ATO) percentage. However, providing this kind of information requires lengthy assessments through a supplier's performance over time within a CM platform, these data will be available over the period CM system is working. Table 6.11 shows assumptions on the quality compliance level and time over-run percentage information for suppliers 1 to 23 in regard to Services 1 to 5. AQC and ATO, then, are used in mathematical formulae – as explained earlier in Chapter 3 - to transform the normalised metric values in the model.

Additionally, suppliers' historical dynamic data for Services 6 to 29 are available in Appendix 3.

Table 6.11: Suppliers historical dynamic data for service 1 to 5

	Suppliers	AQC (0 to 1) where 1 is best	ATO (0 to 1) where 0 is best
Service 1 Design	1	0.90	0.09
	2	0.95	0.10
	3	0.92	0.14
Service 2 Panel	4	0.95	0.11
	5	0.87	0.10
	6	0.92	0.07
	7	0.9	0.20
	8	0.85	0.15
Service 3 Electrical Motor	9	0.75	0.03
	10	0.89	0.16
	11	0.92	0.20
	12	0.93	0.13
	13	0.95	0.10
Service 4 Air-end	14	0.89	0.05
	15	0.95	0.14
	16	0.96	0.20
Service 5 Hose	17	0.94	0.09
	18	0.90	0.17
	19	0.87	0.04
	20	0.96	0.19
	21	0.91	0.08
	22	0.93	0.10
	23	0.94	0.20

6.5 Project Time Planning and Precedence Relationships

The compressed air system project consisted of four manufacturing processes, namely, design, part-sourcing, assembly, and delivery respectively. There are both sequential and parallel relationships among all services through the project (see Figure 6.3).

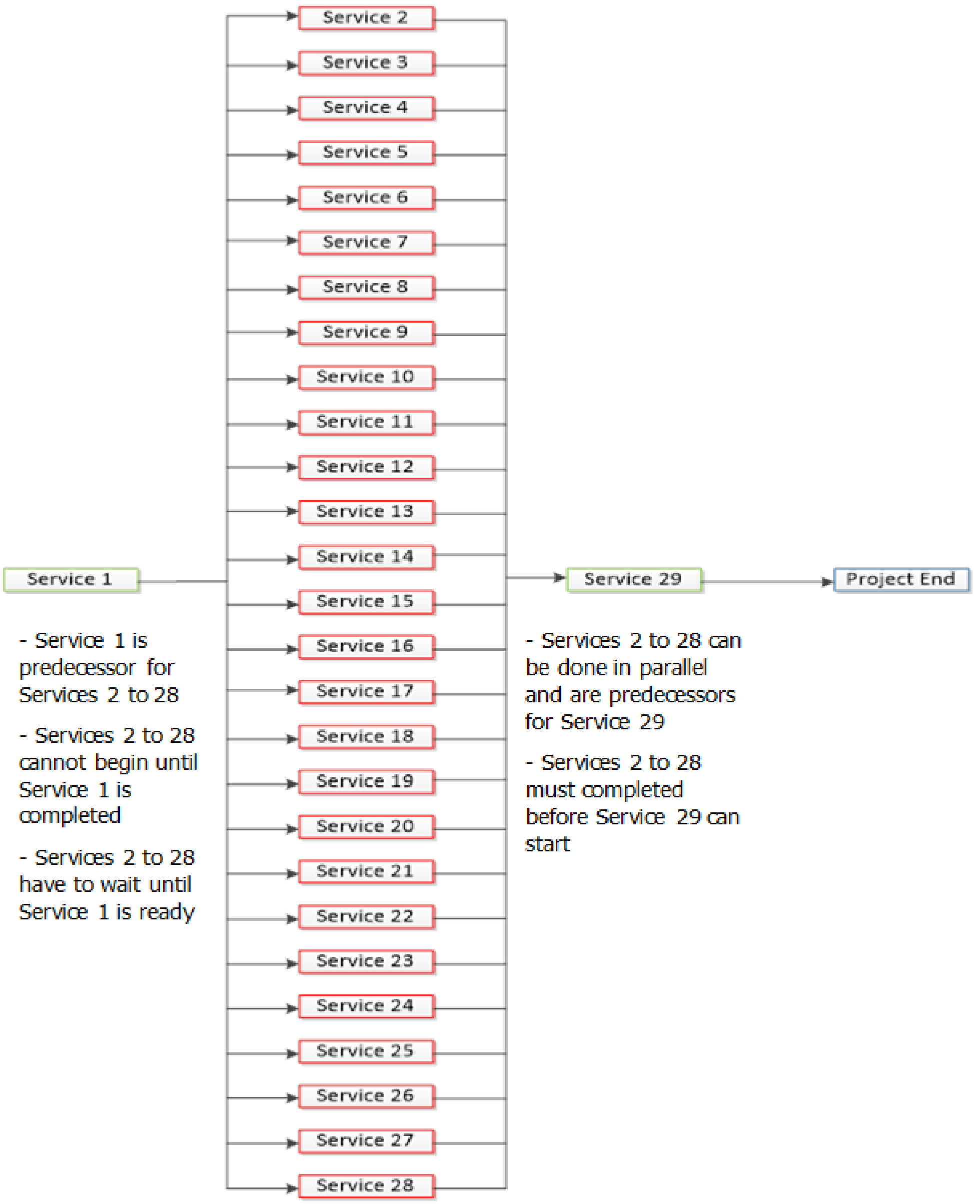

Figure 6.3: Inter-connected services and predecessors

According to Figure 6.3, Services 2 to 28 have to wait until Service 1 is completed. This means Service 1 is the predecessor for Services 2 to 28. On the other hand, Service 29 can only start when Services 2 to 28 are completed, which shows Services 2 to 28 have a parallel relationship and count as predecessors for Service 29 (see Table 6.12).

Table 6.12: Precedence relationships between services in the project

<table>
<tr><th>Services</th><th>Immediate Predecessor Services</th><th>Services</th><th>Immediate Predecessor Services</th><th>Services</th><th>Immediate Predecessor Services</th></tr>
<tr><td>1</td><td>-</td><td>20</td><td>1</td><td>29</td><td>12</td></tr>
<tr><td>2</td><td>1</td><td>21</td><td>1</td><td>29</td><td>13</td></tr>
<tr><td>3</td><td>1</td><td>22</td><td>1</td><td>29</td><td>14</td></tr>
<tr><td>4</td><td>1</td><td>23</td><td>1</td><td>29</td><td>15</td></tr>
<tr><td>5</td><td>1</td><td>24</td><td>1</td><td>29</td><td>16</td></tr>
<tr><td>6</td><td>1</td><td>25</td><td>1</td><td>29</td><td>17</td></tr>
<tr><td>7</td><td>1</td><td>26</td><td>1</td><td>29</td><td>18</td></tr>
<tr><td>8</td><td>1</td><td>27</td><td>1</td><td>29</td><td>19</td></tr>
<tr><td>9</td><td>1</td><td>28</td><td>1</td><td>29</td><td>20</td></tr>
<tr><td>10</td><td>1</td><td>29</td><td>2</td><td>29</td><td>21</td></tr>
<tr><td>11</td><td>1</td><td>29</td><td>3</td><td>29</td><td>22</td></tr>
<tr><td>12</td><td>1</td><td>29</td><td>4</td><td>29</td><td>23</td></tr>
<tr><td>13</td><td>1</td><td>29</td><td>5</td><td>29</td><td>24</td></tr>
<tr><td>14</td><td>1</td><td>29</td><td>6</td><td>29</td><td>25</td></tr>
<tr><td>15</td><td>1</td><td>29</td><td>7</td><td>29</td><td>26</td></tr>
<tr><td>16</td><td>1</td><td>29</td><td>8</td><td>29</td><td>27</td></tr>
<tr><td>17</td><td>1</td><td>29</td><td>9</td><td>29</td><td>28</td></tr>
<tr><td>18</td><td>1</td><td>29</td><td>10</td><td rowspan="2">Project</td><td rowspan="2">29</td></tr>
<tr><td>19</td><td>1</td><td>29</td><td>11</td></tr>
</table>

As discussed in section 6.2.1, the assembly activity related to the compressed air system is not outsourced and is performed by skilled labourers within the firm.

In order to take this internal activity into account, assembly time must be deducted from the total project time (see Figure 6.4). The assembly stage of the compressed air system project is planned to take 30 days.

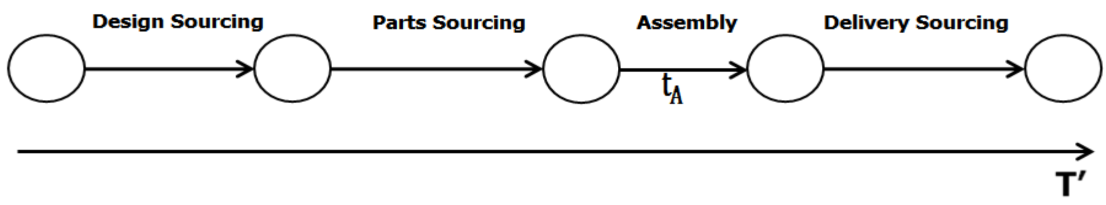

Figure 6.4: Project completion time

Hence, below the formulation is presented to measure time in project.

Equation 6.23: $T = T' - t_A$

Where T denotes the entire outsourcing time in the project (Services 1 to 29), T' denotes the total project time, and t_A denotes the assembly time.

In this case study, the company has set a total deadline 135 days to finish the whole project. Considering the assembly time estimate of 30 days, the remaining 105 days is set as the time target for the whole outsourcing project.

6.6 Eligibility Screening

Havayar Co Group company have set some thresholds on the specifications of proposals received, based on which they conduct eligibility screening. These thresholds have been set - through discussions in the committees - as a company's procurement policy. Those suppliers filtered out will not proceed to the optimisation stage.

The company's thresholds are:

a) minimum acceptable level of quality = 0.6
b) minimum acceptable level of delivery method score = 4

Accordingly, seven of the suppliers proposals were rejected, as shown in table 6.13.

Table 6.13: Suppliers proposals filtered out as a result of 'Eligibility Screening'

Service	Supplier	Quality score	Delivery method score
6	28	0.854	2
7	31	0.907	2
8	36	0.906	2
8	37	0.520	6
8	40	0.862	2
14	74	0.784	2
27	105	1.00	2

6.7 Dominance Screening

'Dominance Screening' step is performed to filter out those suppliers proposals that cannot match any of the other proposals from all the criteria's perspectives. This is again a pre-processing step, which could reduce the problem size resulting in a faster, less complicated problem-solving.

In this case study, the dominance screening was implemented using an Excel©-based Macro code that pre-processes the input data and filters out those proposals dominated by others. Accordingly, four of the supplier proposals were rejected, as shown in Table 6.14.

Table 6.14: Suppliers proposals filtered out as a result of 'Dominance Screening'

Service	Supplier	Quality Score	Cost (£)	Reputation Score	Delivery Method Score	Time
5	19	3.80	95	0.61	6	8.32
7	29	3.34	1400	0.51	8	26.62
22	85	4.10	7	0.20	6	33.90
25	98	3.97	48	0.43	6	11.30

As a result of the above two screening steps, 117 proposals, and 97 suppliers remain as acceptable to be fed into the optimisation module, which is explained in the next section.

6.8 Optimisation Model

The mathematical optimisation model with regard to the collected data from Havayar Co Group, such as suppliers proposals, suppliers information, and criteria weights suggested by the management, consists of a number of formulation components. The proposed formulation is based on a 'Goal Mixed-Integer 0-1 Programming' method, for the suppliers selection part, and a 'Linear Programming' method for the project planning part, which must be mathematically minimised as follows:

6.8.1 Decision Variables

The general definition of decision variables used in the case project are as follows:

y_{ij}: *Equals to 1 if supplier* i *for service* j *is selected and 0 if otherwise* $i = 1, \dots, 97$ and $j = 1, \dots, 29$

d_{jk}: *Negative deviation from goal on criteria* k *with regards to the* j*th service* $j = 1, \dots, 29$ & $k = 1, \dots, 4$

$\ddot{d}_T$*: Negative deviation from goal on criteria 'Time' with regards to the whole project*

S_e *: the starting time of service e in the project* $e = 1, \dots, 29$

S_{PE} *: Project End time*

As a result, the proposed model consists of totally 264 decision variables, including 117 supplier selection variables, 117 deviation variables, and 30 project planning variables.

6.8.2 Objective Function

The general formulation of the objective function, as presented earlier in chapter three, is:

Equation 6.24: Min. Z = $\sum_{j=1}^{J}\sum_{k=1}^{K-1}(w_{jk} \times d_{jk}) + \frac{J \times \ddot{w}_T \times \ddot{d}_T}{T}$

Where,

w_{jk} : the relative weight assigned by the client (PD) to the criteria k (Table 6.7) with regard to the jth service.

The formulation of the objective function for the case project is as follows:

Equation 6.25: $\boldsymbol{Min.z = (3d_{1,1} + 3d_{2,1} + 3d_{3,1} + 3d_{4,1} + 3d_{5,1} + 3d_{6,1} + 3d_{7,1} + 3d_{8,1} + 3d_{9,1} + 3d_{10,1} + 3d_{11,1} + 3d_{12,1} + 3d_{13,1} + 3d_{14,1} + 3d_{15,1} + 3d_{16,1} + 3d_{17,1} + 3d_{18,1} + 3d_{19,1} + 3d_{20,1} + 3d_{21,1} + 3d_{22,1} + 3d_{23,1} + 3d_{24,1} + 3d_{25,1} + 3d_{26,1} + 3d_{27,1} + 3d_{28,1} + 3d_{29,1}) + (1d_{1,2} + 1d_{2,2} + 1d_{3,2} + 1d_{4,2} + 1d_{5,2} + 1d_{6,2} + 1d_{7,2} + 1d_{8,2} + 1d_{9,2} + 1d_{10,2} + 1d_{11,2} + 1d_{12,2} + 1d_{13,2} + 1d_{14,2} + 1d_{15,2} + 1d_{16,2} + 1d_{17,2} + 1d_{18,2} + 1d_{19,2} + 1d_{20,2} + 1d_{21,2} + 1d_{22,2} + 1d_{23,2} + 1d_{24,2} + 1d_{25,2} + 1d_{26,2} + 1d_{27,2} + 1d_{28,2} + 1d_{29,2}) + (3d_{1,3} + 3d_{2,3} + 3d_{3,3} + 3d_{4,3} + 3d_{5,3} + 3d_{6,3} + 3d_{7,3} + 3d_{8,3} + 3d_{9,3} + 3d_{10,3} + 3d_{11,3} + 3d_{12,3} + 3d_{13,3} + 3d_{14,3} + 3d_{15,3} + 3d_{16,3} + 3d_{17,3} + 3d_{18,3} + 3d_{19,3} + 3d_{20,3} + 3d_{21,3} + 3d_{22,3} + 3d_{23,3} + 3d_{24,3} + 3d_{25,3} + 3d_{26,3} + 3d_{27,3} + 3d_{28,3} + 3d_{29,3}) + (1d_{1,4} + 1d_{2,4} + 1d_{3,4} + 1d_{4,4} + 1d_{5,4} + 1d_{6,4} + 1d_{7,4} + 1d_{8,4} + 1d_{9,4} + 1d_{10,4} + 1d_{11,4} + 1d_{12,4} + 1d_{13,4} + 1d_{14,4} + 1d_{15,4} + 1d_{16,4} + 1d_{17,4} + 1d_{18,4} + 1d_{19,4} + 1d_{20,4} + 1d_{21,4} + 1d_{22,4} + 1d_{23,4} + 1d_{24,4} + 1d_{25,4} + 1d_{26,4} + 1d_{27,4} + 1d_{28,4} + 1d_{29,4}) + 87\ddot{d}_T/105}$

6.8.3 Constraints

There are three sets of constraints, namely ‘Goal Constraints’, ‘Supplier Selection Constraints’, and ‘Project Scheduling Constraints’. In total, there are 341 constraints related to the current project, including 117 goal constraints, 29 supplier selection constraints, and 195 project planning constraints. In the following section, some constraints are formulated while the rest are available in Appendix 6.

6.8.3.1 Goal Constraints

Goal constraints are consisted of 117 constraints with regard to 29 services and five criteria. For instance, goal constraints in regard to services 1, 2, and 29, as well as the 'Time' goal constraint are shown below.

Service 1:

Equation 6.26: Quality: (1) $0.81y_{1,1} + 0.92y_{2,1} + 0.92y_{3,1} + d_{1,1} = 1.0$

Equation 6.27: Reputation: (2) $1y_{1,1} + 0.99y_{2,1} + 0.49y_{3,1} + d_{1,2} = 1.0$

Equation 6.28: Cost: (3) $1y_{1,1} + 0.86y_{2,1} + 0.9y_{3,1} + d_{1,3} = 1.0$

Equation 6.29: Delivery method: (4) $1y_{1,1} + 1y_{2,1} + 1y_{3,1} + d_{1,4} = 1.0$

Service 2:

Equation 6.30: Quality: (5) $0.81y_{4,2} + 0.83y_{5,2} + 0.82y_{6,2} + 0.9y_{7,2} + 0.83y_{8,2} + d_{2,1} = 1.0$

Equation 6.31: Reputation: (6) $0.61y_{4,2} + 0.77y_{5,2} + 0.79y_{6,2} + 0.43y_{7,2} + 1y_{8,2} + d_{2,2} = 1.0$

Equation 6.32: Cost: (7) $0.72y_{4,2} + 0.45y_{5,2} + 1y_{6,2} + 0.36y_{7,2} + 0.6y_{8,2} + d_{2,3} = 1.0$

Equation 6.33: Delivery method: (8) $0.8y_{4,2} + 1\,y_{5,2} + 0.6y_{6,2} + 0.8y_{7,2} + 0.8y_{8,2} + d_{2,4} = 1.0$

.

Service 29:

Equation 6.34: Quality: (113) $0.9y_{106,29} + 0.87y_{107,29} + 0.92y_{108,29} + d_{29,1} = 1.0$

Equation 6.35: Reputation: (114) $0.74y_{106,29} + 1y_{107,29} + 0.67y_{108,29} + d_{29,2} = 1.0$

Equation 6.36: Cost: (115) $0.92y_{106,29} + 1y_{107,29} + 0.8y_{108,29} + d_{29,3} = 1.0$

Equation 6.37: Delivery method: (116) $0.8y_{106,29} + 0.6y_{107,29} + 1y_{108,29} + d_{29,4} = 1.0$

Equation 6.38: T (whole project time): (117) $S_{PE} - \ddot{d}_T = 105$

6.8.3.2 Suppliers Selection Constraints

Supplier selection constraints are consisted of 29 constraints in regard to 29 services, a sample of which is shown below while the complete set can be found in Appendix 6.

Equation 6.39: Service 1: (118) $y_{1,1} + y_{2,1} + y_{3,1} = 1.0$

Equation 6.40: Service 2: (119) $y_{4,2} + y_{5,2} + y_{6,2} + y_{7,2} + y_{8,2} + y_{7,1} + y_{8,1} = 1.0$

Equation 6.41: Service 3: (120) $y_{9,3} + y_{10,3} + y_{11,3} + y_{12,3} + y_{13,3} = 1.0$

Equation 6.42: Service 4: (121) $y_{14,4} + y_{15,4} + y_{16,4} = 1.0$

Equation 6.43: Service 5: (122) $y_{17,5} + y_{18,5} + y_{19,5} + y_{20,5} + y_{21,5} + y_{22,5} + y_{23,5} = 1.0$

Equation 6.44: Service 6: (123) $y_{24,6} + y_{25,6} + y_{26,6} + y_{27,6} + y_{28,6} = 1.0$

Equation 6.45: Service 7: (124) $y_{29,7} + y_{30,7} + y_{31,7} + y_{32,7} + y_{33,7} + y_{34,7} = 1.0$

.

Equation 6.46: Service 29: (146) $y_{106,29} + y_{107,29} + y_{108,29} = 1.0$

6.8.3.3 Project Planning Constraints

This includes 195 constraints that represent the precedence relationships in the project. A sample is shown below, while the complete set is available in Appendix 6.

Equation 6.47: (147) $S_1 + 55.95y_{1,1} \leq S_2$

Equation 6.48: (148) $S_1 + 55y_{2,1} \leq S_2$

Equation 6.49: (149) $S_1 + 68.4y_{3,1} \leq S_2$

Equation 6.50: (150) $S_1 + 55.95y_{1,1} \leq S_3$

Equation 6.51: (151) $S_1 + 55y_{2,1} \leq S_3$

Equation 6.52: (152) $S_1 + 68.4y_{3,1} \leq S_3$

Equation 6.53: (153) $S_1 + 55.95y_{1,1} \leq S_4$

Equation 6.54: (154) $S_1 + 55y_{2,1} \leq S_4$

Equation 6.55: (155) $S_1 + 68.4y_{3,1} \leq S_4$

Equation 6.56: (156) $S_1 + 55.95y_{1,1} \leq S_5$

Equation 6.57: (157) $S_1 + 55y_{2,1} \leq S_5$

Equation 6.58: (158) $S_1 + 68.4y_{3,1} \leq S_5$

.

Equation 6.59: (228) $S_2 + 11.1y_{4,2} \leq S_{29}$

Equation 6.60: (229) $S_2 + 7.7y_{5,2} \leq S_{29}$

Equation 6.61: (230) $S_2 + 6.42y_{6,2} \leq S_{29}$

Equation 6.62: (231) $S_2 + 16.8y_{7,2} \leq S_{29}$

Equation 6.63: (232) $S_2 + 9.2y_{8,2} \leq S_{29}$

Equation 6.64: (233) $S_3 + 18.54y_{9,3} \leq S_{29}$

Equation 6.65: (234) $S_3 + 24.36y_{10,3} \leq S_{29}$

Equation 6.66: (235) $S_3 + 24y_{11,3} \leq S_{29}$

Equation 6.67: (236) $S_3 + 28.25y_{12,3} \leq S_{29}$

Equation 6.68: (237) $S_3 + 19.8y_{13,3} \leq S_{29}$

.

Equation 6.69: (339) $S_{29} + 16.8y_{106,29} \leq S_{PE}$

Equation 6.70: (340) $S_{29} + 19.62y_{107,29} \leq S_{PE}$

Equation 6.71: (341) $S_{29} + 22.23y_{108,29} \leq S_{PE}$

6.8.3.4 Non-negativity and Variable Types

$d_{jk} \geq 0 \quad \forall \ j = 1, \dots, 29 \ \& \ k = 1, \dots, 4$

$\ddot{d}_T \geq 0$

$y_{ij} = 0 \ or \ 1 \quad \forall \ i = 1, \dots, 108 \ \& \ j = 1, \dots, 29$

$S_e \geq 0 \quad \forall e = 1, \dots, 29$

$S_{PE} \geq 0$

6.9 Software Optimisation (What'sBest©) and Final Results

All project data were entered into a web-based user-interface system developed in this research, so-called 'OPTiSupply.uk®', as explained later in the next chapter. The web-based system is also responsible for generating data worksheets in the MS-Excel© format. It took OPTiSupply.uk® 25 minutes to generate the worksheets. It also communicates directly with an Excel-based mathematical programming software known as 'What'sBest©' (WB). This means that the OPTiSupply.uk® is able to call WB commands indirectly, allowing the user to run the model from within OPTiSupply.uk® platform. Model running with WB took 1 second using a computer with following specification:

- Processor: Intel(R Core™), I7-4500U CPU@, 1.80GHz
- Installed memory(RAM): 8.00 GB

Table 6.15 shows the final results obtained by using WB software for all 29 services.

Table 6.15: Final results in regard to the baseline scenario

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	32	850	21.66	0.722364	1	0.75
Service 8	42	85	21.6	0.91	1	0.6
Service 9	43	200	21.8	0.839555	0.573234	0.666667
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	81	80	11.1	0.94	0.740659	0.75
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	86	6	21.8	0.787052	0.564317	0.75
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	102	18	14.04	0.808387	0.186265	1
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1,300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 36,903	Project finishing time= 108.55	Average quality= 0.860943	Average reputation= 0.859406	Average delivery method= 0.817816

6.10 Analysis of Results

According to Table 6.15, Suppliers 2, 6, 9,14, 17, 25, 32, 42, 43, 51, 52, 58, 63, 68, 75, 80, 81, 84, 86, 94, 96, 99, 102, and 106 have been chosen to provide services related to the compressed air system production at the total cost of £36,903. The average score of quality, reputation, and delivery mothed is 0.86, 0.86, and 0.82 respectively. The time duration to complete these 29 services is 109 days. As explained in Section 6.5, assembly time must be considered in measuring the project completion time. Hence, the total project completion time will be 139 (=109+30) days. This means that, given the current input data and the set of weights assigned to each criterion, the project can only be finished 4 days later than the planned deadline.

Also, services 1, 4 and 29 constitute the critical path; hence a careful attention should be given to these three services. For instance, one might decide to enter into further negotiations with the selected suppliers of these three critical services to secure a timely or even an early delivery.

While the average reputation score is rather low, it can be explained by the fact that its weight was set relatively low, namely one, against three other criteria namely quality, cost and time, all of which had a weight of three.

6.10.1 Sensitivity Analysis

One of the advantages of the solution approach applied in this research is that it is not considered to be highly parametric. The only parameters involved are criteria weights, which are essential to a multi-criteria approach. Here in this section, sensitivity of the model results to the criteria weights are measured and analysed.

6.10.1.1 Quality - Scenario no.1 - (Quality weight=1)

Table 6.16: Quality weight =1

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	32	850	21.66	0.722364	1	0.75
Service 8	40	65	16.52	0.766848	0.941176	0.2
Service 9	43	200	21.8	0.839555	0.573234	0.666667
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	81	80	11.1	0.94	0.740659	0.75
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	86	6	21.8	0.787052	0.564317	0.75
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	104	20	11	0.73428	1	0.6
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 36,885	Project finishing time= 108.55	Average quality= 0.853451	Average reputation= 0.885438	Average delivery method= 0.79023

Two services, namely cabin (Service 8) and safety valve (Service 27), have now been allocated to two new suppliers, namely suppliers 40 and 104, respectively.

Analysis:

1) Both new suppliers have poorer quality scores, which can be explained by the lower quality weight.
2) Average quality score is reduced from 0.8609 to 0.8534, which can be explained by lower quality weight.
3) Total cost is reduced from £36,903 to £36,885 because cost has now higher priority over three other criteria (quality, delivery method, and reputation).
4) Although reputation, cost and time results improved, delivery performance degraded. This means that the sensitivity of the model to the quality is at about moderate level.

Scenario no. 2 - Quality weight = 5

Table 6.17: Quality weight = 5

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	33	1,200	18.72	0.92	0.734409	1
Service 8	42	85	21.6	0.91	1	0.6
Service 9	43	200	21.8	0.839555	0.573234	0.666667
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	81	80	11.1	0.94	0.740659	0.75
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	88	10	19.36	0.930149	1	1
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	102	18	14.04	0.808387	0.186265	1
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 37,257	Project finishing time= 108.55	Average quality= 0.872692	Average reputation= 0.865272	Average delivery method= 0.835057

Two services, namely Radiator (Service 7) and piping (Service 23), have now been allocated to two new suppliers, namely suppliers 40 and 104, respectively.

Analysis:

1) Both new suppliers have better quality scores, which can be explained by the higher quality weight.
2) Average quality score is increased from 0.8609 to 0.8726, which can be explained by higher quality weight.
3) Total cost is increased from £36,903 to £37,257, because cost has now lower priority over quality criterion.

6.10.1.2 Cost

Scenario no. 3: Cost weight = 1

Table 6.18: Cost weight = 1

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	8	600	9.2	0.829394	1	0.8
Service 3	13	2,200	19.8	0.95	0.522807	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	33	1,200	18.72	0.92	0.734409	1
Service 8	42	85	21.6	0.91	1	0.6
Service 9	45	320	19.98	0.7968	1	0.888889
Service 10	50	240	9.28	0.881296	1	1
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	77	300	20.7	0.9	0.774046	1
Service 17	82	100	14.69	0.892707	1	1
Service 18	50	240	9.28	0.881296	1	1
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	83	6	28.75	0.88614	1	1
Service 23	88	10	19.36	0.930149	1	1
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	104	20	11	0.73428	1	0.6
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1,300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 38,761	Project finishing time= 108.55	Average quality= 0.875134	Average reputation= 0.938309	Average delivery method= 0.894444

11 services, namely Panel (Service 2), Electrical motor (Service 3), Radiator (Service 7) Water trap (Service 9), Shell plate (Service 10) Filter (Service 16), Shaft/Body (Service 17) Shell plate (Service 18), Shuttle valve (Service 22) Piping (Service 23), and Safety valve (Service 27), have now been allocated to 11 new suppliers, namely suppliers 8, 13, 33, 45, 50, 77, 82, 50, 83, 88, and 104 respectively.

Analysis:

1) Average quality score is increased from 0.8609 to 0.8751 which can be explained by a higher quality weight compared to the cost weight.
2) Total cost is increased from £36,903 to £38761, because cost has now lower priority over three other criteria (quality, delivery method, and reputation).

6.10.1.3 Reputation

Scenario no. 4: Reputation weight = 3

Table 6.19: Reputation weight = 1

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	32	850	21.66	0.722364	1	0.75
Service 8	42	85	21.6	0.91	1	0.6
Service 9	45	320	19.98	0.7968	1	0.888889
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	82	100	14.69	0.892707	1	1
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	83	6	28.75	0.88614	1	1
Service 23	88	10	19.36	0.930149	1	1
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	104	20	11	0.73428	1	0.6
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1,300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 37,051	Project finishing time= 108.55	Average quality= 0.85836	Average reputation= 0.938842	Average delivery method= 0.835824

Five services, namely Water trap (Service 9), Shaft/Body (Service 17), Shuttle valve (Service 22) Piping (Service 23), and Safety valve (Service 27) have now been allocated to five new suppliers, namely suppliers 45, 82, 83, 88, 50, and 104, respectively.

Analysis:

1) All five new suppliers have better reputation scores, which can be explained by the higher reputation weight.
2) Average quality score is marginally decreased from 0.8609 to 0.8583, which can be explained by the fact that the relative weight of quality against reputation has lowered.
3) Total cost is increased from £36,903 to £37,051 because the relative weight of cost against reputation has lowered.

6.10.1.4 Delivery Method

Scenario no. 5: Delivery method = 3

Table 6.20: Delivery method weight = 3

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	22	70	8.8	0.85829	0.453521	1
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	33	1,200	18.72	0.92	0.734409	1
Service 8	42	85	21.6	0.91	1	0.6
Service 9	44	280	18.36	0.827473	0.814693	0.888889
Service 10	50	240	9.28	0.881296	1	1
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	77	300	20.7	0.9	0.774046	1
Service 17	82	100	14.69	0.892707	1	1
Service 18	50	240	9.28	0.881296	1	1
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	88	10	19.36	0.930149	1	1
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	102	18	14.04	0.808387	0.186265	1
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1,300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost = 37,667	Project finishing time= 108.55	Average quality= 0.871715	Average reputation= 0.875143	Average delivery method= 0.901341

Seven services, namely hose(Service 5), Water trap (Service 9), shell plate(Service 10) filter (Service 16), shaft/body (Service 17), shell plate (Service18), and piping (Service 23) have now been allocated to seven new suppliers, namely suppliers 22, 44, 50, 77, 82,50 and 88, respectively.

Analysis:

1) Average delivery method score has increased from 0.817816 to 0.901341, which can be explained by the higher delivery method weight.
2) Total cost is increased from £36,903 to £37,667 because the relative weight of cost against delivery method has lowered.

6.10.1.5 Time

Scenario no. 6: Time weight = 1

Table 6.21: Time weight = 1

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	2	21,000	55	0.919031	0.986486	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	32	850	21.66	0.722364	1	0.75
Service 8	42	85	21.6	0.91	1	0.6
Service 9	43	200	21.8	0.839555	0.573234	0.666667
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	81	80	11.1	0.94	0.740659	0.75
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	86	6	21.8	0.787052	0.564317	0.75
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	102	18	14.04	0.808387	0.186265	1
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	106	1,300	16.8	0.9	0.742391	0.8
Project Total	-	Total cost= 36,903	Project finishing time= 108.55	Average quality= 0.860943	Average reputation= 0.859406	Average delivery method= 0.817816

Analysis:

1) The model with this project network structure has no sensitivity on the time weight, because it is actually impossible to finish the project earlier than 109 days.

Scenario no. 7: Deadline = 125 days

Table 6.22: Project deadline = 125 days

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service 1	1	18,000	59.95	0.807851	1	1
Service 2	6	360	6.42	0.815919	0.787084	0.6
Service 3	9	1,400	18.54	0.702749	0.817544	0.75
Service 4	14	10,000	36.75	0.89	1	1
Service 5	17	80	6.54	0.855364	1	0.8
Service 6	25	190	17.4	0.88465	0.84507	0.8
Service 7	32	850	21.66	0.722364	1	0.75
Service 8	42	85	21.6	0.91	1	0.6
Service 9	43	200	21.8	0.839555	0.573234	0.666667
Service 10	51	120	8.54	0.880559	0.834789	0.5
Service 11	52	90	7.42	0.834554	1	1
Service 12	58	280	13.8	0.872758	1	1
Service 13	63	11	7.35	0.89	1	0.8
Service 14	68	22	8.88	0.810705	1	1
Service 15	75	5	13.2	0.913609	1	0.75
Service 16	80	220	24.36	0.873376	0.772519	0.75
Service 17	81	80	11.1	0.94	0.740659	0.75
Service 18	51	120	8.54	0.880559	0.834789	0.5
Service 19	52	90	7.42	0.834554	1	1
Service 20	58	280	13.8	0.872758	1	1
Service 21	63	11	7.35	0.89	1	0.8
Service 22	84	4	22.89	0.94	0.631883	0.8
Service 23	86	6	21.8	0.787052	0.564317	0.75
Service 24	94	4	20.06	0.869759	0.670943	1
Service 25	96	34	11	0.854433	0.934809	0.8
Service 26	99	38	16.35	0.86104	1	1
Service 27	102	18	14.04	0.808387	0.186265	1
Service 28	75	5	13.2	0.913609	1	0.75
Service 29	107	1,200	19.62	0.87327	1	0.6
Project Total	-	Total cost= 33,803	Project finishing time= 125	Average quality= 0.856187	Average reputation= 0.868755	Average delivery method= 0.81092

Two services, namely design (Service 1) and delivery (Service 29), have now been allocated to two new suppliers, namely suppliers 1 and 107, respectively.

Analysis:

1) Project finishing time is now extended to 125 days, which is still acceptable by the client.
2) Total cost is decreased significantly from £36,903 to £33,803 because the time deadline is now more relaxed. This gives opportunity to the model to find less expensive suppliers who are not necessarily very fast in delivering services.

Overall analysis:

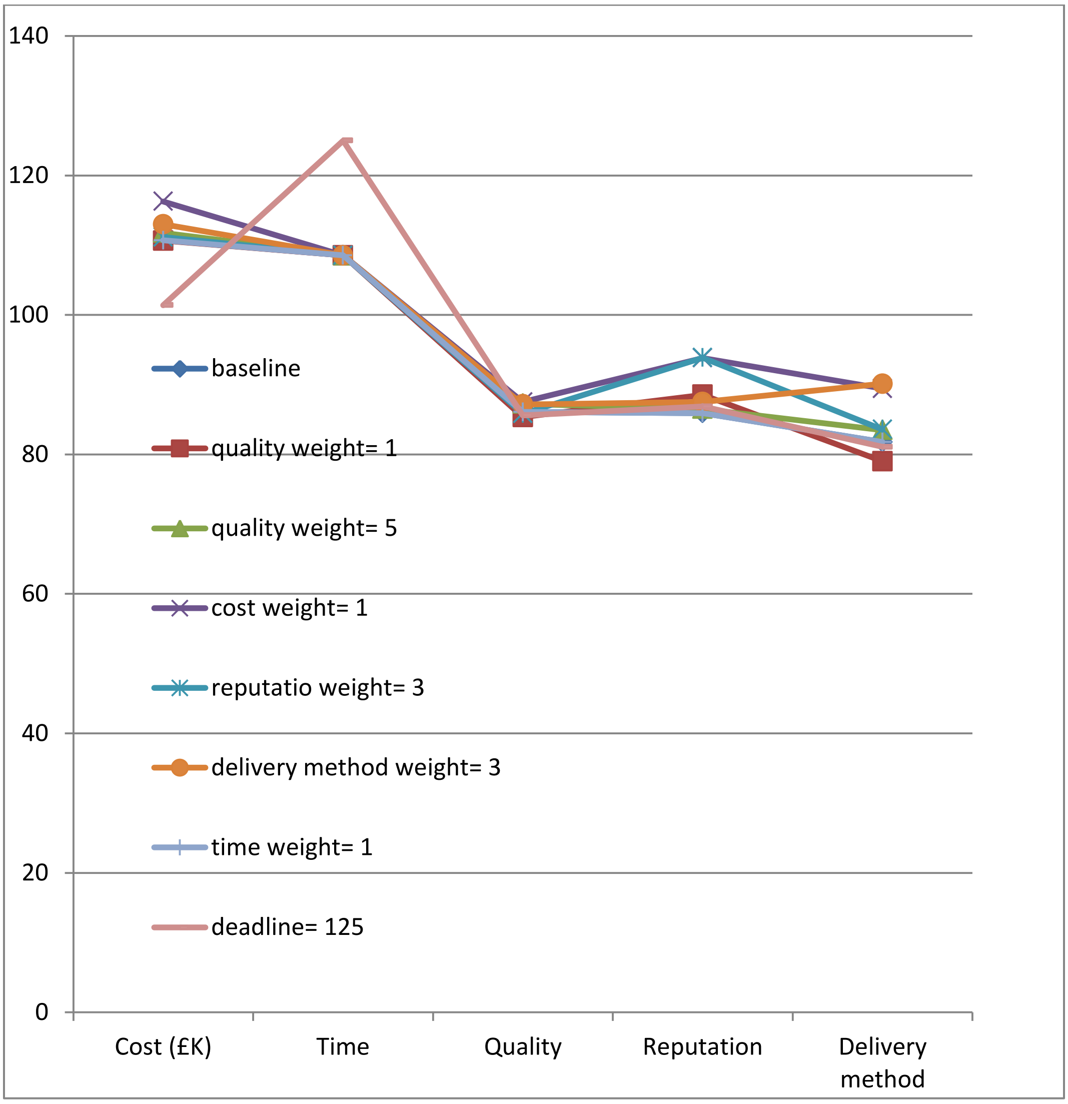

Figure 6.5: Different scenario comparison

*** (Cost: * 3/1000, Quality, Reputation and Delivery Method: *100)**

As shown in Figure 6.5, with regards to criteria weights, changes to the cost weight create results that are relatively more varied compared to the other experiments. This means that the cost criterion has more impacts on the final results. In other words, the model is more sensitive to the cost figures.

On the other hand, the model results express the least sensitivity to the changes on 'Quality weight' and 'Time weight'.

As a whole, however, changes to deadline from 105 to 125 days reflects a much more significant impact compared to changes to the weights in a scale of difference at two units. The impact of looser deadline is especially evident with regards to 'Cost' and 'Time', where cost is decreased over 8% and time is relaxed about 14%.

6.11 Summary

A project in Havayar Co Group in the oil and gas industry was identified as the case study to validate the methodology and the mathematical model. The optimum selection of suppliers for different activities involving the manufacture of compressed air system for the purpose of the Qeshm water and power co-generation plant constitutes another objective of this case study. The project is characterised with 29 services to outsource, in both sequential and parallel relationship, and 108 suppliers who submitted 128 proposals for these services, some of the suppliers submitting several proposals for different services.

Eligibility and dominance screening filtered out 7 and 4 proposals respectively. The results of the multi-criteria model for the baseline scenario generated a solution that suggests the project's finishing time four days late.

Sensitivity analyses on criteria weights proved that the model is valid. Also, it showed that the model is more sensitive to the cost criterion.

Finally, consultations with the company's staff in procurement department provided some reflections on the structure of criteria. This led to the suggestion of having 'Time' and 'Delivery' as two separate major criteria groups that represent 'time of delivery' and 'method of delivery' respectively, rather than as the sub-factors of a single criteria.

CHAPTER 7 CONCLUSIONS AND RECOMENDATIONS FOR FUTURE WORK

7.1 Overall Conclusions

An integrated approach to solve both project scheduling and supplier selection functions simultaneously within a single mathematical programming platform was developed. The proposed framework incorporated a holistic view to the problem addressed containing four modules, which covers all steps from criteria selection to learning from feedbacks. Such a holistic view has not been previously presented in the literature.

An 'expert opinion' survey along with the case study validation, resulted in the selection of five criteria, namely a) cost/price, b) quality, c) delivery time, d) delivery method, and e) reputation/trust. The current research identified seven metrics to measure each supplier proposal quantitatively.

A novel formulation of the problem was developed using the 'Goal Integer 0-1 Programming' method' and the 'Linear Programming' method for supplier selection and project scheduling parts, respectively.

Model running and optimum solution generation on a real case study in the oil and gas industry took only one second on an i7 computer, which proves that the model is computationally efficient.

7.2 Fulfilment of the Project Objectives

Moving from traditional product-orientated manufacturing to a service-orientated type provides new manufacturing solutions to achieve cost-effective, manufacturing systems. However, the research on cloud based manufacturing approach is still in its infancy and has a long way to go before it is adopted and perfectly executed.

This study addressed the strategic significance of suppliers selection approach in CM context by emphasising on different criteria such as quality, cost, reputation, delivery method, and delivery time. This chapter first presents the fulfilment of the research objectives. Then, this is followed by contributions to knowledge, and recommendations for future work.

As outlined in chapter one, four main objectives were defined for this research. Below, fulfilment of the objectives is explained.

1. **To review the literature on CM, and suppliers selection methods**

This objective was covered by Chapters 1 and 2.First, in Chapter 1, the historical trend of the emergence of CM and key concepts such as Supply Chain Management (SCM), Agile Manufacturing (AM), Manufacturing Grid (MGrid), Networked Manufacturing (NM), Cloud Computing (CC) and the analysis of all mentioned approaches have been discussed. This was followed by the emergence of CM, its advantages and challenges.

Then in chapter two, the concept of suppliers selection in manufacturing sectors was discussed, followed by a review of various criteria selection over four periods of time, 'until 1966', '1966 to 1991', '1991 to 2001', and '2001 to present'. In addition, different types of suppliers selection methods, advantages and limitations have been discussed in detail in the second part of this chapter. This literature review managed this project to identify the most appropriate method. Individual methods such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Mathematical Programming (MP), Data Envelopment Analysis DEA), Goal Programming GP), Linear Programming (LP), and Integer Programming (IP) were reviewed comprehensively followed by integrated (mixed) methods. The third part of this chapter included the concept of project management and project network plan development. Mainly, Activity on Node (AON) network diagram have been presented.

2. **To develop a methodology framework that takes into account the characteristics of CM context, such as 'dynamic process', and 'global size'**

This objective is covered in Chapter 3 containing the proposed framework from a high-level perspective with some details of the framework as elements of the overall picture. This chapter also included consideration of the multi-criteria module, the bidding module, the optimisation module, and the learning module.

As a part of the multi-criteria module, five criteria and seven metrics were identified, a normalisation method based on comparison with the best value was adopted to convert the metric values into a unified scale, and the Simple Additive Weighting (SAW) method was adopted to combine various metrics together. In the Bidding module, 'Online Reverse Auction' model was adopted in line with the ultimate goal of CM towards a global made-to-order crowdsourcing platform. RFPs and proposals were managed by the platform. Furthermore, two primary processes, namely Eligibility Screening and Dominance Screening, were developed to filter out those proposals that can be shown from the start not to be able to meet eligibility requirements or to compete with others. The optimisation module, which works as the heart of the whole framework, faces several challenges, such as, complex time calculations in a full-scale project network structure. The novel approach was presented to develop an integrated mathematical model for suppliers selection optimisation and project time planning. Lastly, a learning module allows the model to learn about the suppliers past performance over the course of the system life. A feedback management system was designed in the platform to collect the client's views on two key criteria, namely 'quality' and 'delivery time'. Average performance measures were then calculated over a moving fixed period, results of which are stored in a 'dynamic memory' element as linked to the suppliers' database. The averages past performance measures are retrieved from the memory and are applied to the optimisation and screening algorithms through two proposed mathematical transformation formulations. In other words, it is a search engine platform where the engine is supposed to be used continuously, rather than in a one-off occasion, within the CM community. This feature allows the approach to take advantage of memory and learning functions.

3. **To identify and develop an appropriate set of criteria through conducting a literature review and an opinion survey.**

This objective is covered in Chapter 4 where existing literature was reviewed and 29 criteria were identified that could contribute to the suppliers selection function in general. The literature was assessed, and quantitative metrics were suggested for criteria. Then a survey was designed and administered online for two weeks to elicit domain experts' opinions on the candidate criteria and metrics. In conclusion, four important criteria and seven metrics were suggested by the experts to measure the competencies of suppliers proposals. Further investigations through the case study provided reflections as to split one criterion into two; hence five criteria were selected.

4. **To identify and develop an appropriate type of mathematical programming method suitable for 'multi-criteria decision making' problems.**

The development of mathematical programming, including both goal and mixed-integer programming, as a main research method was discussed in Chapter 5. The general format of the optimisation model followed a Goal Programming structure to deal with the multi-criteria nature of the problem. More specifically, a Mixed Integer (0-1) Linear Programming model was developed to address the other characteristics of the problem. Lastly, a numerical example, including three services as part of a project, was presented in order to show the developed mathematical model.

5. **To define a typical CM setting as a case study with reference to:**
   - **Client industry**
   - **Nature of client business**
   - **Nature of product ordered; and**
   - **Period of orders.**

This objective is covered in Chapter 6. The Havayar Co Group, who were responsible for designing, manufacturing, and delivering an industrial compressed air system for a 'water and power co-generation plant' project in Iran, is identified to cover all aspects of the current research and validate the proposed methodology.

6. **To develop an intelligent web-based suppliers selection system under CM concept.**

In Chapter 7, OPTiSupply.uk® as a web-based suppliers selectin system was presented. To design and develop the OPTiSupply.uk®, various popular programming languages, technologies, platforms, and software were used, such as, C#, Visual Basic (VB), .NET Frame work, ASP, HTML, CSS, SQLite (database engine), Office Programming, Excel Forums, and What's Best (WB).

7.3 Research Contributions

The innovations and major contributions to knowledge from this study are summarised as followings:

- Developing a framework including multi-criteria module, bidding module, optimisation module, and learning module which collectively operate within the CM context and characteristics.
- Identifying five significant supplier selection criteria, including quality, cost, time, reputation, and delivery method, in the CM context while addressing the requirements of quantitative analysis.
- Developing the mathematical modelling in integration with project network planning and the supplier selection optimisation, which are applicable to the CM based selection system.
- Design and development of innovative web-based system for supplier selection, which is suitable with a CM orientated interactive function and able to integrate with the external optimisation software.

7.4 Recommendations for Future Work

In this research, due to nature of cloud based manufacturing, the main focus was on selecting best suppliers for manufacturing industries. Although the proposed methodology, especially web-based system, can be applied for various manufacturing and industrial sectors such as oil and gas and automotive, it is anticipated that the same proposed methodology, probably with very minor changes, could also be applicable for non-manufacturing sectors or businesses such as health care sector. Whereas for some industries, for example aviation, new criteria such as security checks or high level machinery need to be considered in the system, it should be noted that this project studied and collected generic criteria in order to be applicable for a large spread of different industries.

As explained in Chapter 7, the slow speed of calculations in the web-based system might be seen as a drawback of the system. In fact, pre-processes associated with the generation of model could slow down the final calculations.

Hence, it is suggested that the 'LINDO API' optimisation software is used instead of WB software. In fact, Lindo API is more suitable for web-based applications and can deliver final results faster to web customers.

The optimisation model assumes that splitting a service or an order among more than a single supplier is not allowed. For example, if a company required 10,000 of nozzles, all nozzles should be supplied by one supplier. It means that it is not allowed for one supplier to provide 5000 and another supplier to provide the rest. Hence, two different suppliers are not allowed to provide this amount of nozzles. Future work can also focus on relaxing this assumption. This could be justifiable for very large projects, where services, for various relevant reasons, need to be provided by several suppliers. Under these circumstances, the model needs to decide about the share of each supplier as well. Therefore, the numbers of variables are increased and make the problem solving more sophisticated.

Finally, the OPTiSupply.uk® is considered as an educational website, not a commercial one. Obviously, this research should be followed by commercialisation efforts before the system can be implemented.

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Appendices

Appendix 1: Questionnaire

SURVEY QUESTIONNAIRE ON SUPPLIER SELECTION IN THE CONTEXT OF CLOUD MANUFACTURING

INTRODUCTION

Cloud Manufacturing (CM) refers to a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource allocation in response to variable-demand customer generated tasking*. In such environment where the scope of the market is global and the scale of the daily orders is vast and on-going, 'Supplier Selection' function becomes a challenging one.
This survey aims to collect and analyse expert opinions on supplier evaluation and selection metrics in the context of Cloud Manufacturing.

The main part of this questionnaire includes only 8 questions. The title of the metrics will be followed by their main characteristics in the questionnaire. Please express your opinion by ticking the box against your choice of metric. This online tool allows you to save an incomplete questionnaire and continue on the same computer later by simply clicking on the same link provided. Your participation in this survey is entirely on a voluntary basis, but highly appreciated. If you would like a copy of the survey results, please contact Mr. Soheil Hassanzadeh at the address below.
You can choose not to enter your personal information, but if you do, please be assured that your personal information will be kept confidential and will not be disclosed in any shape or form.
Soheil Hassanzadeh (PhD candidate) and Dr. Richard Bateman,

Brunel University London, College of Engineering, Design and Physical Sciences, Department of Mechanical, Aerospace and Civil Engineering, Kingston Lane, Uxbridge, UB8 3PH, UK
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* Wu D, Greer MJ, Rosen DW, Schaefer D. (2013) Cloud manufacturing: strategic vision and state-of-the-art. J Manuf Syst., 32(4).

ABOUT YOU

1. The type of your organisation:

☐ Academic ☐ Industry ☐ Consultancy

☐ Other (please specify) ______

2. Please state your name and organisation. (OPTIONAL. If filled in, your personal details will be kept anonymous).

Name ______

Organisation ______

Criteria 1: QUALITY OF SERVICE

This criterion pertains to the quality of service provided by the suppliers.

Top of Form

3. Do you consider 'Quality of Service' being a criterion for supplier selection function in the context of Cloud Manufacturing?

Strongly Agree Agree Neutral Disagree Strongly Disagree

Don't Know

Your comment:

4. Please specify what single metric you would suggest to evaluate this criterion.

DEFECT RATE: a) Represents a quantitative performance measure of the service quality declared by the supplier. b) The quality measure will be linked to the defect rate via a relation, set by the client. c) It might not be quite applicable to all types of resources, such as intellectual ones.

A COMBINED SCORE: a) Represents an overall assessment of all the quality factors declared by the supplier. b) Can be linked to a few discrete quality levels similar to the Likert scales associated with a metric pre-defined by the clients. c) Each quality level can represent a combination of some quality factors and their attributes (Example: 1=Excellent quality system and 0% defect rate, 0.9=Excellent quality system and up to 2% defect rate, and so on.). d) The levels can be pre-set by the client. c) Applicable to all types of resources and capabilities inc. hardware, software and intellectual.

Other (please specify)

Criteria 2: DELIVERY/TIME

This criterion pertains to the timeliness of service delivery.

Top of Form

5. Do you consider 'Delivery/Time' being a criterion for supplier selection function in the context of Cloud Manufacturing?

Strongly Agree Agree Neutral Disagree Strongly Disagree

Don't Know

Your comment:

6. Please specify what metric you would suggest to evaluate this criterion.

DELIVERY TIME: a) Represents a quantitative performance measure of the service delivery time declared by the supplier. b) The measure will be linked to the delivery time via a relation, set by the client. c) It can incorporate both lateness and earliness of delivery.

A COMBINED SCORE: a) Represents an overall assessment of all the Delivery/Time factors declared by the supplier. b) Can be linked to a few discrete Delivery/Time levels similar to the Likert scales associated with a metric pre-defined by the clients. c) Each level can represent a combination of some Delivery/Time factors and their attributes (Example: 1=Delivery on the day of request with special delivery service, 0.9=Delivery at up to 2 days late or one day early with special delivery service, and so on.). d) The levels can be pre-set by the client.

Other (please specify)

Criteria 3: SUPPLIER'S REPUTATION/TRUST

This criterion pertains to the supplier's overall reputation over time, and could cover factors such as consistency, financial strength, management style, innovation, etc.

Top of Form

7. Do you consider 'Supplier's Reputation or Trust' being a criteria for supplier selection function in the context of Cloud Manufacturing?

Strongly Agree Agree Neutral Disagree Strongly Disagree

Don't Know

Your comment:

8. Please specify what Factor(s) you would suggest to represent this criteria.

SUPPLIER'S EXPERIENCE IN CLOUD MANUFACTURING: Represents the supplier's performance in the cloud manufacturing, rather than in the industry.

SUPPLIER'S PROFILE IN THE INDUSTRY: Looks at the supplier's reputation and experience in the industry rather than those in the Cloud Manufacturing.

A COMBINATION OF THE ABOVE TWO

Other (please specify)

9. If "SUPPLIER'S EXPERIENCE IN CLOUD MANUFACTURING" or "A COMBINATION OF THE ABOVE TWO" was selected in Q8, please specify what metric you would suggest to evaluate the supplier's experience in Cloud Manufacturing.

NO. OF ORDERS RECEIVED

TOTAL VALUE OF ORDERS RECEIVED

NO. OF YEARS OF EXPERIENCE IN CLOUD MANUFACTURING

Other (please specify)

10. If "SUPPLIER'S PROFILE IN THE INDUSTRY" or "A COMBINATION OF THE ABOVE TWO" was selected in Q7, please specify what metric you would suggest to evaluate the supplier's profile in the industry.

- NO. OF YEARS OF EXPERIENCE IN THE INDUSTRY
- YEARS FROM FIRST ESTABLISHMENT
- ANNUAL TURNOVER
- Other (please specify)

Appendix 2: Suppliers Proposals

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Time (days)	Delivery Method
1	Design	1	94	18,000	55	10
		2	98	21000	50	10
		3	96	20,000	60	10
2	Panel	4	97	500	10	8
		5	98	800	7	10
		6	95	360	6	6
		7	99	1,000	14	8
		8	95	600	8	8
3	Electrical motor	9	94	1,400	18	6
		10	89	1,800	21	6
		11	91	2,600	20	8
		12	93	3,600	25	8
		13	97	2,200	18	6
4	Air-end	14	92	10,000	35	10
		15	88	9,000	41	8
		16	93	7,600	45	6
5	Hose	17	92	80	6	8
		18	91	70	7	6
		19	88	95	8	6
		20	93	60	9	4
		21	90	74	12	8
		22	94	70	8	10
		23	92	85	14	8
6	Separator tank	24	92	200	15	10
		25	91	190	15	8
		26	90	400	16	8
		27	88	440	18	4
		28	90	360	16	2
7	Radiator	29	90	1,400	22	8
		30	95	1,000	15	4
		31	91	1,200	18	2
		32	93	850	19	6
		33	99	1,200	16	8
		34	92	1,000	20	6

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Time (days)	Delivery Method
8	Cabin	35	94	140	8	10
		36	89	110	10	2
		37	85	85	15	6
		38	93	90	17	6
		39	90	140	9	4
		40	89	65	14	2
		41	92	130	9	10
		42	97	85	20	6
9	Water trap	43	88	200	20	6
		44	89	280	18	8
		45	91	320	18	8
		46	92	390	15	9
10	Shell plate	47	93	200	8	8
		48	90	240	6	8
		49	91	180	10	6
		50	94	240	8	8
		51	91	120	7	4
11	Solenoid valve	52	92	90	7	8
		53	90	150	8	6
		54	91	120	7	4
		55	87	100	9	6
12	Flange	56	90	360	18	6
		57	92	330	13	4
		58	91	280	12	8
		59	94	300	11	8
13	Nozzle	60	88	16	10	8
		61	89	14	9	6
		62	92	14	8	8
		63	93	11	7	8
		64	91	16	7	10

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Time (days)	Delivery Method
14	Base plate	65	92	34	7	10
		66	93	24	8	8
		67	90	28	10	9
		68	92	22	8	10
		69	90	38	6	8
		70	90	32	9	9
		71	92	40	6	10
		72	95	32	7	8
		73	90	38	7	4
		74	89	42	6	2
15	Painting material	75	94	5	12	6
		76	93	7	10	8
16	Filter	77	94	300	18	8
		78	98	280	18	8
		79	91	260	19	4
		80	92	220	21	6
17	Shaft/Body	81	93	80	10	6
		82	94	100	13	8
18	Shell plate	47	93	200	8	8
		48	90	240	6	8
		49	91	180	10	6
		50	94	240	8	8
		51	91	120	7	4
19	Solenoid valve	52	92	90	7	8
		53	90	150	8	6
		54	91	120	7	4
		55	87	100	9	6
20	Flange	56	90	360	18	6
		57	92	330	13	4
		58	91	280	12	8
		59	94	300	11	8
21	Nozzle	60	88	16	10	8
		61	89	14	9	6
		62	92	14	8	8
		63	93	11	7	8
		64	91	16	7	10

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Time (days)	Delivery Method
22	Shuttle valve	83	89	6	25	10
		84	92	4	21	8
		85	93	7	30	6
23	piping	86	89	6	20	6
		87	92	8	16	6
		88	96	10	16	8
		89	94	14	14	4
		90	92	10	18	4
24	Filter	91	92	8	18	8
		92	86	10	15	6
		93	93	9	15	4
		94	94	4	17	8
25	Desiccant material	95	89	40	14	10
		96	96	34	10	8
		97	97	42	12	8
		98	89	48	10	6
26	Pressure gauge	99	94	38	15	8
		100	94	37	15	6
		101	95	48	12	4
27	Safety valve	102	91	18	13	10
		103	90	20	13	6
		104	88	20	10	6
		105	93	22	11	2
28	Painting material	75	94	5	12	6
		76	93	7	10	8
29	Delivery	106	97	1,300	15	8
		107	98	1,200	18	6
		108	96	1,500	19	10

Appendix 3: Suppliers Fixed Information

Suppliers	TVOA (£)	Year Established (YE)	Quality System Score	AQC (0 to 1) where 1 is best	ATO (0 to 1) where 0 is best
1	43,000	2005	7	0.90	0.09
2	36,000	2000	8	0.95	0.10
3	22,000	2011	9	0.92	0.14
4	12,500	2001	6	0.95	0.11
5	12,000	1994	8	0.87	0.10
6	14,000	1995	7	0.92	0.07
7	10,000	2006	9	0.90	0.20
8	10,800	1984	9	0.85	0.15
9	27,000	1990	8	0.75	0.03
10	30,000	1982	5	0.89	0.16
11	34,000	2010	8	0.92	0.20
12	39,000	2007	7	0.93	0.13
13	21,000	2002	9	0.95	0.10
14	75,000	2008	8	0.89	0.05
15	61,000	2000	7	0.95	0.14
16	66,000	2003	7	0.96	0.20
17	17,600	1995	7	0.94	0.09
18	14,000	1998	6	0.90	0.17
19	10,800	2003	7	0.87	0.04
20	1,344	2011	8	0.96	0.19
21	1,480	2007	6	0.91	0.08
22	1,820	2001	7	0.93	0.10
23	1,200	1999	9	0.94	0.20
24	6,000	2012	7	0.91	0.04
25	4,800	2003	8	0.92	0.16
26	5,200	2008	9	0.94	0.10
27	4,840	2008	7	0.85	0.10
28	4,680	2000	6	0.91	0.07
29	21,000	2013	5	0.87	0.21
30	18,000	2009	7	0.90	0.09
31	18,000	2006	8	0.95	0.10
32	24,000	1997	6	0.87	0.14
33	20,400	2004	9	0.92	0.17
34	16,000	2006	7	0.83	0.09
35	1,680	2008	8	0.96	0.12
36	1,200	2007	8	0.88	0.04

Suppliers	TVOA (£)	Year Established (YE)	Quality System Score	AQC (0 to 1) where 1 is best	ATO (0 to 1) where 0 is best
37	1,050	2011	4	0.75	0.09
38	810	2001	6	0.88	0.15
39	980	2004	7	0.97	0.09
40	960	1999	7	0.89	0.18
41	780	2005	6	0.93	0.05
42	1,020	1998	9	0.91	0.08
43	6,000	2010	6	0.91	0.09
44	6,160	2006	6	0.89	0.02
45	5,120	2002	5	0.89	0.11
46	3,200	2009	7	0.93	0.04
47	8,000	2011	7	0.90	0.15
48	7,680	2008	5	0.89	0.07
49	7,040	2006	5	0.92	0.03
50	9,880	2000	6	0.92	0.16
51	6,400	2001	6	0.94	0.22
52	2,000	1991	7	0.91	0.06
53	2,100	2005	6	0.87	0.08
54	3,000	2009	9	0.90	0.15
55	1,800	2005	4	0.88	0.19
56	9,000	2006	8	0.87	0.08
57	8,000	2001	7	0.89	0.04
58	8,400	2000	7	0.91	0.15
59	7,250	2010	6	0.93	0.19
60	300	2003	8	0.95	0.15
61	280	2008	8	0.94	0.10
62	308	2009	6	0.90	0.08
63	370	1999	8	0.89	0.05
64	352	2006	7	0.9	0.09
65	272	2003	6	0.82	0.06
66	288	1999	8	0.92	0.15
67	448	2006	9	0.95	0.07
68	440	1975	7	0.88	0.11
69	304	2013	8	0.92	0.10
70	384	1982	7	0.93	0.20
71	160	2006	5	0.88	0.06
72	512	2014	6	0.89	0.05

Suppliers	TVOA (£)	Year Established (YE)	Quality System Score	AQC (0 to 1) where 1 is best	ATO (0 to 1) where 0 is best
73	304	2004	4	0.90	0.07
74	432	2003	5	0.90	0.10
75	102	2010	8	0.95	0.10
76	95	2012	9	0.94	0.13
77	6,600	2000	8	0.9	0.15
78	7,000	2003	6	0.92	0.09
79	9,000	1996	6	0.89	0.05
80	7,800	2001	7	0.93	0.16
81	5,600	2006	8	0.94	0.11
82	4,000	2000	7	0.93	0.13
83	120	1975	7	0.95	0.15
84	420	1990	8	0.94	0.09
85	180	2007	7	0.90	0.13
86	200	2006	6	0.89	0.09
87	264	2003	8	0.92	0.19
88	290	1999	7	0.95	0.21
89	150	2009	6	0.98	0.14
90	175	2011	8	0.90	0.09
91	250	1994	8	0.90	0.05
92	140	2000	5	0.89	0.09
93	420	2006	6	0.91	0.12
94	280	2001	7	0.90	0.18
95	1,260	2003	7	0.81	0.10
96	1,450	2004	8	0.9	0.10
97	836	2009	9	0.92	0.12
98	672	2010	6	0.97	0.13
99	20000	1999	6	0.95	0.09
100	1,520	2005	8	0.95	0.05
101	1,440	2011	7	0.96	0.13
102	560	2011	7	0.90	0.08
103	630	2009	8	0.91	0.12
104	1,100	1992	6	0.88	0.10
105	460	2004	9	0.92	0.18
106	15,400	2000	8	0.90	0.12
107	21,000	1995	7	0.91	0.09
108	14,400	2002	8	0.93	0.17

Appendix 4: Quality and Reputation Scores

Service Number	Service Name	Supplier	Quality Score	Reputation Score
1	Design	1	4.433106576	2.22
		2	4.777777778	2.19
		3	4.93877551	1.08
2	Panel	4	4.272727273	1.20
		5	4.747474747	1.53
		6	4.434343434	1.56
		7	5.00	0.85
		8	4.878787879	1.982
3	Electrical motor	9	4.684994273	2.33
		10	3.863688431	2.85
		11	4.592210767	1.61
		12	4.431844215	1.96
		13	5.00	1.49
4	Air-end	14	4.745519713	3.35
		15	4.394265233	3.19
		16	4.555555556	3.24
5	Hose	17	4.491725768	1.704
		18	4.237588652	1.41
		19	4.364066194	1.032
		20	4.745862884	0.25376
		21	4.205673759	0.4592
		22	4.555555556	0.7728
		23	4.936170213	0.848
6	Separator tank	24	4.555555556	0.39
		25	4.745169082	0.792
		26	4.934782609	0.558
		27	4.425120773	0.5436
		28	4.268115942	0.9372
7	Radiator	29	3.838383838	0.94
		30	4.434343434	1.02
		31	4.535353535	1.17
		32	4.151515152	1.86
		33	5.00	1.366
		34	4.343434343	1.09

Service Number	Service Name	Supplier	Quality Score	Reputation Score
8	Cabin	35	4.684994273	0.4172
		36	4.530355097	0.448
		37	3.517754868	0.242
		38	4.209621993	0.7324
		39	4.33906071	0.5892
		40	4.308132875	0.8384
		41	4.178694158	0.5312
		42	5.00	0.8908
9	Water trap	43	4.202898551	0.49
		44	4.235507246	0.6964
		45	4.078502415	0.8548
		46	4.555555556	0.428
10	Shell plate	47	4.523640662	0.52
		48	3.983451537	0.6572
		49	4.01536643	0.7316
		50	4.333333333	1.1452
		51	4.237588652	0.956
11	Solenoid valve	52	4.555555556	1.28
		53	4.268115942	0.584
		54	4.967391304	0.42
		55	3.725845411	0.572
12	Flange	56	4.650118203	0.81
		57	4.491725768	1.02
		58	4.459810875	1.086
		59	4.333333333	0.54
13	Nozzle	60	4.616487455	0.612
		61	4.64874552	0.3612
		62	4.301075269	0.31232
		63	4.777777778	0.8148
		64	4.491039427	0.46408

Service Number	Service Name	Supplier	Quality Score	Reputation Score
14	Base plate	65	4.238596491	0.61088
		66	4.714619883	0.81152
		67	4.842105263	0.46792
		68	4.460818713	2.0176
		69	4.619883041	0.11216
		70	4.397660819	1.66536
		71	4.016374269	0.4564
		72	4.333333333	0.07048
		73	3.730994152	0.56216
		74	3.921637427	0.61728
15	Painting material	75	4.777777778	0.25408
		76	4.968085106	0.1538
16	Filter	77	4.655328798	1.014
		78	4.333333333	0.88
		79	4.119047619	1.31
		80	4.371882086	1.012
17	Shaft/Body	81	4.745862884	0.674
		82	4.555555556	0.91
18	Shell plate	47	4.523640662	0.52
		48	3.983451537	0.6572
		49	4.01536643	0.7316
		50	4.333333333	1.1452
		51	4.237588652	0.956
19	Solenoid valve	52	4.555555556	1.28
		53	4.268115942	0.584
		54	4.967391304	0.42
		55	3.725845411	0.572
20	Flange	56	4.650118203	0.81
		57	4.491725768	1.02
		58	4.459810875	1.086
		59	4.333333333	0.54
21	Nozzle	60	4.616487455	0.612
		61	4.64874552	0.3612
		62	4.301075269	0.31232
		63	4.777777778	0.8148
		64	4.491039427	0.46408

Service Number	Service Name	Supplier	Quality Score	Reputation Score
22	Shuttle valve	83	4.426523297	2.0048
		84	4.745519713	1.2668
		85	4.555555556	0.4072
23	piping	86	4.114583333	0.458
		87	4.652777778	0.61056
		88	4.555555556	0.8116
		89	4.270833333	0.306
		90	4.652777778	0.207
24	Filter	91	4.713947991	1.06
		92	3.855791962	0.7556
		93	4.30141844	0.4668
		94	4.555555556	0.7112
25	Desiccant material	95	4.308132875	0.6504
		96	4.746849943	0.608
		97	5.00	0.33344
		98	4.085910653	0.27688
26	Pressure gauge	99	4.301754386	0.88
		100	4.74619883	0.5608
		101	4.555555556	0.2576
27	Safety valve	102	4.491039427	0.2224
		103	4.681003584	0.3252
		104	4.172043011	1.194
		105	5.00	0.5684
28	Painting material	75	4.777777778	0.25408
		76	4.968085106	0.1538
29	Delivery	106	4.747165533	1.366
		107	4.555555556	1.84
		108	4.716553288	1.226

Appendix 5: Normalised Suppliers Proposals

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Delivery Method	Reputation
1	Design	1	0.8976125	1.00	1.00	1.00
		2	0.9674013	0.857143	1.00	0.9864865
		3	1.00	0.90	1.00	0.4864865
2	Panel	4	0.8545455	0.72	0.8	0.605449
		5	0.9494949	0.45	1.00	0.7719475
		6	0.8868687	1.00	0.60	0.7870838
		7	1.00	0.36	0.80	0.4288597
		8	0.9757576	0.6	0.80	1.00
3	Electrical motor	9	0.9369989	1.00	0.75	0.8175439
		10	0.7727377	0.777778	0.75	1.00
		11	0.9184422	0.538462	1.00	0.5649123
		12	0.8863688	0.388889	1.00	0.6877193
		13	1.00	0.636364	0.75	0.522807
4	Air-end	14	1.00	0.76	1.00	1.00
		15	0.9259819	0.844444	0.80	0.9522388
		16	0.9599698	1.00	0.60	0.9671642
5	Hose	17	0.9099617	0.75	0.80	1.00
		18	0.858477	0.857143	0.60	0.8274648
		19	0.8840996	0.631579	0.60	0.6056338
		20	0.9614464	1.00	0.40	0.1489202
		21	0.8520115	0.810811	0.80	0.2694836
		22	0.9228927	0.857143	1.00	0.4535211
		23	1.00	0.705882	0.80	0.4976526
6	Separator tank	24	0.9231522	0.95	1.00	0.4161332
		25	0.9615761	1.00	0.80	0.8450704
		26	1.00	0.475	0.80	0.5953905
		27	0.8967205	0.431818	0.40	0.5800256
		28	0.8649046	0.527778	0.20	1.00
7	Radiator	29	0.7676768	0.607143	1.00	0.5053763
		30	0.8868687	0.85	0.5	0.5483871
		31	0.9070707	0.708333	0.25	0.6290323
		32	0.830303	1.00	0.75	1.00
		33	1.00	0.708333	1.00	0.7344086
		34	0.8686869	0.85	0.75	0.5860215

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Delivery Method	Reputation
8	Cabin	35	0.9369989	0.464286	1.00	0.4683431
		36	0.906071	0.590909	0.20	0.5029187
		37	0.703551	0.764706	0.60	0.2716659
		38	0.8419244	0.722222	0.60	0.8221823
		39	0.8678121	0.464286	0.40	0.6614279
		40	0.8616266	1.00	0.20	0.9411765
		41	0.8357388	0.50	1.00	0.5963179
		42	1.00	0.764706	0.60	1.00
9	Water trap	43	0.9225875	1.00	0.66666667	0.5732335
		44	0.9297455	0.714286	0.88888889	0.8146935
		45	0.895281	0.625	0.88888889	1.00
		46	1.00	0.512821	1.00	0.5007019
10	Shell plate	47	1.00	0.6	1.00	0.4540692
		48	0.8805853	0.50	1.00	0.5738736
		49	0.8876404	0.666667	0.75	0.6388404
		50	0.9579305	0.50	1.00	1.00
		51	0.9367651	1.00	0.50	0.8347887
11	Solenoid valve	52	0.9170921	1.00	1.00	1.00
		53	0.8592268	0.60	0.75	0.45625
		54	1.00	0.75	0.5	0.328125
		55	0.7500608	0.90	0.75	0.446875
12	Flange	56	1.00	0.777778	0.75	0.7458564
		57	0.965938	0.848485	0.50	0.9392265
		58	0.9590747	1.00	1.00	1.00
		59	0.931876	0.933333	1.00	0.4972376
13	Nozzle	60	0.9662416	0.6875	0.80	0.7511046
		61	0.9729932	0.785714	0.60	0.443299
		62	0.9002251	0.785714	0.80	0.3833088
		63	1.00	1.00	0.80	1.00
		64	0.939985	0.6875	1.00	0.5695631

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Delivery Method	Reputation
14	Base plate	65	0.8753623	0.647059	1.00	0.3027756
		66	0.9736715	0.916667	0.80	0.4022205
		67	1.00	0.785714	0.90	0.2319191
		68	0.921256	1.00	1.00	1.00
		69	0.9541063	0.578947	0.80	0.0555908
		70	0.9082126	0.6875	0.90	0.8254163
		71	0.8294686	0.55	1.00	0.2262094
		72	0.8949275	0.6875	0.80	0.0349326
		73	0.7705314	0.578947	0.40	0.2786281
		74	0.8099034	0.52381	0.20	0.3059477
15	Painting material	75	0.961694	1.00	0.75	1.00
		76	1.00	0.714286	1.00	0.6053212
16	Filter	77	1.00	0.733333	1.00	0.7740458
		78	0.9308329	0.785714	1.00	0.6717557
		79	0.8848027	0.846154	0.50	1.00
		80	0.9391135	1.00	0.75	0.7725191
17	Shaft/Body	81	1.00	1.00	0.75	0.7406593
		82	0.9599004	0.80	1.00	1.00
18	Shell plate	47	1.00	0.60	1.00	0.4540692
		48	0.8805853	0.50	1.00	0.5738736
		49	0.8876404	0.666667	0.75	0.6388404
		50	0.9579305	0.50	1.00	1.00
		51	0.9367651	1.00	0.5	0.8347887
19	Solenoid valve	52	0.9170921	1.00	1.00	1.00
		53	0.8592268	0.60	0.75	0.45625
		54	1.00	0.75	0.50	0.328125
		55	0.7500608	0.90	0.75	0.446875
20	Flange	56	1.00	0.777778	0.75	0.7458564
		57	0.965938	0.848485	0.5	0.9392265
		58	0.9590747	1.00	1.00	1.00
		59	0.931876	0.933333	1.00	0.4972376
21	Nozzle	60	0.9662416	0.6875	0.80	0.7511046
		61	0.9729932	0.785714	0.60	0.443299
		62	0.9002251	0.785714	0.80	0.3833088
		63	1.00	1.00	0.80	1.00
		64	0.939985	0.6875	1.00	0.5695631

Service Number	Service Name	Supplier	Quality Pass rate	Cost (£)	Delivery Method	Reputation
22	Shuttle valve	83	0.9327795	0.666667	1.00	1.00
		84	1.00	1.00	0.8	0.6318835
		85	0.9599698	0.571429	0.6	0.2031125
23	piping	86	0.8843284	1.00	0.75	0.5643174
		87	1.00	0.75	0.75	0.7522918
		88	0.9791045	0.60	1.00	1.00
		89	0.9179104	0.428571	0.50	0.377033
		90	1.00	0.60	0.50	0.2550517
24	Filter	91	1.00	0.50	1.00	1.00
		92	0.8179539	0.40	0.75	0.7128302
		93	0.9124875	0.444444	0.5	0.4403774
		94	0.9663992	1.00	1.00	0.6709434
25	Desiccant material	95	0.8616266	0.85	1.00	1.00
		96	0.94937	1.00	0.8	0.9348093
		97	1.00	0.809524	0.8	0.5126691
		98	0.8171821	0.708333	0.6	0.4257073
26	Pressure gauge	99	0.9063578	0.973684	1.00	1.00
		100	1.00	1.00	0.75	0.6372727
		101	0.9598324	0.770833	0.50	0.2927273
27	Safety valve	102	0.8982079	1.00	1.00	0.1862647
		103	0.9362007	0.90	0.60	0.2723618
		104	0.8344086	0.90	0.60	1.00
		105	1.00	0.818182	0.20	0.4760469
28	Painting material	75	0.961694	1.00	0.75	1.00
		76	1.00	0.714286	1.00	0.6053212
29	Delivery	106	1.00	0.923077	0.80	0.7423913
		107	0.959637	1.00	0.60	1.00
		108	0.9935515	0.80	1.00	0.6663043

Appendix 6: Constraints

Goal Constraints

(1) $0.81y_{1,1} + 0.92y_{2,1} + 0.92y_{3,1} + d_{1,1} = 1.0$

(2) $1y_{1,1} + 0.99y_{2,1} + 0.49y_{3,1} + d_{1,2} = 1.0$

(3) $1y_{1,1} + 0.86y_{2,1} + 0.9y_{3,1} + d_{1,3} = 1.0$

(4) $1y_{1,1} + 1y_{2,1} + 1y_{3,1} + d_{1,4} = 1.0$

(5) $0.81y_{4,2} + 0.83y_{5,2} + 0.82y_{6,2} + 0.90y_{7,2} + 0.83y_{8,2} + d_{2,1} = 1.0$

(6) $0.61y_{4,2} + 0.77y_{5,2} + 0.79y_{6,2} + 0.43y_{7,2} + 1y_{8,2} + d_{2,2} = 1.0$

(7) $0.72y_{4,2} + 0.45y_{5,2} + 1y_{6,2} + 0.36y_{7,2} + 0.6y_{8,2} + d_{2,3} = 1.0$

(8) $0.8y_{4,2} + 1\ y_{5,2} + 0.6y_{6,2} + 0.8y_{7,2} + 0.8y_{8,2} + d_{2,4} = 1.0$

(9) $0.70y_{9,3} + 0.69y_{10,3} + 0.84y_{11,3} + 0.82y_{12,3} + 0.95y_{13,3} + d_{3,1} = 1.0$

(10) $0.82y_{9,3} + 1y_{10,3} + 0.56y_{11,3} + 0.69y_{12,3} + 0.52y_{13,3} + d_{3,2} = 1.0$

(11) $1y_{9,3} + 0.78y_{10,3} + 0.54y_{11,3} + 03.9y_{12,3} + 0.64y_{13,3} + d_{3,3} = 1.0$

(12) $0.75y_{9,3} + 0.75y_{10,3} + 1y_{11,3} + 1y_{12,3} + 0.75y_{13,3} + d_{3,4} = 1.0$

(13) $0.89y_{14,4} + 0.88y_{15,4} + 0.92y_{16,4} + d_{4,1} = 1.0$

(14) $1y_{14,4} + 0.95y_{15,4} + 0.97y_{16,4} + d_{4,2} = 1.0$

(15) $0.76y_{14,4} + 0.84y_{15,4} + 1y_{16,4} + d_{4,3} = 1.0$

(16) $1y_{14,4} + 0.8y_{15,4} + 0.6y_{16,4} + d_{4,4} = 1.0$

(17) $0.86y_{17,5} + 0.77y_{18,5} + 0.77y_{19,5} + 0.92y_{20,5} + 0.78y_{21,5} + 0.86y_{22,5} + 0.94y_{23,5} + d_{5,1} = 1.0$

(18) $1y_{17,5} + 0.83y_{18,5} + 0.61y_{19,5} + 0.15y_{20,5} + 0.27y_{21,5} + 0.45y_{22,5} + 0.50y_{23,5} + d_{5,2} = 1.0$

(19) $0.75y_{17,5} + 0.86y_{18,5} + 0.63y_{19,5} + 1y_{20,5} + 0.81y_{21,5} + 0.86y_{22,5} + 0.71y_{23,5} + d_{5,3} = 1.0$

(20) $0.8y_{17,5} + 0.6y_{18,5} + 0.6y_{19,5} + 0.4y_{20,5} + 0.8y_{21,5} + 1y_{22,5} + 0.8y_{23,5} + d_{5,4} = 1.0$

(21) $0.84y_{24,6} + 0.88y_{25,6} + 0.84y_{26,6} + 0.76y_{27,6} + 0.79y_{28,6} + d_{6,1} = 1.0$

(22) $0.45y_{24,6} + 0.85y_{25,6} + 0.6y_{26,6} + 0.58y_{27,6} + 1y_{28,6} + d_{6,2} == 1.0$

(23) $0.95y_{24,6} + 1y_{25,6} + 0.48y_{26,6} + 0.43y_{27,6} + 0.53y_{28,6} + d_{6,3} == 1.0$

(24) $1y_{24,6} + 0.8y_{25,6} + 0.8y_{26,6} + 0.4y_{27,6} + 0.2y_{28,6} + d_{6,4} = 1.0$

(25) $0.67y_{29,7} + 0.80y_{30,7} + 0.86y_{31,7} + 0.72y_{32,7} + 0.92y_{33,7} + 0.72y_{34,7} + d_{7,1} = 1.0$

(26) $0.51y_{29,7} + 0.55y_{30,7} + 0.63y_{31,7} + 1y_{32,7} + 0.73y_{33,7} + 0.59y_{34,7} + d_{7,2} = 1.0$

(27) $0.61y_{29,7} + 0.85y_{30,7} + 0.71y_{31,7} + 1y_{32,7} + 0.71y_{33,7} + 0.85y_{34,7} + d_{7,3} = 1.0$

(28) $1y_{29,7} + 0.5y_{30,7} + 0.25y_{31,7} + 0.75y_{32,7} + 1y_{33,7} + 0.75y_{34,7} + d_{7,4} = 1.0$

(29) $0.90y_{35,8} + 0.80y_{36,8} + 0.53y_{37,8} + 0.74y_{38,8} + 0.84y_{39,8} + 0.77y_{40,8} + 0.78y_{41,8} + 0.91y_{42,8} + d_{8,1} = 1.0$

(30) $0.47y_{35,8} + 0.5y_{36,8} + 0.27y_{37,8} + 0.82y_{38,8} + 0.66y_{39,8} + 0.94y_{40,8} + 0.6y_{41,8} + 1y_{42,8} + d_{8,2} = 1.0$

(31) $0.46y_{35,8} + 0.59y_{36,8} + 0.76y_{37,8} + 0.72y_{38,8} + 0.46y_{39,8} + 1y_{40,8} + 0.50y_{41,8} + 0.76y_{42,8} + d_{8,3} = 1.0$

(32) $1y_{35,8} + 0.2y_{36,8} + 0.6y_{37,8} + 0.6y_{38,8} + 0.4y_{39,8} + 0.2y_{40,8} + 1y_{41,8} + 0.6y_{42,8} + d_{8,4} = 1.0$

(33) $0.84y_{43,9} + 0.83y_{44,9} + 0.80y_{45,9} + 0.93y_{46,9} + d_{9,1} = 1.0$

(34) $0.57y_{43,9} + 0.81y_{44,9} + 1y_{45,9} + 0.5y_{46,9} + d_{9,2} = 1.0$

(35) $1y_{43,9} + 0.71y_{44,9} + 0.63y_{45,9} + 0.51y_{46,9} + d_{9,3} = 1.0$

(36) $0.67y_{43,9} + 0.89y_{44,9} + 0.89y_{45,9} + 1y_{46,9} + d_{9,4} = 1.0$

(37) $0.90y_{47,10} + 0.78y_{48,10} + 0.82y_{49,10} + 0.88y_{50,10} + 0.88y_{51,10} + d_{10,1} = 1.0$

(38) $0.45y_{47,10} + 0.57y_{48,10} + 0.64y_{49,10} + 1y_{50,10} + 0.83y_{51,10} + d_{10,2} = 1.0$

(39) $0.6y_{47,10} + 0.5y_{48,10} + 0.67y_{49,10} + 0.5y_{50,10} + 1y_{51,10} + d_{10,3} = 1.0$

(40) $1y_{47,10} + 1y_{48,10} + 0.75y_{49,10} + 1y_{50,10} + 0.5y_{51,10} + d_{10,4} = 1.0$

(41) $0.83y_{52,11} + 0.75y_{53,11} + 0.90y_{54,11} + 0.66y_{55,11} + d_{11,1} = 1.0$

(42) $1y_{52,11} + 0.46y_{53,11} + 0.33y_{54,11} + 0.45y_{55,11} + d_{11,2} = 1.0$

(43) $1y_{52,11} + 0.6y_{53,11} + 0.75y_{54,11} + 0.90y_{55,11} + d_{11,3} = 1.0$

(44) $1y_{52,11} + 0.75y_{53,11} + 0.50y_{54,11} + 0.75y_{55,11} + d_{11,4} = 1.0$

(45) $0.87y_{56,12} + 0.86y_{57,12} + 0.87y_{58,12} + 0.87y_{59,12} + d_{12,1} = 1.0$

(46) $0.75y_{56,12} + 0.94y_{57,12} + 1y_{58,12} + 0.50y_{59,12} + d_{12,2} = 1.0$

(47)$0.78y_{56,12} + 0.85y_{57,12} + 1y_{58,12} + 0.93y_{59,12} + d_{12,3} = 1.0$

(48) $0.75y_{56,12} + 0.50y_{57,12} + 01y_{58,12} + 1y_{59,12} + d_{12,4} = 1.0$

(49) $0.92y_{60,13} + 0.91y_{61,13} + 0.81y_{62,13} + 0.89y_{63,13} + 0.85y_{64,13} + d_{13,1} = 1.0$

(50) $0.75y_{60,13} + 0.44y_{61,13} + 0.38y_{62,13} + 1y_{63,13} + 0.57y_{64,13} + d_{13,2} = 1.0$

(51) $0.69y_{60,13} + 0.79y_{61,13} + 0.79y_{62,13} + 1y_{63,13} + 0.69y_{64,13} + d_{13,3} = 1.0$

(52) $0.8y_{60,13} + 0.6y_{61,13} + 0.8y_{62,13} + 0.8y_{63,13} + 1y_{64,13} + d_{13,4} = 1.0$

(53) $0.72y_{65,14} + 0.90y_{66,14} + 0.95y_{67,14} + 0.81y_{68,14} + 0.88y_{69,14} + 0.84y_{70,14} + 0.73y_{71,14} + 0.80y_{72,14} + 0.69y_{73,14} + 0.73y_{74,14} + d_{14,1} = 1.0$

(54) $0.3y_{65,14} + 0.4y_{66,14} + 0.23y_{67,14} + 1y_{68,14} + 0.06y_{69,14} + 0.83y_{70,14} + 0.23y_{71,14} + 0.03y_{72,14} + 0.28y_{73,14} + 0.31y_{74,14} + d_{14,2} = 1.0$

(55) $0.65y_{65,14} + 0.92y_{66,14} + 0.79y_{67,14} + 1y_{68,14} + 0.58y_{69,14} + 0.69y_{70,14} + 0.55y_{71,14} + 0.69y_{72,14} + 0.58y_{73,14} + 0.52y_{74,14} + d_{14,3} = 1.0$

(56)$1y_{65,14} + 0.8y_{66,14} + 0.9y_{67,14} + 1y_{68,14} + 0.8y_{69,14} + 0.9y_{70,14} + 1y_{71,14} + 0.8y_{72,14} + 0.4y_{73,14} + 0.2y_{74,14} + d_{14,4} = 1.0$

(57) $0.91y_{75,15} + 0.94y_{76,15} + d_{15,1} = 1.0$

(58) $1y_{75,15} + 0.61y_{76,15} + d_{15,2} = 1.0$

(59) $1y_{75,15} + 0.71y_{76,15} + d_{15,3} = 1.0$

(60) $0.75y_{75,15} + 1y_{76,15} + d_{15,4} = 1.0$

(61) $0.90y_{77,16} + 0.86y_{78,16} + 0.79y_{79,16} + 0.87y_{80,16} + d_{16,1} = 1.0$

(62) $0.77y_{77,16} + 0.67y_{78,16} + 1y_{79,16} + 0.77y_{80,16} + d_{16,2} = 1.0$

(63) $0.73y_{77,16} + 0.79y_{78,16} + 0.85y_{79,16} + 1y_{80,16} + d_{16,3} = 1.0$

(64) $1y_{77,16} + 1y_{78,16} + 0.5y_{79,16} + 0.75y_{80,16} + d_{16,4} = 1.0$

(65) $0.94y_{81,17} + 0.89y_{82,17} + d_{17,1} = 1.0$

(66) $0.74y_{81,17} + 1y_{82,17} + d_{17,2} = 1.0$

(67) $1y_{81,17} + 0.80y_{82,17} + d_{17,3} = 1.0$

(68) $0.75y_{81,17} + 1y_{82,17} + d_{17,4} = 1.0$

(69) $0.90y_{47,18} + 0.78y_{48,18} + 0.82y_{49,18} + 0.88y_{50,18} + 0.88y_{51,18} + d_{18,1} = 1.0$

(70) $0.45y_{47,18} + 0.57y_{48,18} + 0.64y_{49,18} + 1y_{50,18} + 0.83y_{51,18} + d_{18,2} = 1.0$

(71) $0.6y_{47,18} + 0.5y_{48,18} + 0.67y_{49,18} + 0.5y_{50,18} + 1y_{51,18} + d_{18,3} = 1.0$

(72) $1y_{47,18} + 1y_{48,18} + 0.75y_{49,18} + 1y_{50,18} + 0.5y_{51,18} + d_{18,4} = 1.0$

(73) $0.83y_{52,19} + 0.75y_{53,19} + 0.90y_{54,19} + 0.66y_{55,19} + d_{19,1} = 1.0$

(74) $1y_{52,19} + 0.46y_{53,19} + 0.33y_{54,19} + 0.45y_{55,19} + d_{19,2} = 1.0$

(75) $1y_{52,19} + 0.6y_{53,19} + 0.75y_{54,19} + 0.90y_{55,19} + d_{19,3} = 1.0$

(76) $1y_{52,19} + 0.75y_{53,19} + 0.50y_{54,19} + 0.75y_{55,19} + d_{19,4} = 1.0$

(77) $0.87y_{56,20} + 0.86y_{57,20} + 0.87y_{58,20} + 0.87y_{59,20} + d_{20,1} = 1.0$

(78) $0.75y_{56,20} + 0.94y_{57,20} + 1y_{58,20} + 0.50y_{59,20} + d_{20,2} = 1.0$

(79)$0.78y_{56,20} + 0.85y_{57,20} + 1y_{58,20} + 0.93y_{59,20} + d_{20,3} = 1.0$

(80) $0.75y_{56,20} + 0.50y_{57,20} + 01y_{58,20} + 1y_{59,20} + d_{20,4} = 1.0$

(81) $0.92y_{60,21} + 0.91y_{61,21} + 0.81y_{62,21} + 0.89y_{63,21} + 0.85y_{64,21} + d_{21,1} = 1.0$

(82) $0.75y_{60,21} + 0.44y_{61,21} + 0.38y_{62,21} + 1y_{63,21} + 0.57y_{64,21} + d_{21,2} = 1.0$

(83) $0.69y_{60,21} + 0.79y_{61,21} + 0.79y_{62,21} + 1y_{63,21} + 0.69y_{64,21} + d_{21,3} = 1.0$

(84) $0.8y_{60,21} + 0.6y_{61,21} + 0.8y_{62,21} + 0.8y_{63,21} + 1y_{64,21} + d_{21,4} = 1.0$

(85) $0.89y_{83,22} + 0.94y_{84,22} + 0.86y_{85,22} + d_{22,1} = 1.0$

(86) $1y_{83,22} + 0.63y_{84,22} + 0.20y_{85,22} + d_{22,2} = 1.0$

(87)$0.67y_{83,22} + 1y_{84,22} + 0.57y_{85,22} + d_{22,3} = 1.0$

(88) $1y_{83,22} + 0.80y_{84,22} + 0.60y_{85,22} + d_{22,4} = 1.0$

(89) $0.79y_{86,23} + 0.92y_{87,23} + 0.93y_{88,23} + 0.90y_{89,23} + 0.90y_{90,23} + d_{23,1} = 1.0$

(90) $0.56y_{86,23} + 0.75y_{87,23} + 1y_{88,23} + 0.38y_{89,23} + 0.26y_{90,23} + d_{23,2} = 1.0$

(91) $01y_{86,23} + 0.75y_{87,23} + 0.60y_{88,23} + 0.43y_{89,23} + 0.60y_{90,23} + d_{23,3} = 1.0$

(92) $0.75y_{86,23} + 0.75y_{87,23} + 1y_{88,23} + 0.50y_{89,23} + 0.50y_{90,23} + d_{23,4} = 1.0$

(93) $0.90y_{91,24} + 0.73y_{92,24} + 0.83y_{93,24} + 0.87y_{94,24} + d_{24,1} = 1.0$

(94) $1y_{91,24} + 0.71y_{92,24} + 0.44y_{93,24} + 0.67y_{94,24} + d_{24,2} = 1.0$

(95) $0.50y_{91,24} + 0.40y_{92,24} + 0.44y_{93,24} + 1y_{94,24} + d_{24,3} = 1.0$

(96) $1y_{91,24} + 0.75y_{92,24} + 0.50y_{93,24} + 1y_{94,24} + d_{24,4} = 1.0$

(97) $0.70y_{95,25} + 0.85y_{96,25} + 0.92y_{97,25} + 0.79y_{98,25} + d_{25,1} = 1.0$

(98) $1y_{95,25} + 0.93y_{96,25} + 0.51y_{97,25} + 0.43y_{98,25} + d_{25,2} = 1.0$

(99) $0.85y_{95,25} + 1y_{96,25} + 0.81y_{97,25} + 0.71y_{98,25} + d_{25,3} = 1.0$

(100) $1y_{95,25} + 0.80y_{96,25} + 0.80y_{97,25} + 0.60y_{98,25} + d_{25,4} = 1.0$

(101) $0.86y_{99,26} + 0.95y_{100,26} + 0.92y_{101,26} + d_{26,1} = 1.0$

(102) $1y_{99,26} + 0.64y_{100,26} + 0.29y_{101,26} + d_{26,2} = 1.0$

(103) $0.97y_{99,26} + 1y_{100,26} + 0.77y_{101,26} + d_{26,3} = 1.0$

(104) $1y_{99,26} + 0.75y_{100,26} + 0.50y_{101,26} + d_{26,4} = 1.0$

(105) $0.81y_{102,27} + 0.85y_{103,27} + 0.73y_{104,27} + 0.92y_{105,27} + d_{27,1} = 1.0$

(106) $0.19y_{102,27} + 0.27y_{103,27} + 1y_{104,27} + 0.48y_{105,27} + d_{27,2} = 1.0$

(107) $1y_{102,27} + 0.90y_{103,27} + 0.90y_{104,27} + 0.82y_{105,27} + d_{27,3} = 1.0$

(108) $1y_{102,27} + 0.60y_{103,27} + 0.60y_{104,27} + 0.20y_{105,27} + d_{27,4} = 1.0$

(109) $0.91y_{75,28} + 0.94y_{76,28} + d_{28,1} = 1.0$

(110) $1y_{75,28} + 0.61y_{76,28} + d_{28,2} = 1.0$

(111) $1y_{75,28} + 0.71y_{76,28} + d_{28,3} = 1.0$

(112) $0.75y_{75,28} + 1y_{76,28} + d_{28,4} = 1.0$

(113) $0.90y_{106,29} + 0.87y_{107,29} + 0.92y_{108,29} + d_{29,1} = 1.0$

(114) $0.74y_{106,29} + 1y_{107,29} + 0.67y_{108,29} + d_{29,2} = 1.0$

(115) $0.92y_{106,29} + 1y_{107,29} + 0.80y_{108,29} + d_{29,3} = 1.0$

(116) $0.80y_{106,29} + 0.60y_{107,29} + 1y_{108,29} + d_{29,4} = 1.0$

(117) $S_4 - \ddot{d}_T = 105$

Demand Constraints:

(118) $y_{1,1} + y_{2,1} + y_{3,1} = 1.0$

(119) $y_{4,2} + y_{5,2} + y_{6,2} + y_{7,2} + y_{8,2} + y_{7,1} + y_{8,1} = 1.0$

(120) $y_{9,3} + y_{10,3} + y_{11,3} + y_{12,3} + y_{13,3} = 1.0$

(121) $y_{14,4} + y_{15,4} + y_{16,4} = 1.0$

(122) $y_{17,5} + y_{18,5} + y_{19,5} + y_{20,5} + y_{21,5} + y_{22,5} + y_{23,5} = 1.0$

(123) $y_{24,6} + y_{25,6} + y_{26,6} + y_{27,6} + y_{28,6} = 1.0$

(124) $y_{29,7} + y_{30,7} + y_{31,7} + y_{32,7} + y_{33,7} + y_{34,7} = 1.0$

(125) $y_{35,8} + y_{36,8} + y_{37,8} + y_{38,8} + y_{39,8} + y_{40,8} + y_{41,8} + y_{42,8} = 1.0$

(126) $y_{43,9} + y_{44,9} + y_{45,9} + y_{46,9} = 1.0$

(127) $y_{47,10} + y_{48,10} + y_{49,10} + y_{50,10} + y_{51,10} = 1.0$

(128) $y_{52,11} + y_{53,11} + y_{54,11} + y_{55,11} = 1.0$

(129) $y_{56,12} + y_{57,12} + y_{58,12} + y_{59,12} = 1.0$

(130) $y_{60,13} + y_{61,13} + y_{62,13} + y_{63,13} + y_{64,13} = 1.0$

(131) $y_{65,14} + y_{66,14} + y_{67,14} + y_{68,14} + y_{69,14} + y_{70,14} + y_{71,14} + y_{72,14} + y_{73,14} + y_{74,14} = 1.0$

(132) $y_{75,15} + y_{76,15} = 1.0$

(133) $y_{77,16} + y_{78,16} + y_{79,16} + y_{80,16} = 1.0$

(134) $y_{81,17} + y_{82,17} = 1.0$

(135) $y_{47,18} + y_{48,18} + y_{49,18} + y_{50,18} + y_{51,18} = 1.0$

(136) $y_{52,19} + y_{53,19} + y_{54,19} + y_{55,19} = 1.0$

(137) $y_{56,20} + y_{57,20} + y_{58,20} + y_{59,20} = 1.0$

(138) $y_{60,21} + y_{61,21} + y_{62,21} + y_{63,21} + y_{64,21} += 1.0$

(139) $y_{83,22} + y_{84,22} + y_{85,22} = 1.0$

(140) $y_{86,23} + y_{87,23} + y_{88,23} + y_{89,23} + y_{90,23} = 1.0$

(141) $y_{91,24} + y_{92,24} + y_{93,24} + y_{94,24} = 1.0$

(142) $y_{95,25} + y_{96,25} + y_{97,25} + y_{98,25} = 1.0$

(143) $y_{99,26} + y_{100,26} + y_{101,26} = 1.0$

(144) $y_{102,27} + y_{103,27} + y_{104,27} + y_{105,27} = 1.0$

(145) $y_{75,28} + y_{76,28} = 1.0$

(146) $y_{106,29} + y_{107,29} + y_{108,29} = 1.0$

Project Planning Precedence Constraints:

(147) $S_1 + 55.95y_{1,1} \leq S_2$

(148) $S_1 + 55y_{2,1} \leq S_2$

(149) $S_1 + 68.4y_{3,1} \leq S_2$

(150) $S_1 + 55.95y_{1,1} \leq S_3$

(151) $S_1 + 55y_{2,1} \leq S_3$

(152) $S_1 + 68.4y_{3,1} \leq S_3$

(153) $S_1 + 55.95y_{1,1} \leq S_4$

(154) $S_1 + 55y_{2,1} \leq S_4$

(155) $S_1 + 68.4y_{3,1} \leq S_4$

(156) $S_1 + 55.95y_{1,1} \leq S_5$

(157) $S_1 + 55y_{2,1} \leq S_5$

(158) $S_1 + 68.4y_{3,1} \leq S_5$

(159) $S_1 + 55.95y_{1,1} \leq S_6$

(160) $S_1 + 55y_{2,1} \leq S_6$

(161) $S_1 + 68.4y_{3,1} \leq S_6$

(162) $S_1 + 55.95y_{1,1} \leq S_7$

(163) $S_1 + 55y_{2,1} \leq S_7$

(164) $S_1 + 68.4y_{3,1} \leq S_7$

(165) $S_1 + 55.95y_{1,1} \leq S_8$

(166) $S_1 + 55y_{2,1} \leq S_8$

(167) $S_1 + 68.4y_{3,1} \leq S_8$

(168) $S_1 + 55.95y_{1,1} \leq S_9$

(169) $S_1 + 55y_{2,1} \leq S_9$

(170) $S_1 + 68.4y_{3,1} \leq S_9$

(171) $S_1 + 55.95y_{1,1} \leq S_{10}$

(172) $S_1 + 55y_{2,1} \leq S_{10}$

(173) $S_1 + 68.4y_{3,1} \leq S_{10}$

(174) $S_1 + 55.95y_{1,1} \leq S_{11}$

(175) $S_1 + 55y_{2,1} \leq S_{11}$

(176) $S_1 + 68.4y_{3,1} \leq S_{11}$

(177) $S_1 + 55.95y_{1,1} \leq S_{12}$

(178) $S_1 + 55y_{2,1} \leq S_{12}$

(179) $S_1 + 68.4y_{3,1} \leq S_{12}$

(180) $S_1 + 55.95y_{1,1} \leq S_{13}$

(181) $S_1 + 55y_{2,1} \leq S_{13}$

(182) $S_1 + 68.4y_{3,1} \leq S_{13}$

(183) $S_1 + 55.95y_{1,1} \leq S_{14}$

(184) $S_1 + 55y_{2,1} \leq S_{14}$

(185) $S_1 + 68.4y_{3,1} \leq S_{14}$

(186) $S_1 + 55.95y_{1,1} \leq S_{15}$

(187) $S_1 + 55y_{2,1} \leq S_{15}$

(188) $S_1 + 68.4y_{3,1} \leq S_{15}$

(189) $S_1 + 55.95y_{1,1} \leq S_{16}$

(190) $S_1 + 55y_{2,1} \leq S_{16}$

(191) $S_1 + 68.4y_{3,1} \leq S_{16}$

(192) $S_1 + 55.95y_{1,1} \leq S_{17}$

(193) $S_1 + 55y_{2,1} \leq S_{17}$

(194) $S_1 + 68.4y_{3,1} \leq S_{17}$

(195) $S_1 + 55.95y_{1,1} \leq S_{18}$

(196) $S_1 + 55y_{2,1} \leq S_{18}$

(197) $S_1 + 68.4y_{3,1} \leq S_{18}$

(198) $S_1 + 55.95y_{1,1} \leq S_{19}$

(199) $S_1 + 55y_{2,1} \leq S_{19}$

(200) $S_1 + 68.4y_{3,1} \leq S_{19}$

(201) $S_1 + 55.95y_{1,1} \leq S_{20}$

(202) $S_1 + 55y_{2,1} \leq S_{20}$

(203) $S_1 + 68.4y_{3,1} \leq S_{20}$

(204) $S_1 + 55.95y_{1,1} \leq S_{21}$

(205) $S_1 + 55y_{2,1} \leq S_{21}$

(206) $S_1 + 68.4y_{3,1} \leq S_{21}$

(207) $S_1 + 55.95y_{1,1} \leq S_{22}$

(208) $S_1 + 55y_{2,1} \leq S_{22}$

(209) $S_1 + 68.4y_{3,1} \leq S_{22}$

(210) $S_1 + 55.95y_{1,1} \leq S_{23}$

(211) $S_1 + 55y_{2,1} \leq S_{23}$

(212) $S_1 + 68.4y_{3,1} \leq S_{23}$

(213) $S_1 + 55.95y_{1,1} \leq S_{24}$

(214) $S_1 + 55y_{2,1} \leq S_{24}$

(215) $S_1 + 68.4y_{3,1} \leq S_{24}$

(216) $S_1 + 55.95y_{1,1} \leq S_{25}$

(217) $S_1 + 55y_{2,1} \leq S_{25}$

(218) $S_1 + 68.4y_{3,1} \leq S_{25}$

(219) $S_1 + 55.95y_{1,1} \leq S_{26}$

(220) $S_1 + 55y_{2,1} \leq S_{26}$

(221) $S_1 + 68.4y_{3,1} \leq S_{26}$

(222) $S_1 + 55.95y_{1,1} \leq S_{27}$

(223) $S_1 + 55y_{2,1} \leq S_{27}$

(224) $S_1 + 68.4y_{3,1} \leq S_{27}$

(225) $S_1 + 55.95y_{1,1} \leq S_{28}$

(226) $S_1 + 55y_{2,1} \leq S_{28}$

(227) $S_1 + 68.4y_{3,1} \leq S_{28}$

(228) $S_2 + 11.1y_{4,2} \leq S_{29}$

(229) $S_2 + 7.7y_{5,2} \leq S_{29}$

(230) $S_2 + 6.42y_{6,2} \leq S_{29}$

(231) $S_2 + 16.8y_{7,2} \leq S_{29}$

(232) $S_2 + 9.2y_{8,2} \leq S_{29}$

(233) $S_3 + 18.54y_{9,3} \leq S_{29}$

(234) $S_3 + 24.36y_{10,3} \leq S_{29}$

(235) $S_3 + 24y_{11,3} \leq S_{29}$

(236) $S_3 + 28.25y_{12,3} \leq S_{29}$

(237) $S_3 + 19.8y_{13,3} \leq S_{29}$

(238) $S_4 + 36.75y_{14,4} \leq S_{29}$

(239) $S_4 + 46.74y_{15,4} \leq S_{29}$

(240) $S_4 + 54y_{16,4} \leq S_{29}$

(241) $S_5 + 6.54y_{17,5} \leq S_{29}$

(242) $S_5 + 8.19y_{18,5} \leq S_{29}$

(243) $S_5 + 10.71y_{20,5} \leq S_{29}$

(244) $S_5 + 12.96y_{21,5} \leq S_{29}$

(245) $S_5 + 8.8y_{22,5} \leq S_{29}$

(246) $S_5 + 16.8y_{23,5} \leq S_{29}$

(247) $S_6 + 15.6y_{24,6} \leq S_{29}$

(248) $S_6 + 17.4y_{25,6} \leq S_{29}$

(249) $S_6 + 17.6y_{26,6} \leq S_{29}$

(250) $S_6 + 19.8y_{27,6} \leq S_{29}$

(251) $S_7 + 16.35y_{30,7} \leq S_{29}$

(252) $S_7 + 21.66y_{32,7} \leq S_{29}$

(253) $S_7 + 18.72y_{33,7} \leq S_{29}$

(254) $S_7 + 21.8y_{34,7} \leq S_{29}$

(255) $S_8 + 8.96y_{35,8} \leq S_{29}$

(256) $S_8 + 19.55y_{38,8} \leq S_{29}$

(257) $S_8 + 9.81y_{39,8} \leq S_{29}$

(258) $S_8 + 9.45y_{41,8} \leq S_{29}$

(259) $S_8 + 21.6y_{42,8} \leq S_{29}$

(260) $S_9 + 21.8y_{43,9} \leq S_{29}$

(261) $S_9 + 18.36y_{44,9} \leq S_{29}$

(262) $S_9 + 19.98y_{45,9} \leq S_{29}$

(263) $S_9 + 15.6y_{46,9} \leq S_{29}$

(264) $S_{10} + 9.2y_{47,10} \leq S_{29}$

(265) $S_{10} + 6.42y_{48,10} \leq S_{29}$

(266) $S_{10} + 10.3y_{49,10} \leq S_{29}$

(267) $S_{10} + 9.28y_{50,10} \leq S_{29}$

(268) $S_{10} + 8.54y_{51,10} \leq S_{29}$

(269) $S_{11} + 7.42y_{52,11} \leq S_{29}$

(270) $S_{11} + 8.64y_{53,11} \leq S_{29}$

(271) $S_{11} + 8.05y_{54,11} \leq S_{29}$

(272) $S_{11} + 10.71y_{55,11} \leq S_{29}$

(273) $S_{12} + 19.44y_{56,12} \leq S_{29}$

(274) $S_{12} + 13.52y_{57,12} \leq S_{29}$

(275) $S_{12} + 13.8y_{58,12} \leq S_{29}$

(276)$S_{12} + 13.09y_{59,12} \leq S_{29}$

(277)$S_{13} + 11.5y_{60,13} \leq S_{29}$

(278)$S_{13} + 9.9y_{61,13} \leq S_{29}$

(279)$S_{13} + 8.64y_{62,13} \leq S_{29}$

(280)$S_{13} + 7.35y_{63,13} \leq S_{29}$

(281)$S_{13} + 7.63y_{64,13} \leq S_{29}$

(282)$S_{14} + 7.42y_{65,14} \leq S_{29}$

(283)$S_{14} + 9.2y_{66,14} \leq S_{29}$

(284)$S_{14} + 10.7y_{67,14} \leq S_{29}$

(285)$S_{14} + 8.88y_{68,14} \leq S_{29}$

(286)$S_{14} + 6.6y_{69,14} \leq S_{29}$

(287)$S_{14} + 10.8y_{70,14} \leq S_{29}$

(288)$S_{14} + 6.36y_{71,14} \leq S_{29}$

(289)$S_{14} + 7.35y_{72,14} \leq S_{29}$

(290)$S_{14} + 7.49y_{73,14} \leq S_{29}$

(291)$S_{15} + 13.2y_{75,15} \leq S_{29}$

(292)$S_{15} + 11.2y_{76,15} \leq S_{29}$

(293)$S_{16} + 20.7y_{77,16} \leq S_{29}$

(294)$S_{16} + 19.62y_{78,16} \leq S_{29}$

(295)$S_{16} + 19.95y_{79,16} \leq S_{29}$

(296)$S_{16} + 24.36y_{80,16} \leq S_{29}$

(297)$S_{17} + 11.1y_{81,17} \leq S_{29}$

(298)$S_{17} + 14.69y_{82,17} \leq S_{29}$

(299)$S_{18} + 9.2y_{47,18} \leq S_{29}$

(300)$S_{18} + 6.42y_{48,18} \leq S_{29}$

(301)$S_{18} + 10.3y_{49,18} \leq S_{29}$

(302)$S_{18} + 9.28y_{50,18} \leq S_{29}$

(303)$S_{18} + 8.54y_{51,18} \leq S_{29}$

(304)$S_{19} + 7.42y_{52,19} \leq S_{29}$

(305)$S_{19} + 8.64y_{53,19} \leq S_{29}$

(306)$S_{19} + 8.05y_{54,19} \leq S_{29}$

(307)$S_{19} + 10.71y_{55,19} \leq S_{29}$

(308)$S_{20} + 19.44y_{56,20} \leq S_{29}$

(309)$S_{20} + 13.52y_{57,20} \leq S_{29}$

(310)$S_{20} + 13.8y_{58,20} \leq S_{29}$

(311)$S_{20} + 13.09y_{59,20} \leq S_{29}$

(312)$S_{21} + 11.5y_{60,21} \leq S_{29}$

(313)$S_{21} + 9.9y_{61,21} \leq S_{29}$

(314)$S_{21} + 8.64y_{62,21} \leq S_{29}$

(315)$S_{21} + 7.35y_{63,21} \leq S_{29}$

(316)$S_{21} + 7.63y_{64,21} \leq S_{29}$

(317)$S_{22} + 28.75y_{83,22} \leq S_{29}$

(318)$S_{22} + 22.89y_{84,22} \leq S_{29}$

(319)$S_{23} + 21.8y_{86,23} \leq S_{29}$

(320)$S_{23} + 19.04y_{87,23} \leq S_{29}$

(321)$S_{23} + 19.36y_{88,23} \leq S_{29}$

(322)$S_{23} + 15.96y_{89,23} \leq S_{29}$

(323)$S_{23}19.62 + y_{90,23} \leq S_{29}$

(324)$S_{24} + 18.9y_{91,24} \leq S_{29}$

(325)$S_{24} + 16.35y_{92,24} \leq S_{29}$

(326)$S_{24} + 16.8y_{93,24} \leq S_{29}$

(327)$S_{24} + 20.06y_{94,24} \leq S_{29}$

(328)$S_{25} + 15.4y_{95,25} \leq S_{29}$

(329)$S_{25} + 11y_{96,25} \leq S_{29}$

(330)$S_{25} + 13.44y_{97,25} \leq S_{29}$

(331)$S_{26} + 16.35y_{99,26} \leq S_{29}$

(332)$S_{26} + 15.75y_{100,26} \leq S_{29}$

(333)$S_{26} + 13.56y_{101,26} \leq S_{29}$

(334)$S_{27} + 14.04y_{102,27} \leq S_{29}$

(335)$S_{27} + 14.56y_{103,27} \leq S_{29}$

(336)$S_{27} + 11y_{104,27} \leq S_{29}$

(337)$S_{28} + 13.2y_{75,28} \leq S_{29}$

(338)$S_{28} + 11.3y_{76,28} \leq S_{29}$

(339) $S_{29} + 16.8y_{106,29} \leq S_{PE}$

(340) $S_{29} + 19.62y_{107,29} \leq S_{PE}$

(341) $S_{29} + 22.23y_{108,29} \leq S_{PE}$

Appendix 7: System Development

Introduction

This chapter introduces the proposed web-based suppliers selection system in the context of CM. The system is developed on Amazon Elastic Compute Cloud (EC2), with the utilisation of multiple software tools and programming languages such as Microsoft Excel, What's Best Excel add-in (WB), and C#.

Software Development Environment and Tools

The web-based suppliers selection system is designed and uploaded on the virtual server of Amazon EC2. This provides a web-based environment which enables customers (such as, end users or enterprise users), manufacturers, suppliers, and retailers to offer and receive various services by visiting WWW.OPTiSupply.uk®. In fact, there are two main objectives with regard to developing a web-based suppliers selection system. First, OPTiSupply.uk® is user friendly interface (UFI) acting in a similar way with a search engine in order to find, introduce, and offer different suppliers, based on predefined criteria in the manufacturing sectors.

Secondly, the main methodology used in the current research is mathematical programming. As discussed in Chapter 5, WB is the optimising software used to model the problems. Hence, the OPTiSupply.uk® can produce Excel spreadsheets in every size without any limitations.

To create and develop the OPTiSupply.uk®, various popular programming languages are used, such as, C#, Visual Basic (VB), and JavaScript. In addition, various technologies, platforms, and software are used to design and upload the website, such as, .NET Frame work, ASP, HTML, CSS, SQLite (database engine), Office Programming, Excel Forums, and WB.

Amazon EC2

Amazon Elastic Compute Cloud (Amazon EC2) is a web service that provides resizable compute capacity in the cloud. It is designed to make web-scale CC easier for developers.

Amazon EC2's simple web service interface allows the procurement and configuration capacity with minimal friction. It provides complete control of the computing resources and allows the running on the Amazon proven computing environment. Amazon EC2 reduces the time required to obtain and boot a new server instances to minutes, allowing capacity to be quickly scaled, both up and down, as computing requirements change. Amazon EC2 changes the economics of computing by allowing the user to pay only for capacity that they actually use. Amazon EC2 provides developers the tools to build failure resilient applications and isolates them from common failure scenarios.

ASP.NET

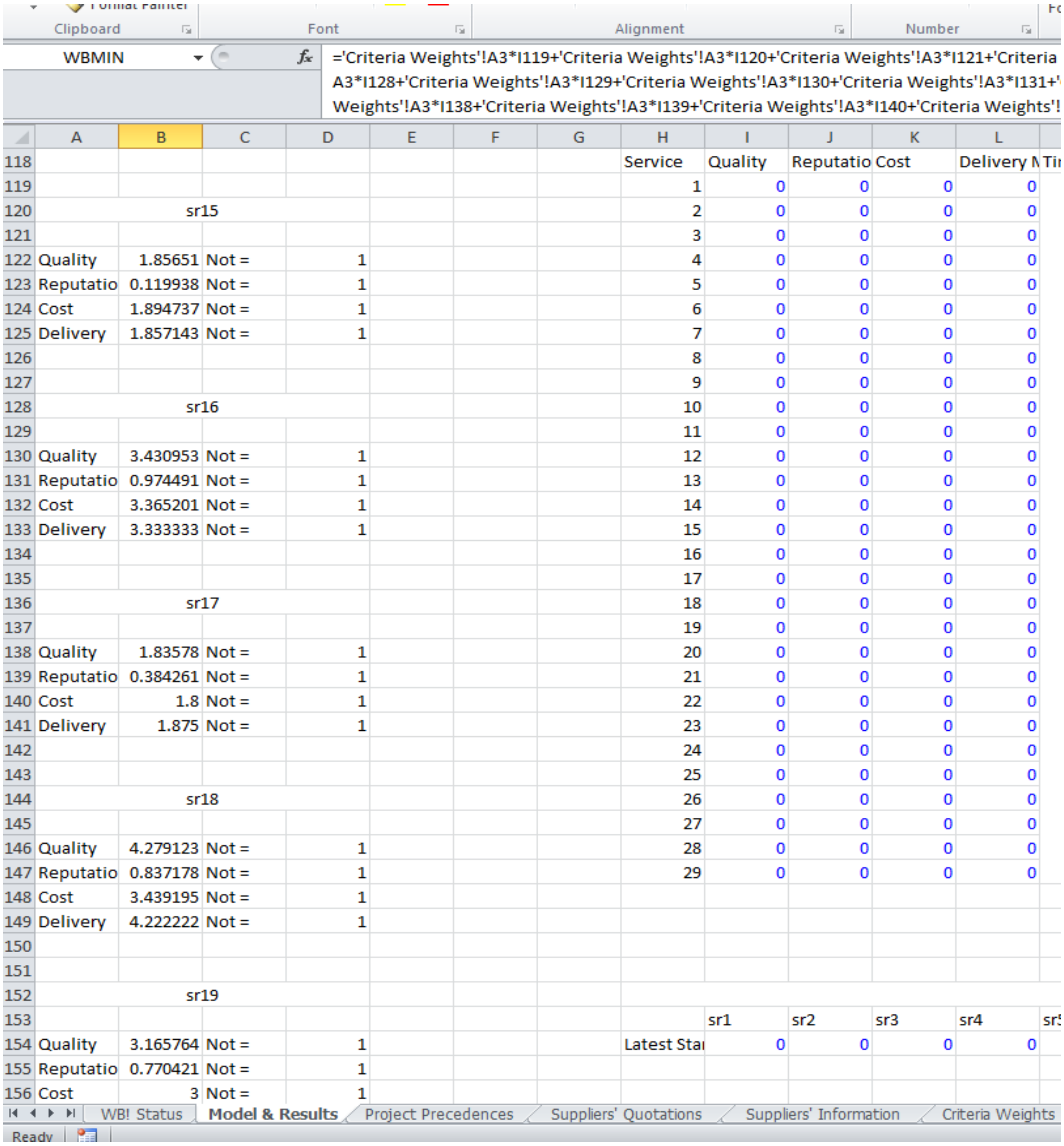
The need for ASPs has evolved from the increasing costs of specialized software that have far exceeded the price range of small to medium-sized businesses. Additionally, the growing complexities of software have led to huge costs in distributing the software to end-users. Through ASPs, the complexities and costs of such software can be minimised. The issues of upgrading have been eliminated from the end-firm by placing the onus on the ASP to maintain up-to-date services, 24 x 7 technical support, physical and electronic security and in-built support for business continuity and flexible working.

Calculation Process

The core calculation process of the software is created by the combination of the C# language and a collection of Microsoft Excel tools. The following explains how the system operates.

The raw data/information that is obtained from users' interaction with specific variables will be saved on the computer's memory. Consequently such information will be standardised in a way that could be read by Excel and its add-in, called WB.

The process in which the information is transformed in order to be read by Excel is as follows. Initially, a sample Excel file that contains all the formulae is prepared. Next, by using the pattern made by C#, all the received information will be transformed into formulae and will be inputted to an Excel file (See Figure 7.1).



Clipboard Font Alignment Number

WBMIN =‘Criteria Weights’!A3*I119+‘Criteria Weights’!A3*I120+‘Criteria Weights’!A3*I121+‘Criteria
A3*I128+‘Criteria Weights’!A3*I129+‘Criteria Weights’!A3*I130+‘Criteria Weights’!A3*I131+‘
Weights’!A3*I138+‘Criteria Weights’!A3*I139+‘Criteria Weights’!A3*I140+‘Criteria Weights’!

	A	B	C	D	E	F	G	H	I	J	K	L
118								Service	Quality	Reputatio	Cost	Delivery N Ti
119								1	0	0	0	0
120		sr15						2	0	0	0	0
121								3	0	0	0	0
122	Quality	1.85651	Not =	1				4	0	0	0	0
123	Reputatio	0.119938	Not =	1				5	0	0	0	0
124	Cost	1.894737	Not =	1				6	0	0	0	0
125	Delivery	1.857143	Not =	1				7	0	0	0	0
126								8	0	0	0	0
127								9	0	0	0	0
128		sr16						10	0	0	0	0
129								11	0	0	0	0
130	Quality	3.430953	Not =	1				12	0	0	0	0
131	Reputatio	0.974491	Not =	1				13	0	0	0	0
132	Cost	3.365201	Not =	1				14	0	0	0	0
133	Delivery	3.333333	Not =	1				15	0	0	0	0
134								16	0	0	0	0
135								17	0	0	0	0
136		sr17						18	0	0	0	0
137								19	0	0	0	0
138	Quality	1.83578	Not =	1				20	0	0	0	0
139	Reputatio	0.384261	Not =	1				21	0	0	0	0
140	Cost	1.8	Not =	1				22	0	0	0	0
141	Delivery	1.875	Not =	1				23	0	0	0	0
142								24	0	0	0	0
143								25	0	0	0	0
144		sr18						26	0	0	0	0
145								27	0	0	0	0
146	Quality	4.279123	Not =	1				28	0	0	0	0
147	Reputatio	0.837178	Not =	1				29	0	0	0	0
148	Cost	3.439195	Not =	1								
149	Delivery	4.222222	Not =	1								
150												
151												
152		sr19										
153									sr1	sr2	sr3	sr4 sr5
154	Quality	3.165764	Not =	1				Latest Sta	0	0	0	0
155	Reputatio	0.770421	Not =	1								
156	Cost	3	Not =	1								

WB! Status | Model & Results | Project Precedences | Suppliers' Quotations | Suppliers' Information | Criteria Weights

Ready

Figure 7.1: Excel file, model and results page

This pre-programmed file, which can be edited by the software, contains commands and code written in the VB language (Figure 7.2). The formulae that contain the input information are calculated in this file and consequently produce data that will be processed by the WB.

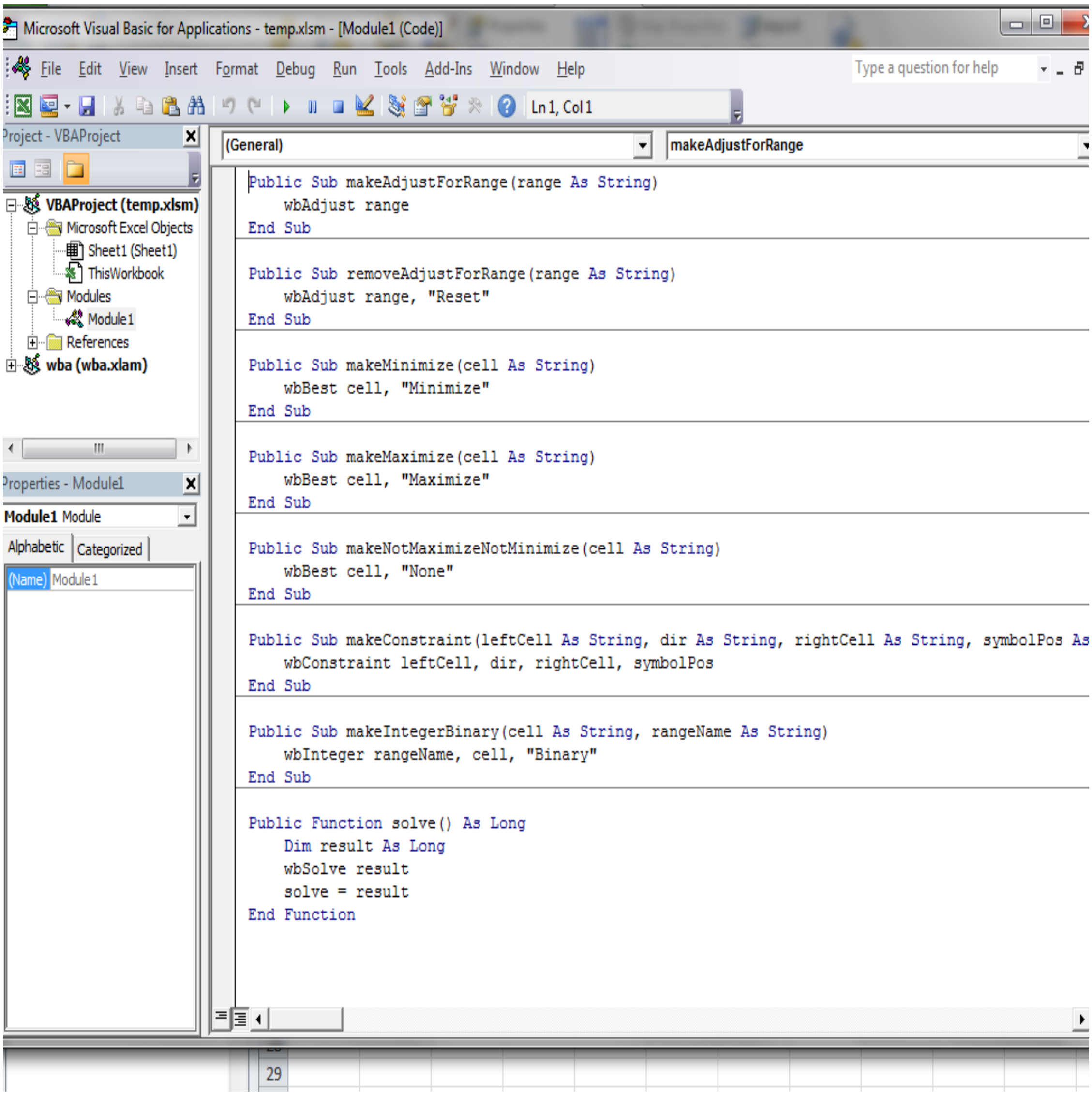


Figure7.2: Sample commands in VB

These commands in WB help users to formulate and generate a mathematical model, such as, main objective function, constraints, and decision variables. To program the proposed web based system, called OPTiSupply.uk®, VB interface is used to direct all required commands to WB in order to develop a model. In fact, by using the VB interface, it is possible to utilise all the power and functionality of WB in Excel. Hence, it is necessary to create VB functions to simulate the WB toolbar buttons (See Figure 7.3).

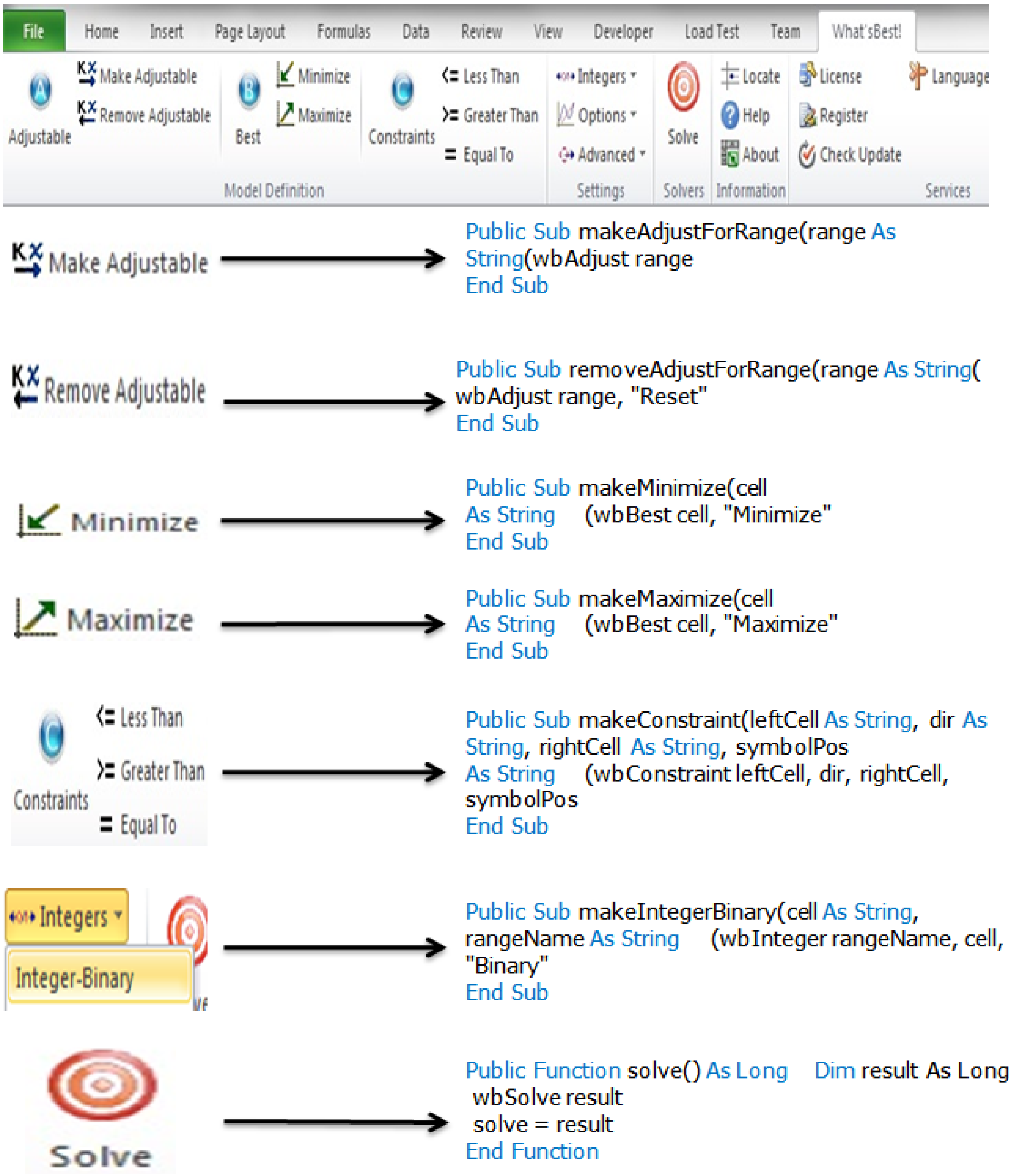


Figure 7.3: Transforming WB buttons to VB interface

As shown in Figure 7.3, the formulae that contain the input information are calculated in this file and consequently produce data that will be processed by the WB. Following the processing of such information, the functions that have been defined/predetermined in Excel (in VB) will be called through C#. These functions, whose main responsibility is to execute the commands and to define WB parameters by using the numbers from for Excel sheet, make modifications to the Excel files following their execution. Once the modifications have been completed, the software uses a function in Excel which conducts the final calculations. Figure 7.4 shows the summary of the whole process:

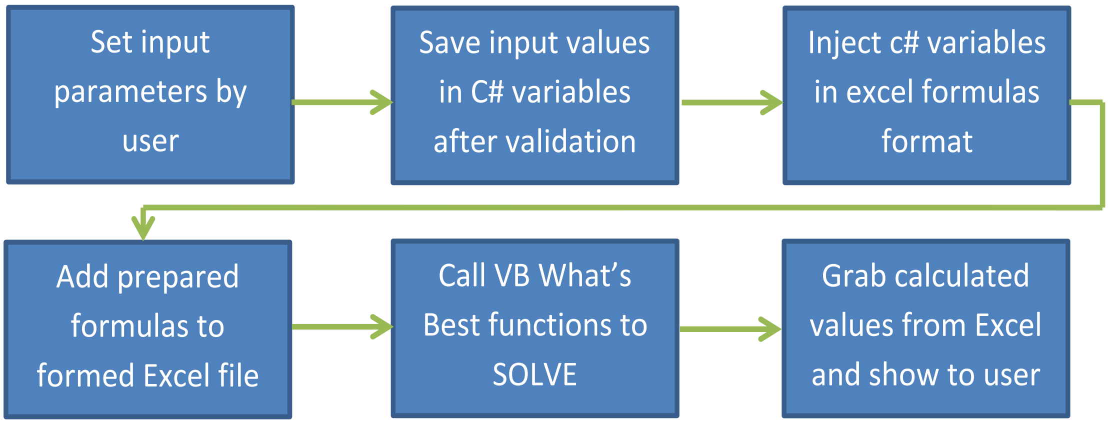


Figure 7. 4: Calculation process diagram

Database Management System

There are mainly two types of information that need to be stored in the database storage. The first type is subscription information, which allows visitors to subscribe to the website by signing up and take advantages of the offered services. This information is stored in the SQLite library. In order to activate a customer`s account, information, such as full name, preferred password, company name, country, email address, job title, and telephone number are optional. After activation of the account, customers can sign in on OPTiSupply.uk®, either on the homepage, or on the sign-in page (Figure7.5).

Figure 7.5: Sign in section in homepage

The second type of information is with regard to suppliers, services, and relationships among services kept in the virtual computer provided by Amazon EC2.

The relationship structure in the OPTiSupply.uk® system is established in a way that each supplier can offer one or more services in each project, while each service could be assigned with one or more suppliers. In other words, the relationship between suppliers and services are M to N or M:N.

Furthermore, the inter-relationship among services is 1 to N or 1:N, because each service can have one or more predecessors in each project. Figure 7.6 indicates both types of relationships including relationships between suppliers and services, and inter-relationships among services.

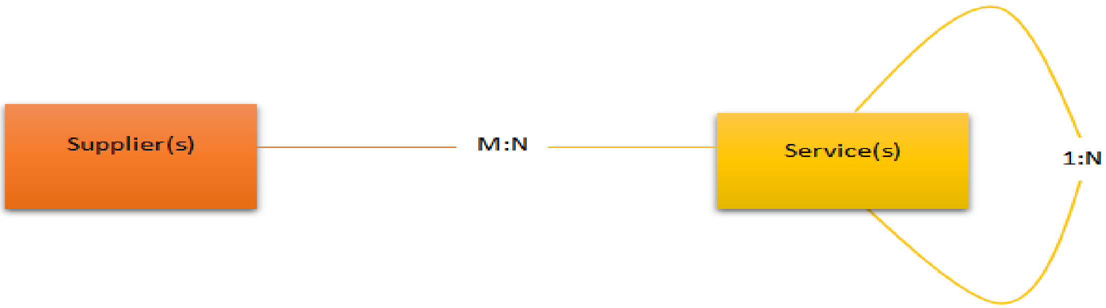


Figure 7.6: Relationships among suppliers and services

User Interface

User Interface consisted of five pages, of which four pages, namely, 'criteria weights', 'services and predecessors, 'suppliers information', suppliers quotations', are responsible for receiving data from both users and suppliers/manufacturers, while the 'final result' page shows the output of the system created by Excel and WB. This next section will define these five pages in detail. Figure 7.7 represents the information diagram in related to use the OPTiSupply.uk®.

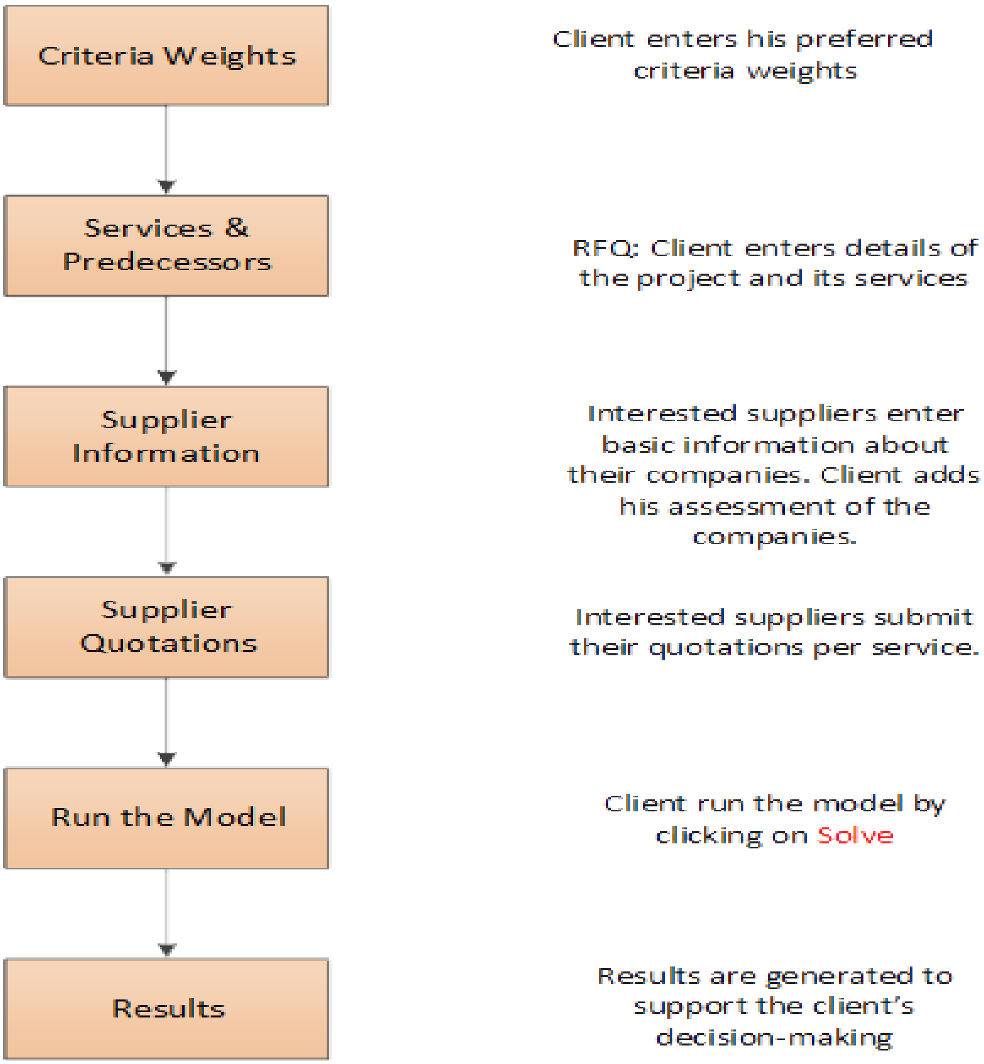


Figure 7.7: Information diagram

Criteria Weights Page

The first page of the system receives two types of information, criteria weightings and sub-criteria weightings for quality and reputation criteria. In this page, customers need to enter preferred weighting scores with regard to five predefined criteria such as quality, reputation, cost, delivery method, and time. In order to have a correct format and range, all the information is checked by the system and then saved to utilise in next page. These weightings can be within a scale of 1 to 10 where 10 represent the most significant. For example, it is noted at the bottom of the page that 6 is twice as important as 3, and 9 is three times as important as 3. Figure 7.8 represents the 'criteria weightings' page according to the information provided by the P.D in Havayar Co Group, as shown in Chapter 6.

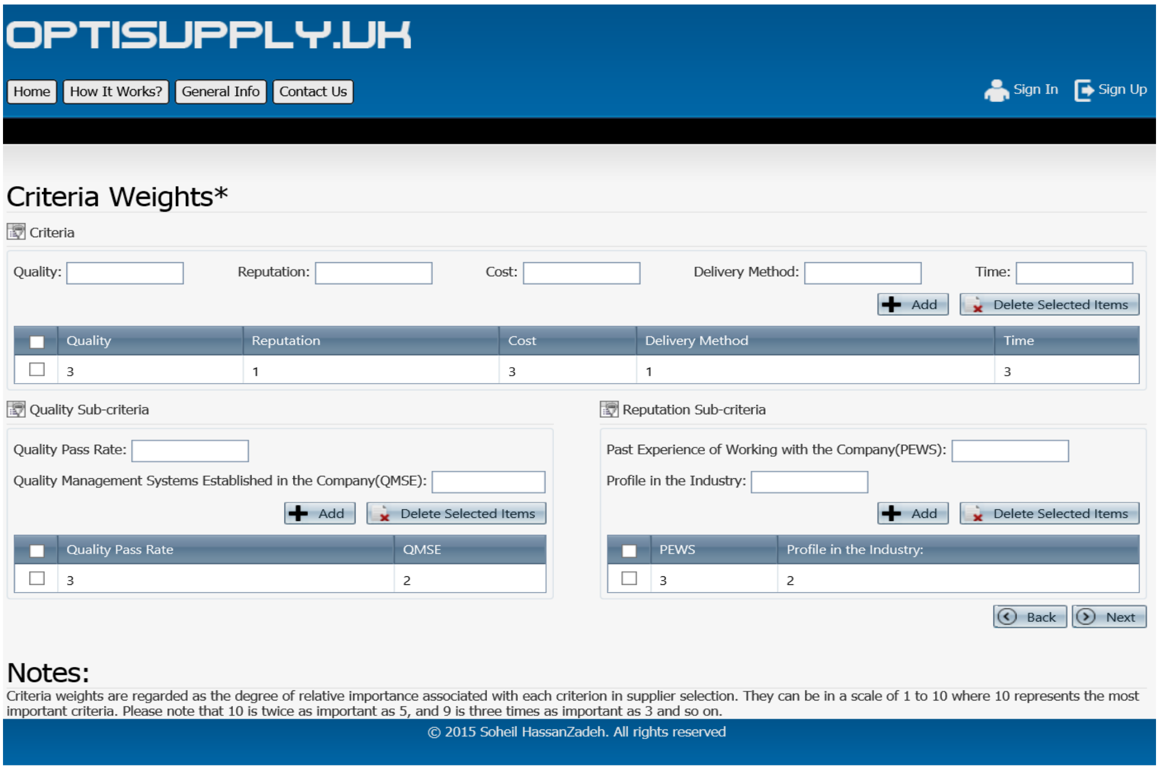


Figure 7.8: Criteria weightings page

Services and Predecessors Page

Information such as project title, project duration (days), project start date, service titles, and immediate predecessors need to be entered to the system by customer.

The project title shows the title/name of the project or a part of the project. Project duration shows the project completion time, which is estimated by the customer. If the estimated (desired) time is less or equal to the real final completion time, the system will show the real project completion time in the final result page. This means the earliest project completion time is more than the customer desired time. On the other hand, if the estimated time by the customer is more than a real completion time of the project, the system will show the required time by customer. Hence, there is no extra time in the project.

Project start time shows the exact, preferred day that the customer wishes the project to start. Based on the project start time, a Gantt chart will be presented in the final result page.

Lastly, customer needs to enter all services and predecessors in the project in order to define inter-connected services to the system.

Figure 7.9 represents the 'services and predecessors' page in regard with information from Chapter 6.

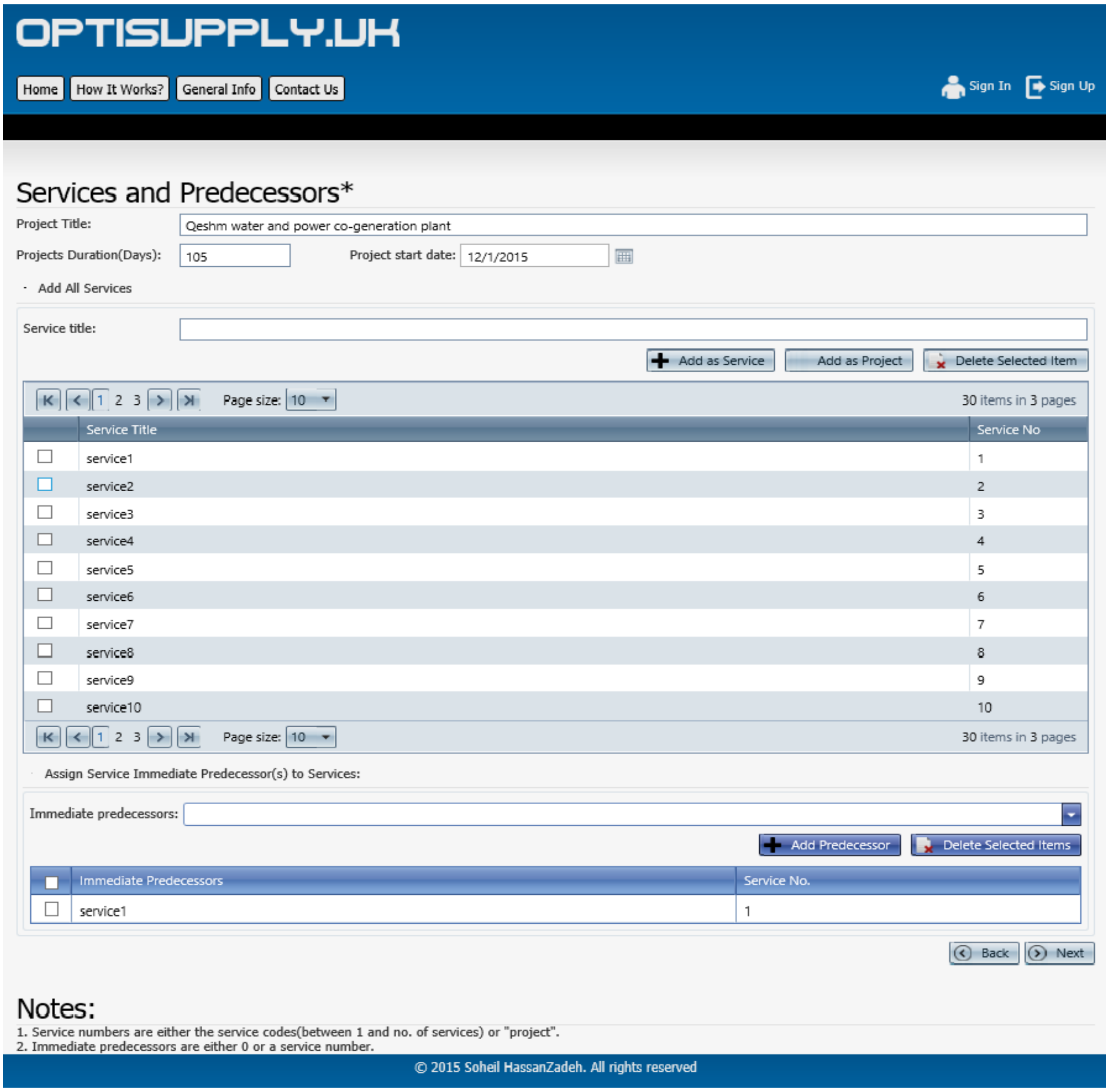


Figure 7.9: Services and predecessors page

Suppliers Information Page

This page shows two types of information, suppliers information and suppliers historical dynamic data.

As explained in previous chapters, interested suppliers need to provide basic information about their companies, such as total value of orders allocated to their company (TVOA), number of years of experience in the industry or year stablished (YE), and quality management system certifications (QMSC). Hence, this information and name of each supplier is entered into this page in order to measure quality and reputation scores, as well as being stored in a database.

According to customer feedback and assessments on suppliers performance over time, historical quality compliance level (HQCL) and historical time over-run percentage (HTOP) are entered in this page. In general, all this information validates the memory function, learning algorithms, and management system proposed in this research. Figure 7.10 shows the suppliers information page with regard to the information shown in Chapter 6.

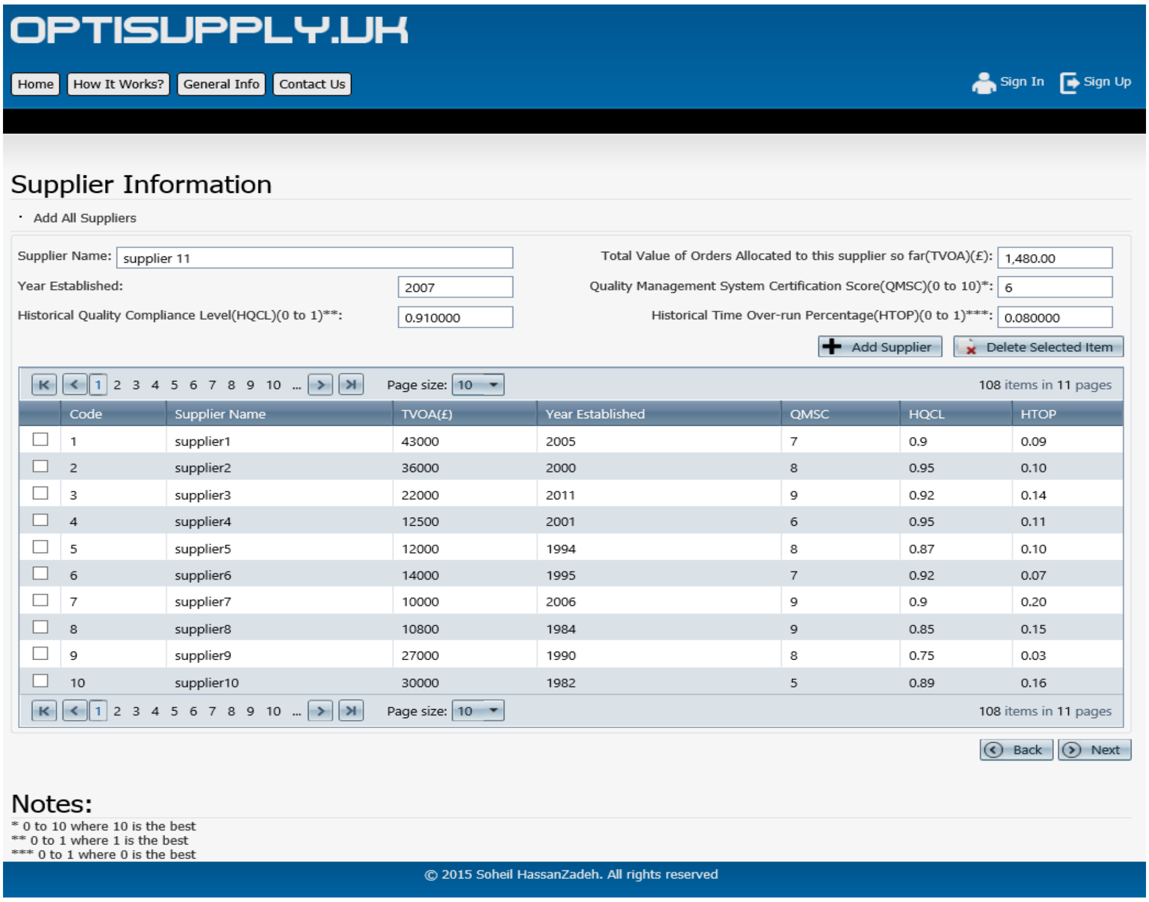
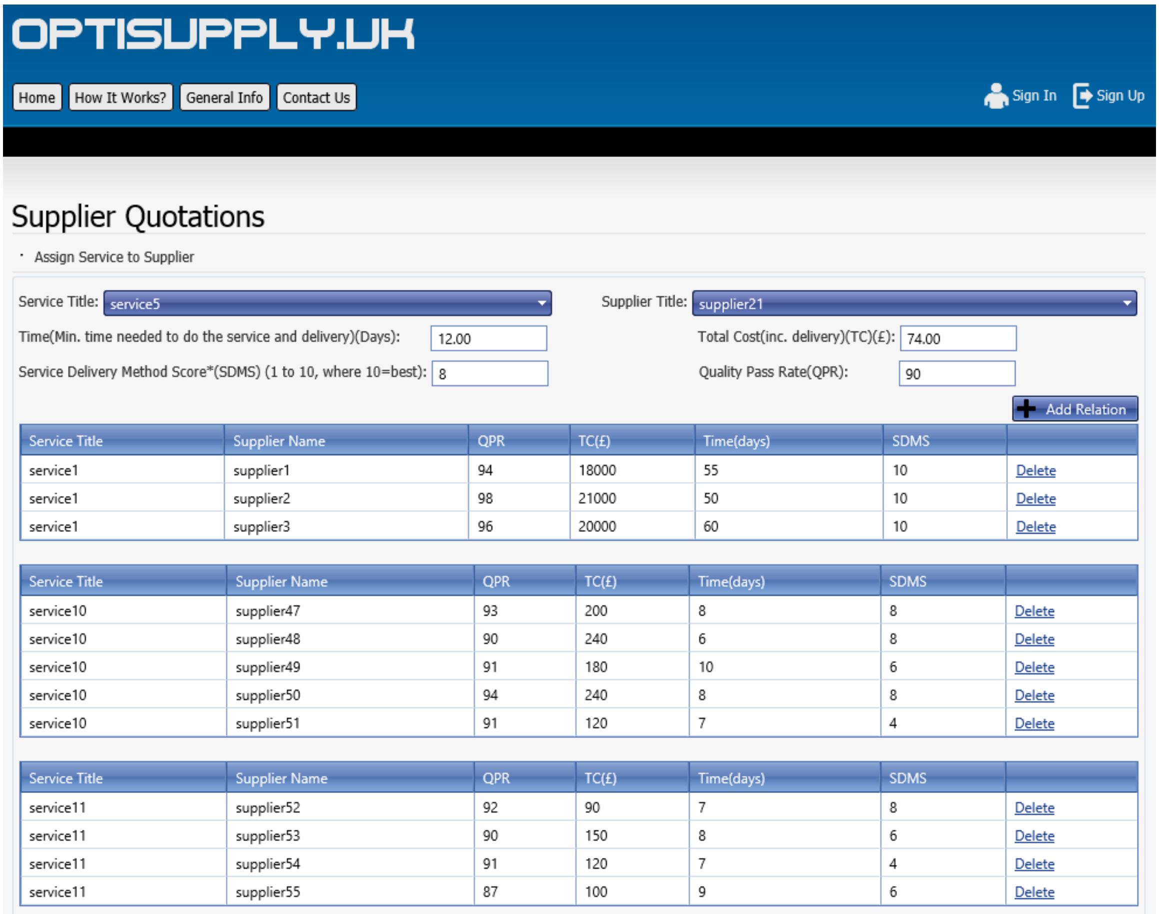


Figure 7.10: Suppliers information page

Suppliers Quotations Page

The supplier quotation page is the last page in which information is entered. Suppliers need to submit their proposals, such as, quality pass rate (QPR), time, cost, and delivery method for each service. According to the system, there are various relationships between services and suppliers. For example, one supplier can offer one or more services in the project, while one service could be assigned to one or more suppliers.

Figure 7.11 indicates a suppliers quotation page with regard to supplier proposals for various services in the compressed air system discussed in Chapter 6.



Service Title	Supplier Name	QPR	TC(£)	Time(days)	SDMS	
service1	supplier1	94	18000	55	10	Delete
service1	supplier2	98	21000	50	10	Delete
service1	supplier3	96	20000	60	10	Delete

Service Title	Supplier Name	QPR	TC(£)	Time(days)	SDMS	
service10	supplier47	93	200	8	8	Delete
service10	supplier48	90	240	6	8	Delete
service10	supplier49	91	180	10	6	Delete
service10	supplier50	94	240	8	8	Delete
service10	supplier51	91	120	7	4	Delete

Service Title	Supplier Name	QPR	TC(£)	Time(days)	SDMS	
service11	supplier52	92	90	7	8	Delete
service11	supplier53	90	150	8	6	Delete
service11	supplier54	91	120	7	4	Delete
service11	supplier55	87	100	9	6	Delete

Figure 7.11: Suppliers quotation page

When all the information is entered into the system, the client needs to run the model by clicking on the 'solve' button. At this stage, the system automatically starts generating an Excel model based on all the information already entered into the system. Then WB solves the problem and sends back the results to be reviewed by clients.

Final Results Page

This page is an output of the system showing final results to the customer and consists of a results table, pie chart, and Gantt chart. Figure 7.12 shows the final result table with regard to the information represented in Chapter 6.

OPTISUPPLY.UK

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Sign In | Sign Up

Final Results

final result: Qeshm water and power co-generation plan

	Supplier	Cost(£)	Time (Days)	Quality	Reputation	Delivery
service1	2	21000	55	0.92	0.65	1
service2	6	360	7	0.82	0.47	0.6
service3	9	1400	19	0.7	0.7	0.75
service4	14	10000	37	0.89	1	1
service5	22	70	9	0.86	0.23	1
service6	25	190	18	0.88	0.24	0.8
service7	32	850	22	0.72	0.56	0.75
service8	42	85	22	0.91	0.27	0.6
service9	43	200	22	0.84	0.15	0.75
service10	51	120	9	0.88	0.29	0.5
service11	52	90	8	0.83	0.38	1
service12	58	280	14	0.87	0.32	1
service13	63	11	8	0.89	0.24	0.8
service14	68	22	9	0.81	0.6	1
service15	75	5	14	0.91	0.08	0.75
service16	80	220	25	0.87	0.3	0.75
service17	81	80	12	0.94	0.2	0.75
service18	51	120	9	0.88	0.29	0.5
service19	52	90	8	0.83	0.38	1
service20	58	280	14	0.87	0.32	1
service21	63	11	8	0.89	0.24	0.8
service22	84	4	23	0.94	0.38	0.8
service23	86	6	22	0.79	0.14	0.75
service24	94	4	21	0.87	0.21	1
service25	96	34	11	0.85	0.18	0.8
service26	100	37	16	0.95	0.17	0.75
service27	102	18	15	0.81	0.07	1
service28	75	5	14	0.91	0.08	0.75
service29	106	1300	17	0.9	0.41	0.8
Project Total	-	36892	109	0.86	0.33	0.82

Figure 7.12: Final results page in regard with 108 suppliers and 29 services

As explained in Section 7.4.2, this system provides a Gantt chart in order to show the start and finish time of each service, and critical path sequence for further analysis. Hence, according to Figure 7.13, the critical path sequence is ‘Service 1, Service 4, and Service 29’ (see also Appendix 7). It means if any delay happens in these three services, the final project completion time will face delay. For example, if Supplier 2 ,who is responsible to provide a Service 1 (design service), actually delivers design files in 56 days, instead of 55 days, the final project completion time will change from 109 days to 110 days.

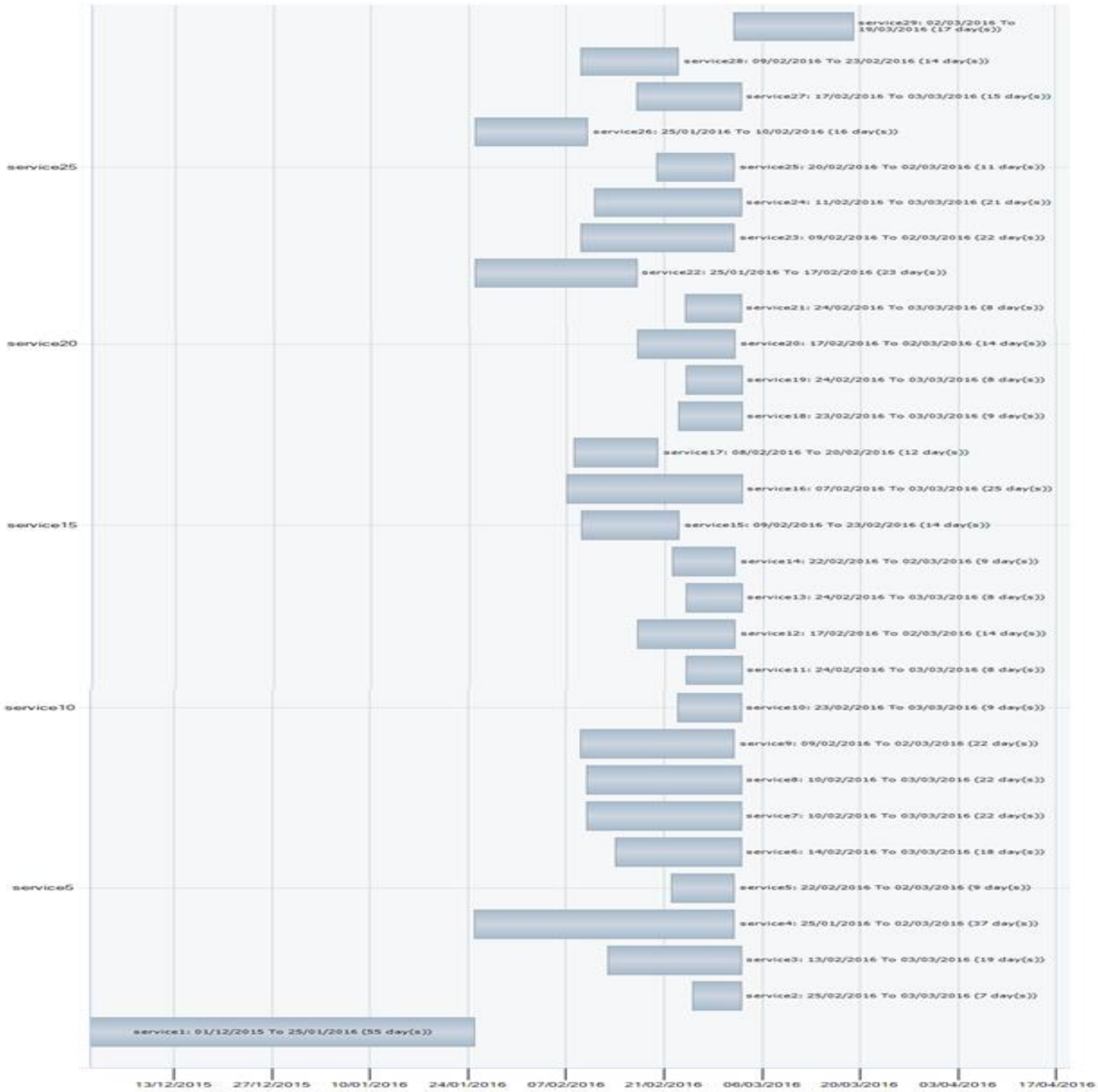

Figure 7.13: Gantt chart

It should be noted that all costs associated with the project are shown in a Pie chart provided in the final results page (Figure 7.14).

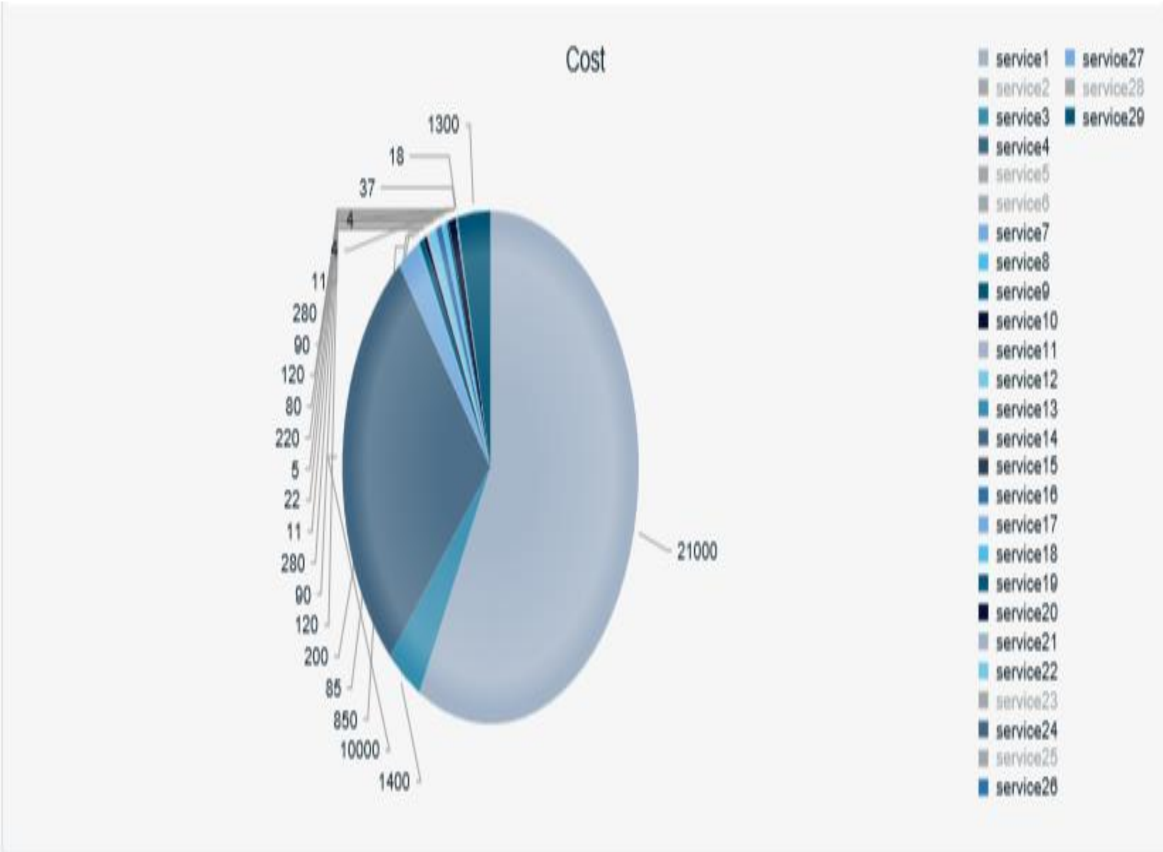

Figure 7.14: Pie chart

In addition, Figure 7.15 shows the final results page with regard to a numerical example which has been shown in Chapter 5.

	Supplier	Cost (£)	Time (Days)	Quality	Reputation	Delivery
Service1	7	330	32	0.84	1	1
Service2	3	400	14	0.79	0.93	1
Service3	8	180	15	0.9	0.62	0.8
Project Total	-	910	47	0.84	0.85	0.93

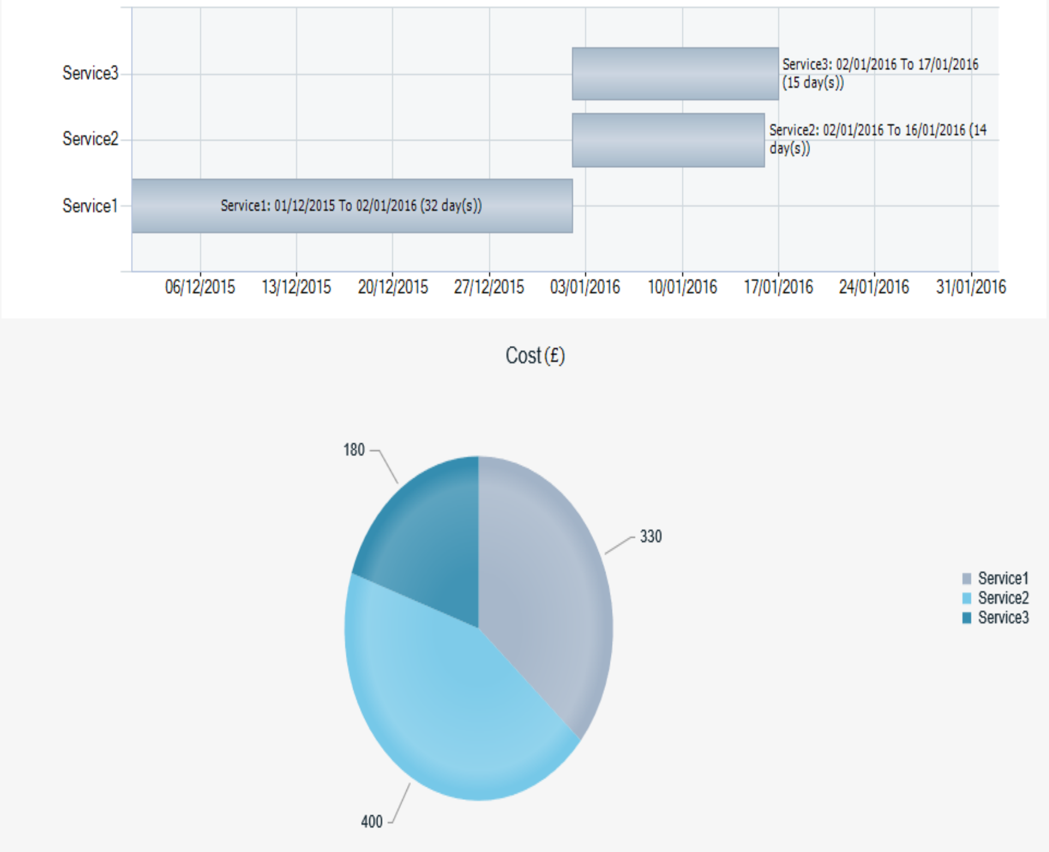

Figure7.15: Final results related to numerical example in Chapter 5

Advantages and Limitations of the System

Some of the advantages of the system include:

- The software has unlimited capacity to take an unlimited number of parameters. For example, the users have no limitations in setting as many services or suppliers, or the creation of relationships between them.
- The software is online and can be accessed at any time.

- The software can be used at a commercial level and has the option for new users to become members.
- The software is user friendly and has an appealing interface.

However, the proposed system includes limitations such as:

- The main weakness of the software is the slow speed of calculation, in particular when there are a large number of input parameters. In fact, the indirect calculation could slow down the final calculations. As explained earlier, the time required for the initial information to be prepared by Excel, followed by undertaking calculations and then the results being interpreted and standardised could be quite time consuming.
- All the user interface activities are executed server-side. This could cause delays for the user while the interface waits for response from the server. One solution to this could be to process more data client-side, for example, using JavaScript, before submitting data to the server.

Appendix 8: A List of Publications Arising from the PhD Research

Conferences:

Hassanzadeh, S., Cheng, K., (2013), 'An Investigation on the Cloud Based Approach towards Global High Value Manufacturing for SMES', Advanced in manufacturing technology, *11th International Conference on Manufacturing Research*, pp. 189-194, Cranfield, UK.

Hassanzadeh, S., Cheng, K., (2016), 'Manufacturing Supplier Selection in Cloud Manufacturing Context and its Implementation and Application Perspectives (Submitted)', *Proceedings of the 2016 Manufacturing Science and Engineering Conference*, MSEC 2016, Virginia, USA.

Journal:

Hassanzadeh, S., Cheng, K., (2016), 'Suppliers Selection in Manufacturing Industries and Associated Multi-Objective Decision Making Methods: Past, Present, and the Future'. *European Scientific Journal* (ESJ), Vol.12, No.1, pp.93-113.