INTEGRATED DECISION MAKING IN GLOBAL SUPPLY CHAINS AND NETWORKS

by

Ozlem Arisoy

B.S. in Industrial Engineering, Bogazici University, 2003

M.S. in Industrial Engineering, University of Pittsburgh, 2004

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This dissertation was presented

by

Ozlem Arisoy

It was defended on

July 6, 2007

and approved by

Dissertation Director: Bopaya Bidanda, Professor, Industrial Engineering Department

Dissertation Co-Director: Larry J. Shuman, Professor, Industrial Engineering Department

Brady Hunsaker, Assistant Professor, Industrial Engineering Department

Ravindranath Madhavan, Associate Professor, Business Administration

Kim LaScola Needy, Associate Professor, Industrial Engineering Department

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Ozlem Arisoy, PhD

University of Pittsburgh, 2007

One of the more visible and often controversial effects of globalization is the rising trend in global sourcing, commonly referred to as outsourcing, offshoring and offshore outsourcing. Today, many organizations experience the necessity of growing globally in order to remain profitable and competitive. This research focuses on the process that organizations undergo in making strategic decisions of whether or not to go offshore, and then on the location and volume of these offshore operations.

This research considers the strategic decision of offshoring and sub-divides it into two components: analysis of monetary benefits and evaluation of intangible variables. In this research, these two components are integrated by developing an analytical decision approach that can incorporate quantitative and qualitative factors in a structure based on multiple solution methodologies. The decision approach developed consists of two phases which concurrently assess the offshoring decision by utilizing mixed integer programming and multi-attribute decision modeling, specifically using Analytic Network Process, followed by multi-objective optimization and tradeoff analysis. The decision approach is further enhanced by employing engineering economic tools such as life cycle costing and activity based costing. As a result, the approach determines optimal offshoring strategies and provides a framework to investigate the optimality of the decisions with changing parameters and priorities.

The applicability, compliance and effectiveness of the developed integrated decision making approach is demonstrated on two real life cases in two different industry types. Through empirical studies, different dimensions of offshoring decisions are examined, classified and characterized within the framework of the developed decision approach. The solutions are evaluated by their value, level of support and relevance to the decision makers. The utilization of the developed systematic approach showed that counterintuitive decisions may sometimes be the best strategy.

This study contributes to the literature with a comprehensive decision approach for determining the most advantageous offshoring location and distribution strategies by integrating multiple solution methodologies. This approach can be adapted in the corporate world as a tool to improve global perspective and direction.

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PREFACE

I would like to gratefully acknowledge my dissertation advisor, Dr. Bopaya Bidanda, for his motivation, inspiration and positive disposition throughout my doctoral study. Additionally, I would like to extend my sincere gratitude to Dr. Larry J. Shuman who provided me invaluable advice and generous support. Thank you for believing in me, investing in me and giving continuous support for my professional and personal development.

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1.0 INTRODUCTION

Outsourcing is the transfer of internal functions to an outside corporation whereas "offshore" outsourcing is the transfer of these functions to overseas locations. A.T. Kearney [1] defines the relationship between outsourcing and offshoring by classifying the operational transfer into four parts. The concept of "supply chain and network" in this research is incorporated into this classification scheme as shown in Figure 1-1.

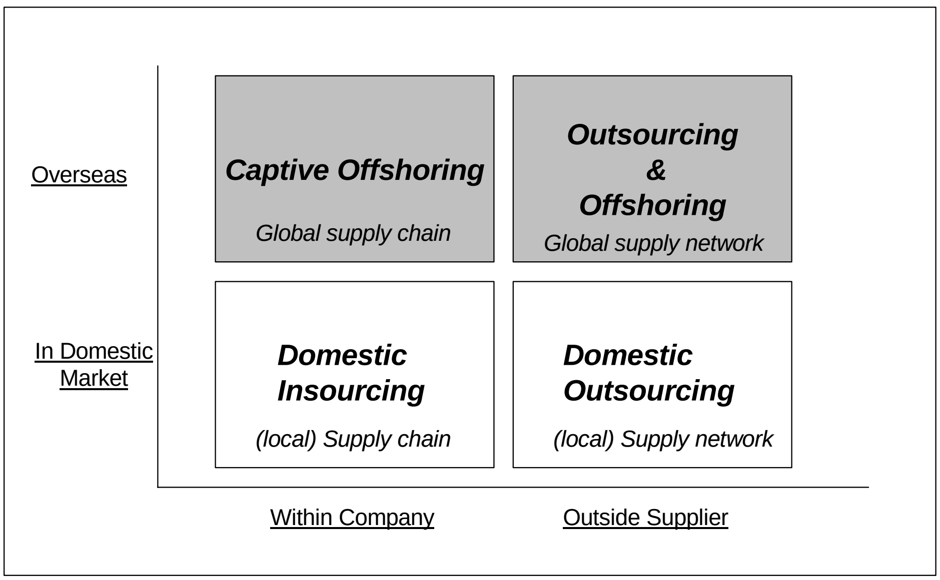

Figure 1-1. Description of Concepts

Domestic insourcing and outsourcing happen when the market demand exceeds the capacity of production (or services) and the company seeks support from either outside suppliers or inside parties without going outside of the domestic market. These are common practices to enlarge the size of the business temporarily or permanently. On the other hand, a company may want to broaden its operations by expanding outside of the local region. Typically in these cases multi-national companies grow globally by investments in different countries. This is called "captive offshoring." Instead of making investments, an organization may be willing to go offshore (perhaps without expanding the market) by contractual agreements with an outside supplier. By doing so, the risks involved in captive offshoring is mitigated, while some of the benefits such as lower cost production are accrued. This case is called "offshore outsourcing" where in many instances the corporations can gain the advantages of international business while protecting itself from the complications. The term "offshoring" encompasses a company's strategic action of going offshore either by outsourcing based on an agreement with a third party or by investing in an overseas region.

If the operations are performed in-house then the coordination of manufacturing, service and transportation operations are executed within a chain structure and information flow is unidirectional against the flow of material. Such a structure is common in a majority of businesses and it is called a "supply chain." On the other hand, if the operations are performed with the participation of outside suppliers, the information and material flows are multi-directional and their directions may or may not be opposite to each other. Rather than being a chain, this structure is a "network" of different vendors. Depending on the location of the operations, the supply chain (or network) is distinguished as global or domestic. This research focuses specifically on global supply chains and networks with outsourcing and captive offshoring, which combined is called "offshoring."

Globalization and offshoring are complementary subjects commonly debated on many levels. The reality is that globalization is occurring as a result of scientific and technological advancements and its growth likely will escalate. As businesses continue their global expansion the option of offshoring has also increased as a viable alternative. During this process organizations encounter decisions concerning the selection of manufacturing and service locations and the distribution of these manufacturing and service operations. Such strategic decisions are often assessed from a quantitative point of view where the analyses mostly involve financial elements. However there are many other factors, including risks and intangible opportunity variables, which need to be considered with a structured approach for selecting destination locations and distributions of operations. The purpose of this research is to present a thorough analysis of offshoring practices and consequently, provide an integrated decision model that can handle the complexities and multidimensionality of strategic selection of site location and distribution in order to better optimize global supply chains and networks.

This study first discusses the globalization trend in the world and examines the factors that lead to the growth of offshoring and the intended and unintended economic and social consequences in the developed and developing worlds. After a brief discussion, the study focuses on corporate decisions in going offshore which is followed by the evolution of the supply chain structure towards a global supply network structure. The literature on corporate decision making, decision modeling, supply chain management and supplier selection models is elucidated. Later, the study presents the motivation, development, practice and results of an integrated decision model that is specifically and extensively built to support offshoring decisions, including the decision to stay in-house or to go offshore and the decision on where to locate and how to distribute operations across the world.

1.1 MOTIVATION

Globalization is a term that encompasses the increases in the world trade as well as the borderless worldwide interdependencies within a framework of political and social relationships. The integration of the global economy through trade has given rise to the interconnectedness of international economies and politics. Decisions and activities in one part of the world can no longer remain local; their effects ripple through the societies and economies of multiple communities in various parts of the world.

The inter-connectedness of national economies, the rapid ascent of countries such as China and India on the global manufacturing scene, and the pro-active role of the World Trade Organization, regional alliances, including the European Union, NAFTA and the more fledging Mercosur (southern Latin America) have all been factors in synergizing this movement towards Thomas Friedman's "flat world."[2] However, the biggest factor has been the high speed communication links that have arisen over the past ten years which have enabled many high-end, technical tasks to be performed almost anywhere on the planet.

Table 1-1 provides evidence of the significant growth in economic interaction during the last decade.

Table 1-1. International Trade in the U.S. 1993-2004[3]

in mil.USD	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Total Exports	464,858	512,416	583,031	622,827	687,598	680,474
Total Imports	580,469	663,830	743,505	791,315	870,213	913,885
in mil. USD	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total Exports	692,821	780,419	731,026	693,257	723,743	817,936
Total Imports	1,024,766	1,216,888	1,141,959	1,163,549	1,259,396	1,469,671

As noted, the growth in trade is the result of both technological developments and a concerted effort to reduce trade barriers. First, the trade liberalization enabled the expansion of international relationships. Since 1947, when the General Agreement on Tariffs and Trade (GATT) was created, the world trading system has benefited from eight rounds of multilateral trade liberalization, as well as from unilateral and regional liberalization. The last of these eight rounds (the so-called "Uruguay Round" completed in 1994) led to the establishment of the World Trade Organization to help administer the growing body of multilateral trade agreements [4]. Newer organizations such as the European Union and the Mercosur have helped to accelerate the growth of today's inter-connected economy (although both the EU and Mercosur have recently suffered major setbacks in terms of their constitution and the failure to reach a broader, western hemispheric agreement respectively).

With this trade liberalization in recent years, there have been continuous improvements in communication and transportation technologies. These two factors have facilitated easy access to distant locations, especially in large, urban areas around the world. The evolutions in the Internet and the World Wide Web has had an enormous effect on the communication technology and the current advances such as wireless networks and quantum computers promise inconceivable progress for future communications systems.

As a consequence, national boundaries are becoming less important to the large, multinational corporations who now operate on a global scale. Indeed, as boundaries have become permeable due to the technological explosion in global communications and low cost travel, these companies have become transnational, owing allegiance, or even headquarters to no particular country. This has led to the creation of new markets, new customers, and even a "new manufacturing order." Globalization has also spurred competition among companies on an international scale, especially in the highly developed countries.

One result of globalization is the rapid growth of offshore outsourcing or offshoring, i.e., the outsourcing of functions and jobs to offshore locations. In the U.S. offshoring has progressed to the point where it affects everyday lives, from the cars we drive (of which a large portion of the work and components are outsourced) to computers (which are typically manufactured offshore and shipped back to the United States) and to electronic diagnostics (where calls are answered overseas). This phenomenon has implications on our lives and on the jobs that engineers and scientists will assume both now and in the future. Further, it is something that all highly developed and even some lesser developed countries must face.

The rapid development of communications systems combined with a competitive need to find lower cost alternatives without sacrificing quality or performance has resulted in corporations that operate on a global scale. Rather than this being a new phenomenon, it is part of a long-term trend that in the U.S. started in the 1970s with manufacturing. Over the past thirty-plus years an increasing number of U.S. manufacturing jobs, as well as similar jobs in other highly developed countries, have migrated to countries with substantially lower labor costs. While these were initially low-end, low-skilled jobs, it is the current movement of high-end, highly-skilled work that is creating concern within U.S. government, industry and educational circles. Today the Internet and high-speed data networks enable knowledge tasks to be done practically anywhere in the world, potentially allowing companies in the developed world to achieve cost savings or simply to stay competitive enough to remain in business by shifting work offshore [5]. In addition to the labor cost advantages, the use of English as the medium of education in such East Asian countries as India and the Philippines has also helped to attract an increasing amount of outsourced work from the U.S. as well as from European countries and Japan, Taiwan and Korea. This is especially true as English becomes the primary language of international business [6]. As a result, an increasing movement of work to low-cost countries continues to appear in certain industries across the developed world.

Due to its significant impact on the economies of both the developing and developed worlds, offshoring has been subject to many controversial discussions. Although the offshoring trend drew some attention when blue-collar workers began losing jobs, as U.S. unemployment rates rose after 2000 and high tech jobs started moving offshore, the effects on the economy of the current globalization phase is now being questioned. As a result, a large shift towards low-cost countries has appeared in certain industries at an increasing rate. In fact, offshoring in the areas of information technology (IT) and business process operations (BPO) has become an accepted practice [7]. In a frequently cited 2005 report, Forrester Research predicted that 3.3 million U.S. service jobs would be relocated abroad in the next 10 years. Further, McKinsey & Co. reported that the U.S., Europe and Japan combined are losing 600,000 service and manufacturing jobs a year [8]. According to Gartner Inc. in another widely cited report, this trend is likely to continue so that by 2010 one of every four high technology jobs in developed nations will be outsourced to emerging markets in India, China and elsewhere[6]. Farrell of McKinsey and Company has estimated that engineering is the most vulnerable of the professions relative to offshoring with up to 52% of the jobs at risk [7].

For some people, offshoring is a globalization effort that creates opportunities for future innovations, contributing to the world economy. For others, it has a destructive effect on local economies, increasing unemployment rates and weakening the industrial power of the offshoring country. Above all, offshoring is a result of blending effects coming from globalization and market competition which actually trigger one another. On one side, world cultures unify through the rise of communication technologies (a part of globalization) leading to enormous expansion in the consumer and production markets beyond the boundaries of the developed world. On the other side, political and economic developments, such as privatization of public-sector organizations and free trade agreements establish a liberated setting for corporations to do business globally. At the same time, the development of manufacturing processes and technological enhancements cause a reduction in product life cycles. As a result, both the supply and demand for low price, high quality and largely customized products (and services) have increased dramatically. With the growing market competition, big box retailers such as Wal-Mart and Home Depot gain power over manufacturers. By means of this power shift, retailers have more incentive for tougher negotiations [9] which leads to an inconceivable chase for low cost and high quality production and services.

In conclusion, offshoring is not a simple search for lower cost alternatives. It is a consequence of several intertwined factors that cannot be simply avoided. Companies now go offshore not simply because of low labor costs. The availability of highly educated young workers, government subsidies, tax reduction and infrastructural improvement in developing countries are also attractive for the corporations seeking a competitive edge in the global market. However, offshoring is not always the best or even the only option for corporations in many industries. In spite of the immense market competition, in many cases it is more advantageous to stay in-house for several reasons. The decision as to whether or not to go offshore and where to go is a complex one. The goal of this research is to investigate the factors that should be considering in making offshoring decisions and to develop an integrated model that can be utilized to make the decisions of where (in-house vs. overseas country) and in what proportions to keep/transfer manufacturing and service operations.

1.2 PROBLEM STATEMENT

Today, offshoring stands out as an attractive option for a growing number of companies to reduce costs of their operational activities by either engaging in direct investment or having strategic alliances in low-labor-rate countries. From a financial point of view, companies also anticipate a remarkable reduction in their capital requirements by such moves.

Offshoring ranges from short-term term contracts to long term investments in developing countries. The decisions of whether or not to go offshore and where and how much production/service to transfer are important and challenging strategic decisions for corporations. In many cases, organizational strategies are driven by the economic environment and the market conditions and for some companies offshoring decisions may be determined by an inevitable effort to gain competitiveness in the market by lowering the prices and concentrating on the core competences. However, offshoring does not always lead to greater market share and business success because there is a much higher complexity in the process. There are numerous challenges during the implementation, operation and later on supervision of the offshore processes. According to a Deloitte study [10] 64% of participants brought offshore services back in-house to regain control and companies recognize the need for improvement in decision-making.

Global supply networks with offshoring are inherently complex not only because of the existence of multiple parties and geographical locations, but also because of the multidimensionality of factors in it. In order to achieve success, corporations need to start by taking the decision about whether or not to go offshore, where to go offshore and in to what extend to transfer or keep operations. These decisions involve quantitative and qualitative factors as well as different expert views. They are sophisticated strategic decisions that need to be analyzed in a comprehensive system. There are various tools such as mathematical modeling which is a well-established tool to solve decision problems with purely numerical values in various levels of complexities. In cases where there are many intangible factors, multi-criteria decision making methods are appropriate to make rational decisions.

In many cases the decisions of going offshore and offshore supplier selection are largely based on cost analyses where the decision alternatives are evaluated solely on a monetary basis. The final decision is then often taken by management by considering the intangible factors and making an approximately good decision based on the results of the cost analysis and intuition. Although this is the common practice, it may not be the best one. Offshoring has a strategic importance and affects the performance, profitability and the existence of a corporation. Once an offshoring decision is made and implemented, it cannot be reversed easily. A small shift from the optimal decision can have disastrous effects on the competitiveness of the company. Therefore, it needs preciseness and immense analytical evaluation in a disciplined and structured framework that can integrate all of the factors in a decision process to generate the best strategic actions.

The offshoring decisions considered in this research are: (1) Whether (or not) to go offshore, (2) Where to locate operations (selecting suppliers or regions), and (3) How much production/service to transfer offshore or to keep in-house

This research intends to analyze the nature of offshore outsourcing decisions and develop a systematic approach by utilizing both mathematical and multi-criteria modeling specifically for these problems. The objective is to build an integrated decision model that can handle the multidimensionality of the offshoring decisions involving location selection and distribution of production and services in global supply networks. A detailed and structured framework of tangible and intangible factors that should go into such decisions is provided.

2.0 LITERATURE REVIEW

The topics of interests in this study can be classified into three areas: offshoring, strategic supply chain decisions including supplier selection and decision modeling.

There is an extensive literature that discusses the progress, practice and effects of offshoring. These discussions examine the offshoring phenomenon from different perspectives and provide background material on the management and decision making process of business practices that are considered for transferring offshore. They are valuable sources in identifying the fundamental variables, factors and perceptions that should go into a composite decision model.

Offshoring is essentially a strategic supply chain decision that includes selection of suppliers (or regions for investment) and assignment of production and service jobs to those suppliers (or to the regions). The supply chain management literature presents a large collection of methods and applications for selecting suppliers, locating businesses, distributing products and services and managing the relationships in the supply chain. For this reason, the supply chain management literature provides an invaluable insight on methodologies that can also be utilized for offshoring decisions.

Decision modeling literature embraces all aspects of decision making (including supply chain and other business decisions). The application areas and tools for analysis are numerous. These tools draw from a wide variety of disciplines such as operations research, probability and statistics, economics and psychology. The literature on decision modeling is important in identifying the most appropriate modeling tools for offshoring decisions in terms of applicability, ease of use, exhaustiveness and preciseness.

In essence, this study is at the intersection of research on offshoring, supply chain management and decision modeling. The following literature survey will first present the evolution of globalization, its consequences on businesses and the concept of offshoring. Then, a review of supply chain management problems and decision models for strategic decisions in local and global supply chains will be presented. The last section will provide a detailed discussion of quantitative and qualitative decision modeling methods that are selected for developing an integrated approach for offshoring decisions.

2.1 OFFSHORING

The majority of companies operating in the nineteenth and twentieth centuries were vertically integrated organization that controlled every level of the business including procurement, production and services. Later, as organizations became horizontal, they spread to multiple locations in the world, some investing internationally and some procuring globally. The word "offshoring" and "offshore outsourcing" arose when large parts of organizations such as manufacturing began to be transferred to low labor rate countries overseas. Although the phenomenon existed for decades, offshore outsourcing was first identified as a business strategy in 1989 [11] after Eastman Kodak's decision to outsource its information technology (IT) operations. While many businesses were becoming familiar with the idea of offshoring, its visibility was enhanced with the growth in the number of call centers located in India and rapid proliferation in the number of products "made in China." Today, Americans import six dollars worth of goods from China for every one dollar of U.S. products sold in China. 50% of cameras, 30% of air conditioners and televisions, 25% of washing machines and 20% of refrigerators are manufactured in China [12]. World Bank data in Table 2-1 and Table 2-2 illustrates the China and India factors in global markets.

Table 2-1. Economy of China [13]

CHINA	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Exports of goods and services (% of GDP)	23%	23%	25%	30%	34%	..
Foreign direct investment, net inflows(BoP) (bil.)	$ 38.4	$ 44.2	$ 49.3	$ 53.5	$ 54.9	..
GDP (current US$) (bil.)	$ 1,198	$ 1,325	$ 1,454	$ 1,641	$ 1,931	$ 2,229
GDP growth (annual %)	8%	8%	9%	10%	10%	10%
GNI per capita, Atlas method (current US$)	$ 930	$ 1,000	$ 1,100	$ 1,270	$1,500	$ 1,740
Gross capital formation (% of GDP)	33%	34%	35%	38%	39%	..
High-technology exports (% of manufactured exports)	19%	21%	23%	27%	30%	..
Imports of goods and services (% of GDP)	21%	20%	23%	27%	31%	..
Industry, value added (% of GDP)	46%	45%	45%	46%	46%	..

On the other hand, India has become the hub of business process outsourcing. In 2004-05, the Indian offshore IT and business-process outsourcing industry generated approximately $17.3 billion and employed 695,000 people. By 2007-08, workforce will consist of about 1,450,000 to 1,550,000 people [14].

Table 2-2. Economy of India

INDIA	2000	2001	2002	2003	2004	2005
Exports of goods and services (% of GDP)	13%	13%	15%	15%	19%	..
Foreign direct investment, net inflows (BoP) (bil.)	$ 3.58	$ 5.47	$ 5.63	$ 4.59	$ 5.34	..
GDP (current US$) (bil.)	$ 461.4	$ 478.3	$ 506.1	$ 600.7	$ 694.7	$ 785.5
GDP growth (annual %)	4%	5%	4%	8%	9%	9%
GNI per capita, Atlas method (current US$)	$ 450	$ 460	$ 470	$ 530	$ 630	$ 720
Gross capital formation (% of GDP)	24%	23%	25%	27%	30%	..
High-technology exports (% of manufactured exports)	5%	5%	5%	5%	5%	..
Imports of goods and services (% of GDP)	14%	14%	16%	16%	21%	..
Industry, value added (% of GDP)	26%	26%	27%	26%	27%	28%

The growth of offshoring was fueled not only by corporations looking for ways to gain competitive advantage but also by those developing countries which prepared the appropriate, welcoming environment for businesses. Today many governments provide tax concessions and infrastructural support to attract companies. In the late 1980s India built technology parks where software production and call centers could be located. China, on the other hand, has doubled its investment on highway construction in the last decade and is focusing on connecting the shore regions to the inner mainland. The government philosophies in first China and then India are very instrumental in facilitating both countries' development.

The scope of offshoring has expanded over time. In the past, the price of the product would be the major determinant in the decision whereas today, quality, reliability and technology are also factors affecting these decisions [15]. Reasons for offshoring have been broadly investigated by academicians and industrial experts. According to Deavers [16], four fundamental changes in the global market lead to the increase of offshoring. These are:

1- Rapid technological change

2- Increased risk and the search for flexibility

3- Greater emphasis on core competencies

4- Globalization

According to another survey [1] of 165 procurement executives across 24 industries globally, most of the offshoring work is done in information technology, distribution, legal operations, manufacturing, detailed design and call centers. The details of the survey results are shown below. The percentages indicate the proportion of respondents that reported the corresponding factor as a driver behind offshoring decisions.

Costs:

- Reduce operating cost (89%)
- Reduce capital investment (81%)
- Turn fixed costs into variable costs (58%)
- Meet downsizing requirements (38%)
- Reduce development costs (35%)
- Obtain intelligence of competitiveness (29%)

Competitive Focus:

- Focus on core businesses (81%)
- Gain access to technology not in company (60%)
- Gain access to needed skills (55%)
- Provide alternative to building capability (52%)

- Create additional capacity (42%)
- Provide backup capabilities (34%)
- Align with policy/philosophy/culture (18%)

Revenue:

- Increase flexibility and responsiveness (60%)
- Increase speed to market (46%)
- Improve quality (42%)
- Reduce customer response time (40%)
- Grow revenue (38%)
- Gain access to markets (22%)

The immediate results can be seen as cost savings and asset reductions in the short term. Program flexibility, enhanced attention to critical customer service and lower turnover rates are also some of the direct consequences. Furthermore, several companies pursue international talent and opportunities for bigger foreign markets through economic investment [17]. In the long term, good decisions in offshoring practices give competitive advantage by improving productivity and ensuring concentration on core competences.

On the other hand, the results of offshoring are not always satisfactory. There are numerous examples of offshoring projects that failed due to unexpected complications. According to a DiamondCluster survey of 210 companies offshoring IT services, recently there has been significant decline in offshoring satisfaction levels [18]. The same research also reports that the number of IT offshoring contracts terminated abnormally has doubled from 2004 to 2005; 36% of survey participants cited poor provider performance as the primary reason whereas change in strategic direction, transfer of function in-house and dissatisfaction in cost savings were cited by 16%, 11% and 7% of participants, respectively.

Offshoring failures can be broadly categorized into two reasons: financial problems and operational problems. Financial problems arise when the anticipated cost savings cannot be realized as a result of wrong assumptions. When production and service costs in a developing country (such as China and India) are compared to the costs in the U.S., the difference may be deceptively perceived as cost savings. Yet, the cost differences cannot be fully incurred as savings due to the hidden costs behind the offshore process. For instance, with any outsourced service, the expense of selecting a service provider can cost from 0.2% to 2% in addition to the annual cost of the contract [19]. There are also costs involved in managing the distributed operations which include travel costs, legal documentation fees and communication expenses. Managers often need to travel periodically to manage the operations that are miles away. Overall, when hidden costs are factored in, the cost savings may not be as large as expected.

In addition to the financial problems, offshore failures may appear due to other factors. Cultural differences and communication difficulties are rapidly becoming challenges that are not easy to overcome. Even though cultural differences are getting less severe with the development of media channels and the Internet, perceptions are still not the same. For instance in an Asian company, a message may not be appreciated without going through different levels of hierarchy within the organization in contrast to the U.S. Both the practice and the governance of offshoring needs effort, money and flexibility. Exogenous factors such as political stability, infrastructure and economical conditions in the country affect the performance of operations. Profits are directly altered by currency fluctuations and inflation rates. Even if the offshore manufacturer or service provider meets the technical, quality and capacity criteria, the environmental factors within the region may limit the operations. For this reason a company needs to choose the country based on not only the cost levels but also on the macro-economic and political conditions.

Although some factors leading to failure can be eliminated by proper governance and management, it should be noted that offshoring is not always a good strategy. Among the primary reasons that a company chooses not to outsource are concerns over loss of control, intellectual property protection and willingness to keep core activities inside. Company policy and philosophy are also revealed as a rationale for staying in-house [20]. Moreover, decentralization of operations globally complicates the supply chain. The fact is that product flows in global supply networks are slower with a loss in flexibility. For example some organizations within the fashion industry like American Apparel choose to stay in the U.S. to maintain their competitiveness in fast product launches.

In summary, offshoring is a complex decision that may lead to both gain and loss of competitive advantage. It is a strategic decision involving the design and control of an organization’s global supply network. Its importance and complexity necessitates structured guidelines for evaluating the short and long term consequences upon the business. The offshoring decision is a strategic problem in supply chain management, which is commonly encountered by today’s large corporations.

2.2 DECISION MODELS IN SUPPLY CHAIN MANAGEMENT

Decision models are critical in the evaluation of data to gain greater understanding of the problem at hand. Decision analyses and models have been of interest to scholars from several research areas, including management science, operations research, mathematics and psychology. In the last decade, researchers have developed decision models that facilitate strategic configuration of supply chains. A large part of this research concentrates on strategic decisions involving facilities, transportation and distribution within local geographic regions. The complexity of these decision problems escalates as the businesses expand globally and the supply chains become global supply networks with the inclusion of international partners and offshoring.

Literature in the supply chain management area is vast and can be classified into four major decision areas: location, production, distribution and inventory. This study focuses mainly on strategic location and distribution decisions. The next section presents a review of the literature with a concentration of location/supplier selection models. As companies grow internationally, the research on supply chain management expanded to embrace the complexities in global operations and the decisions specific to offshoring. The latter section will review the models that are specifically developed for complex supply networks operating in multiple locations.

2.2.1 Strategic Supply Chain Models: Supplier Selection

Supply chain management decisions are conceived in three levels: strategic, tactical and operational. Figure 2-1 gives a schematic description of decisions in supply chains. Strategic decisions are long range and involve designing the supply chain, selecting the size and geographic locations for manufacturing, service and distribution operations and implementing control systems. Tactical decisions are medium term and determine the monthly (or weekly) production schedules, distribution and transportation planning and materials requirements planning. Operational level decisions are short term and mainly assure continuous production and service in daily basis.

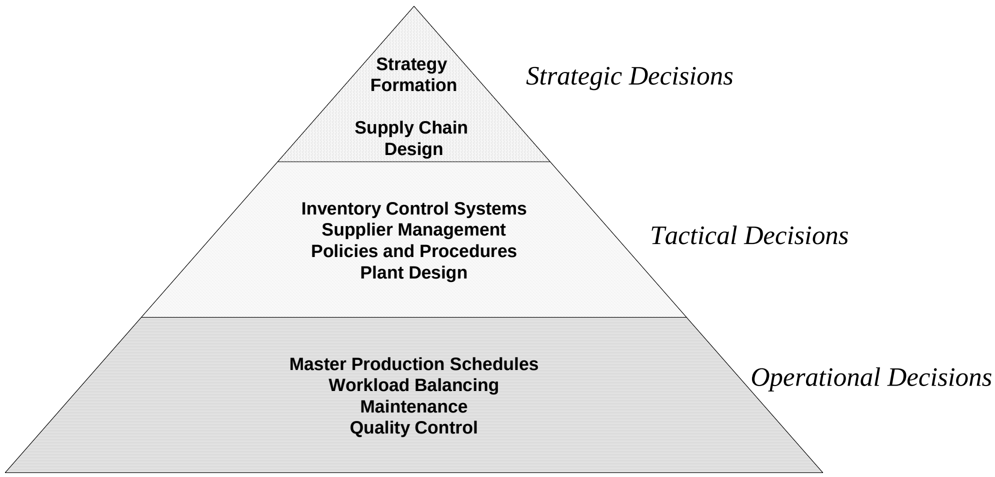

Figure 2-1. Supply Chain Decisions

Strategic decisions encompass the whole supply chain and require comprehensive understanding of the dynamics at every level as well as the corporate values and long-term objectives. Two areas of research in strategic decision making are strategy formation and location decisions.

Vertical integration, acquisitions and mergers are some of the issues that are explored under strategy formation. Based on the core competencies, a company may decide to stay as a local company or conversely expand to global markets. Product mix is also a strategic decision that has critical effects on the organization's competitiveness. Product mix, product life cycle planning, research and development initiatives and resource acquisitions overlap with strategic supply chain decisions and are addressed by multiple disciplines.

The strategy of the organization in turn defines the structural elements of the most advantageous and profit driven supply chain. Models for locating supply chain entities, determining the capacity of manufacturing and establishing transportation routes are used to assist strategic supply chain management decisions. This research focuses mainly on decision models to select locations of suppliers and facilities and determine the distribution of manufacturing/service products among these locations. These decision models are derived from different disciplines and their content as well as approach vary depending on the tools used. A brief summary of the widely-used model types and their applications in location and supplier selections is given. These models are also analyzed with respect to their appropriateness and applicability for offshoring decisions.

Mathematical Modeling:

In operations management, the biggest concentration has been on mathematical modeling of supply chain decisions by using formulations to express elements of the supply chain (i.e., product quantities, time, sequence). Location and supplier selection problems are often formulated as mixed integer programming models by representing the product quantities with continuous variables and the selections by discrete variables. Geoffrion and Graves [21] presented the first mixed integer model to find the optimal location of distribution facilities in a supply chain. The problem is formulated as a multi-commodity capacitated single-period problem. A solution technique based on Benders Decomposition is developed, implemented and applied to a real life problem with 17 commodity classes, 14 plants and 45 possible distribution center sites.

Mixed integer programming (MIP) encompasses decision variables corresponding to both location selection (binary) and distribution of production/service (continuous). MIP is a reliable efficient modeling technique for medium size problems and it can support decisions by covering quantitative attributes. It is an appropriate and effective technique to achieve precise, optimal solutions for offshore supplier and destination selection models. There is a vast literature on MIP to solve supplier and location selection problems. The MIP methodology and its applications will be discussed further in the next sections.

Total Cost Models:

Total cost models focus on selecting the supplier which provides products (or services) with at the least cost over a period of time. Mathematical programming is also used in many of these models but instead of minimizing only the cost of product, these models minimize the total cost of procurement by including transportation, invoicing and negotiations. Degraeve and Roodhooft [22] presented the first total cost model in the context of supplier selection by using information from management accounting to calculate the total cost of ownership by means of activity based costing, leading to the selection of the best supplier(s). The authors implemented the decision model at a large multinational Belgian steel producer and test it for two product groups. In another publication [23], they compared different supplier selection models and conclude that mathematical programming combined with activity based costing provide superior answers.

AHP & ANP:

Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are multi-criteria decision models that fundamentally rely on comparison of entities with respect to criteria by using a ratio scale. The details of the theory and application of these methods will be discussed in the next section. These methods have attracted much attention from different areas including supply chain management. There are various applications of AHP and ANP in supplier and location selection literature. An example is a group decision tool developed by Muralidharan et al. [24] by integrating the Delphi method and AHP for supplier selection problems. Confidence intervals of the AHP ratings done by individuals are calculated and depending on the interquartile range, the ratings are repeated by utilizing the Delphi method. This procedure helps reduce the effect of individual biases. Even though the AHP and ANP methods may not be as precise as mathematical modeling in terms of the quantitative decision variables, they provide a strong tool to quantify intangible values that otherwise are not easily included in a decision model. It also supports group decision making by integrating perspectives of different stakeholders.

Multi-objective Programming:

A supplier selection problem involves optimization of multiple objectives which are often conflicting. Multi-objective programming allows solving multiple objectives by assessing the tradeoffs between the solutions. More discussion on multi-objective programming can be found in the next sections. Multi-objective programming is used as a tool in many areas including supplier selection problems. One of the most recent works combines fuzzy methods with multi-objective optimization problem. Amid et al. [25] presented a fuzzy multi-objective supplier selection model in which the objectives are not equally important and have different weights. The authors applied the model on a numerical example and perform sensitivity analysis. This model is useful in encompassing different objectives.

Multi-attribute Utility:

In economic theory, utility is understood as a numerical representation of a preference relation; preferences are assumed to satisfy certain conditions of internal consistency, which ensure that a utility representation exists for preferences and that choosing consistently with one's preferences can be represented as the maximization of utility [26]. Utility of a reward is denoted as a function of that reward (*r*), and is elicited by asking the decision maker the indifference point between the preference of *r* and the preference of a probabilistic combination of the least and most favorable outcomes. According to utility theory, the decisions are made by maximizing the utilities of the attributes which affect the decision. For instance if a decision is solely based on monetary outcomes, the decision maker chooses the alternative which maximizes the utility of that outcome. If a decision is made based on multiple attributes, the decision maker's preference is expressed as a multi-attribute utility function that represents the compound utility coming from all of the attributes.

Utility theory and multi-attribute utility modeling have been interest to scholars from different areas, including supply chain management. As an example, Min [27] introduced a multi-attribute utility approach for international supplier selection problems. The author first structured the international supplier selection problem into a hierarchy of four levels and then determined the main attributes such as service performance, quality assurance and communication. The approach is illustrated with a base-line scenario that involves selecting the most appropriate foreign supplier that manufactures and sells the components of personal computers.

Conceptual Models:

Conceptual models have been developed in an effort to build a decision and a control mechanism for corporations. These models are not meant to solve specific decisions in an analytical framework; rather they are geared towards implementing a business strategy.

The SCOR (Supply Chain Operations Reference) model is a strategic decision making tool developed by the Supply Chain Council [28]. A process reference model is described as one that integrates the concepts of business process re-engineering, benchmarking, and process measurement into a cross-functional framework. THE SCOR model is built in detail to capture management processes in a supply chain; by using performance metrics the supply chain performance is monitored and continuously improved. SCOR structurally describes, measures and evaluates supply chain configurations.

2.2.2 Integrated Models

A more comprehensive evaluation of supply chains requires the integration of performance factors other than costs. There is a limited amount of research on supplier and location selection models that utilize multiple methods from different disciplines. As supply chains expand both in terms of the location dispersion and the complexity of management, the necessity for using multiple tools increases.

Talluri and Baker [29] proposed a multi-phase mathematical programming approach that designs an effective supply chain by considering the efficiencies of participating candidates, capacity and transportation issues. The model incorporated multiple objectives but all of these objectives are quantitative measures.

Ghoudyspour and O'Brien [30] proposed a method that integrates AHP and linear programming by formulating a linear program with the objective of maximizing the total rating score of procurement. Each supplier's score is determined by using an AHP model that includes quality, cost and service criteria and these scores are multiplied by the amount of procurement from each associated supplier; their sum is then maximized subject to demand and capacity constraints. Although the proposed model is an effort to integrate quantitative factors in supplier selection, the integration is not theorically consistent. The calculation of supplier score involves the addition of quality, cost and service ratings, however the principal of engineering economic benefit/cost analysis requires the assessment of incremental differences, rather than a simple addition. Moreover, the model does not include the fixed costs involved and assumes that the cost, quality and service values are linearly proportional to the product amount. Such an assumption is not valid in practical cases where the suppliers usually quote different prices on different amounts and charge fixed ordering costs.

Instead of finding the best supplier selection, Weber et al. [31] followed a different approach and illustrate how multi-objective programming and data envelopment analysis can be used to evaluate the number of suppliers to employ. The authors took into account the fact that the low cost supplier is not always the one with the best performance. The model finds the non-inferior set of suppliers whose criteria values are most in line with specified criteria weights.

Although these models have a strong foundation in supply chain design, they lack complexities that are encountered in global environment. For example political risks and social opportunities are not taken into account. Recently the research on strategic decisions for supply chains has broadened to include supply networks that are located internationally. The next section will give an overview of models that are developed specifically for global supplier and location selection problems with offshoring.

2.2.3 Global Supply Network Models

One effect of globalization is that more organizations are doing business internationally. Today, supply chains can no longer be defined as series of suppliers that are connected linearly, rather suppliers have relationships that involve two-way commodity flows with one-to-many connections. Additionally, these supply networks are located internationally, usually distributed in different continents. Unlike local supply chains global supply networks include variables that cannot be controlled by the decision maker. For instance risks associated with macroeconomic conditions in different regions and cultural as well as social diversity add enormous uncertainty. Moreover, today's global variables supply networks mostly embrace offshore practices that require consideration of multiple both during the decision and process and through the operations. For this reason, global supply networks are modeled with more sophisticated formulations to incorporate the complications of various factors. The inclusion of taxes and duties, fluctuating exchange rates, trade barriers, transfer prices and duty drawbacks is fundamental for a model to more accurately represent a global supply network problem [32].

Compared to traditional supply chains there is a limited body of literature focusing on the modeling of global supply networks and offshoring decisions. The number of publications and researchers interested in the area is increasing rapidly, but still the extent is limited short for the global supply network problems.

As in the case of traditional supply chains, the decision modeling literature can be divided into two streams. One stream of literature extensively utilizes operations research techniques to model the decisions and assess the profitability of production (or service) operations on the basis of quantitative variables. The other stream of literature concentrates on intangible determinants and evaluates the drivers and consequences of global operations by examining the business conditions, risk factors, opportunities and other qualitative as well as quantitative variables.

The mathematical formulation based literature on decision models in global supply networks mostly includes tools from decision sciences, operations research and economics. A review of applications was presented by Cohen and Mallik [33] in which the authors discuss the globalization of supply chains. These models typically include financial parameters and address global supply network problems to find production quantities, production locations, distribution routes, etc. The next section provides examples from various disciplines that utilize different methodologies to model the global supply networks and solve the global supplier and region selection and production allocation problems.

Arnzten et al. [34] have formulated a global supply chain model (GSCM) that minimizes a weighted combination of total cost and activity days where the total cost includes production and inventory costs, taxes, facility fixed charges, production line fixed costs, transportation costs, fixed costs associated with a particular method of manufacturing, and duty avoidance. This MIP model is solved for a digital equipment corporation that is in the process of determining plant charters and allocation of production loads. The model is then utilized to analyze the supply chain for new products as well as the supply bases for existing commodities. The decision model is applicable to a multi-stage, multi-product manufacturing environment.

Huchzermeier and Cohen [35] developed a stochastic dynamic programming formulation for the valuation of global manufacturing options. These options are delineated by distinct time periods that are defined by the available sources of supply, plant capacities, product allocations to market regions, and open supply linkages within the global supply network. There is a cost associated with switching between options over the time horizon of the strategic decision. The model maximizes the global after-tax profits and incorporates option valuation and exchange rates.

Nagurney et al. [36] developed a framework for the modeling and analysis of global supply networks. The authors built an extensive mathematical model that includes dynamics of price and behaviors of supply chain partners. The model maximizes the total profit by deciding on the amount of product shipments based on the costs as well as the equilibrium prices of products in different currencies at the various demand markets (countries). It allows for the analysis and solution of the equilibrium product flows and prices by considering the behavior of multiple parties (customers, retailers, etc.) in the supply network. The authors apply an iterative algorithm to compute solutions to several numerical examples.

Grossman and Helpman [37] studied the determinants of outsourcing and model outsourcing activities as the equilibrium of production and trade between the parties. The authors presented an economic model of location selection with respect to market conditions, supplies and demands. The authors first studied how labor supply, country size and technological investment affect the pattern of outsourcing and location equilibrium. Then they investigated the role of the contracting environment by incorporating the legal setting of countries. Based on macroeconomic and product cost data, the authors drew conclusions on how an organization should proceed in choosing specific locations to transfer activities.

Kouvelis and Munson [38] developed a mixed integer model to represent the cost of global facility networks by incorporating government subsidies, tariffs and taxations. They presented an MIP formulation that maximizes the net present value of profit subject to demand and capacity constraints. The model incorporates the time value of money by including the interest rates on loans and discount rate of after tax cash flows for each country. Based on the MIP formulation, the authors found the variables which significantly influence the solution and develop a structural equation by using these variables.

Goetschalckx et al. [39] presented two global logistics system models. The first one is a non-convex optimization problem that focuses on the transfer prices in a global supply chain with an objective of maximizing the after tax profit of an international corporation. The second one focuses on the production and distribution allocation of a single country system when customers have seasonal demands.

Steenhuis and De Burijn [40] followed a different approach and compare manufacturing location alternatives in a global supply network by utilizing productivity measures as the basis for analyzing the international location/industry combination options. GDP values and dependencies of industries are used to calculate the productivity levels in each country (or region) and a decision process that can be utilized by both corporations and governments is suggested.

The other stream of literature concentrates primarily on the qualitative determinants of global operations such as risk, knowledge bases and market opportunities. Researchers in both academia and industry have generated various studies that emphasize the value of intangible attributes in global supplier selection and production allocation decisions.

Bartmess and Cerny [41] stated that capability focused approaches to the facility location decision in global environment will support a company's competitive advantage on an enduring basis. Traditional approaches such as static snap-shot analysis and single functional focus can provide only short-term solutions that will not lead to long-term benefits. Instead, the authors propose capability focused approaches including non-manufacturing issues and demonstrate the superiority of these approaches by giving real business examples.

MacCormack et al. [42] examined the impact of qualitative factors on the performance and efficiency of global supply networks. They called attention to the importance of incorporating parameters such as exchange rates, tax systems, government regulations and technological capabilities. The authors presented an overview of the macroeconomic and business level trends while summarizing the technological advances in production systems and related trends in management philosophies. After highlighting the insufficiency of cost based decision models, the authors proposed a new framework for assisting in site location decisions and a model of the future global manufacturing firm.

The global management consulting firm A.T. Kearney [43] has developed a scheme for offshore decisions based on the offshore location attractiveness indices of countries. Their report also highlights the issues that corporations must balance in their strategic offshore decisions. Countries are evaluated based on corporate surveys, current offshore IT and business process outsourcing activities, labor skills and availabilities, business environment, infrastructure, culture adaptability, security of intellectual property, and financial structure.

On the other hand, the Global Outsourcing Report 2005 [44] assesses countries in terms of two indices: the Global Outsourcing Index (GOI) and the Future Outsourcing Rank (FOR). According to this report, India and China are the two distinct low-cost labor countries that emerge as leaders for organizations considering outsourcing. China is mostly known for low cost manufacturing labor, whereas India has the advantage of an English speaking population and thus attracts a large amount of Business Process Outsourcing (BPO) and IT contracts.

Alternatively, Taiwan and Korea are known as the centers of the semi-conductor industry. Besides these big players, countries such as Indonesia, Philippines and Malaysia also can effectively compete for the offshoring business.

Multi-attribute modeling approaches are also exploited in order to integrate intangible decision variables into supply network decisions. Udo [45] employed the analytic hierarchy process (AHP) technique to analyze information system outsourcing decisions. The supplier of choice is selected based on five criteria: strategic importance, stakeholder's interest, supplier's issues, cost of operations and industry environment. The supplier alternatives are assessed by paired comparisons and the decision is made based on the overall synthesized ranking values associated with each supplier. In another application, Badri [46] combined AHP with goal programming for a global facility location allocation problem. The author first defines seven quantitative goals, including minimizing the total cost and maximizing the environmental quality. Then, AHP is used to determine weight factors for each goal, and goal programming is used to solve the aggregate model.

2.2.4 Summary

As more businesses are expanding globally and more processes are outsourced, the need for detailed global supply network modeling escalates. Supplier selection, determining locations of suppliers and the allocation of production and services require consideration of quantitative and qualitative criteria. These decisions often involve many alternatives and conflicting objectives as well as constraints arising from uncertainties associated with the economy of countries. The literature includes various applications of supplier and location selections models that utilize tools like multi-attribute modeling, mathematical modeling, artificial intelligence, expert systems, multivariate statistical analysis and multi-attribute utility models. Some of the models integrate different tools to incorporate intangible variables, too. However there is not a systematic approach that:

- Includes all of the quantitative and qualitative criteria involved. There are models which consider some of these criteria but there is no single model that actually defines the risks and opportunities and then incorporates these into a decision approach.
- Is designed specifically for global supplier and location selection. In particular, the offshoring phenomenon is not adequately emphasized as a part of the decision process.
- Uses both continuous and discrete decision variables to represent the supplier and location selection problem and the problem of allocating products and services.
- Facilitates sensitivity analysis, therefore assists the decision maker in negotiations and decision changes in case of prospective economical and social variables.
- Encompasses the complexity, interdependency and vastness of criteria in global business processes and the decisions associated with global practices.
- Deals specifically with the offshoring problems and the decision of whether or not to go offshore.

This research aims to provide a decision approach that can alleviate these gaps in the published literature. The next section presents the methodology used in the decision approach developed in this study.

3.0 METHODOLOGY

Offshoring decisions are similar to strategic supply chain decisions involving location selection and production distribution. The difference is that offshoring decisions are more complex necessitating an integrated decision making approach that can manage various tangible and intangible factors. The next section will detail the factors affecting offshoring. Finally, the methodology for developing an integrated decision making approach is presented.

3.1 PROBLEM CHARACTERISTICS

Although some perceive offshoring as a strategic decision made in response to the inflating cost competition, in essence it has multiple facets that should be considered during the decision process. Even though cost is often the primary objective there are many other objectives such as concentration in core competences. In choosing an offshore supplier and a location a company wants to minimize the total risk of going offshore while realizing the benefits of it. There also are several stakeholders who may have conflicting expectations and priorities. For instance, for shareholders cost reduction is the most important outcome whereas for customers, product and service quality may be as important as the price. Therefore, the decision needs to be considered not only in terms of different objectives, but also from different perspectives. Figure 3-1 presents the multiple facets of offshoring decisions in a scheme.

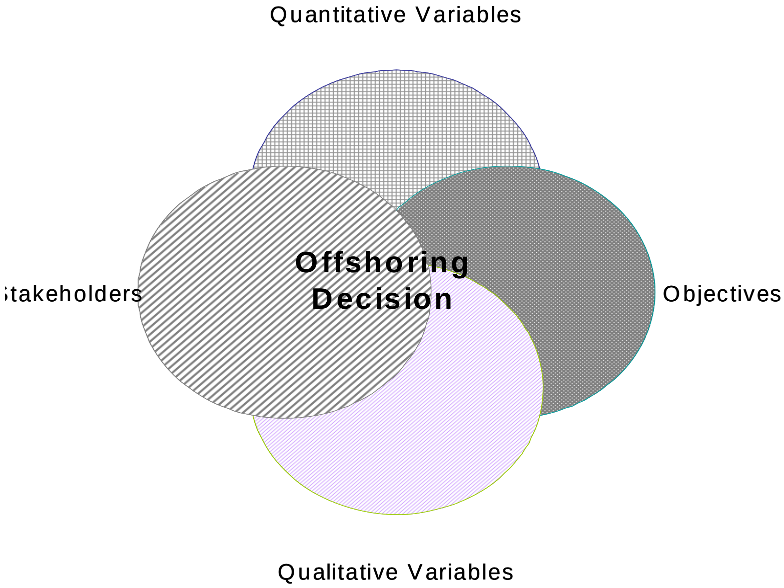

Figure 3-1. Multiple Facets of Offshoring Decisions

It may be computationally complex but often not very difficult to identify good offshoring decisions in terms of monetary values. There are well-established mathematical tools to evaluate the financial factors that can lead to profitable results. On the other hand, financial factors are only one determinant in the decision space that can make an offshoring process successful. Offshoring is a long-term strategic action that has risks and benefits that are not always reflected in a financial statement. Thus, only a decision model that covers all of the intangible values as well as the monetary objectives can give a reliable offshoring strategy. The existence of multiple objectives, stakeholders, tangible and intangible values necessitates a systematic approach that can synthesize strengths of multiple tools.

3.2 SOLUTION APPROACH

Operations research tools are commonly used for modeling and optimizing systems with tangible values. These models are practical and can accurately represent complex systems with several constraints and variables. For an offshoring decision, cost minimization (or profit maximization) is a major objective which can be expressed mathematically as a function of production and service amounts. Transaction costs and other constraints can also be formulated in a mathematical model. From a cost minimization perspective, mathematical modeling techniques can give the optimal offshoring decision. Rationale for the selected methodologies are detailed in the next sections

The cost of operations consists of fixed costs such as asset depreciation (site selection) as well as variable costs that vary with production and service amount. For this reason, finding the optimal distribution of products and services in a network of possible alternative suppliers (or locations) requires inclusion of both discrete and continuous variables in a mathematical model. Continuous variables represent production and service amounts whereas selection of suppliers is represented by binary (0-1) variables. Such a problem with a mixture of integer and continuous variables can ideally be formulated as a mixed-integer programming problem.

Although such a mixed-integer program can find the best supplier and location selection along with the optimal production and service distributions, it does not embrace the intangible factors that significantly influence the decisions in offshoring. For example, organizations operating in a global environment are subject to political risks that exist overseas. Moreover, the community perspective is a very important issue for global decisions, especially for offshoring decisions where there are controversial arguments which can affect the welfare of stakeholders. In order to obtain a comprehensive and reliable decision, the qualitative values associated with the problem have to be assessed as part of the decision process. The challenge is that many of the qualitative influences are unforeseeable, making the decision fuzzy in nature. A remedy to this challenge can be using multi-criteria decision making (MCDM) techniques.

MCDM focuses on finding the best decision among a set of alternatives for a set of given criteria. As illustrated in Figure 3-2, MCDM can be broadly categorized into multi-objective decision making (MODM) and multi-attribute decision making (MADM). MODM focuses on decision problems where the decision space is continuous, whereas MADM problems are characterized by discrete decision spaces [47] with predetermined alternatives. A typical example of MODM is mathematical programming and goal programming (GP) [48]. Analytical Hierarchy Process (AHP) [49], Analytic Network Process (ANP) [50], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [51], Simple Multi-attribute Rating Technique (SMART) [52] and Elimination and Choice Translating Reality (ELECTRE) [53] are some of the more common MADM solution methods.

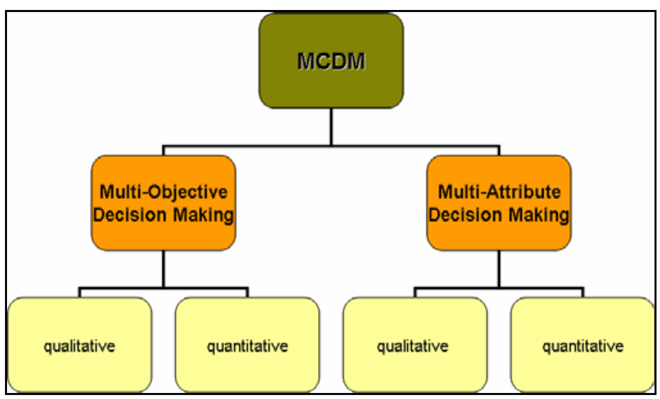

Figure 3-2. Multi-criteria Decision Making Methods

Both types may involve quantitative and qualitative variables, but MODM methods are often used to solve purely quantitative decision problems, whereas MADM methods have quantification tools that are applied to qualitative elements. Both MADM and MODM models contribute to the decision science literature and have an accepted scientific base. The applicability of each method depends on the configuration of the specified decision problem.

MADM methods utilize different tools to quantify the intangible values by elucidating the preferences of decision makers. Utility theory is a widely used tool to derive mathematical functions based on individuals' desirability and preferences towards particular actions. However, in practice obtaining utility functions in such a complex situation with many different attributes is time consuming, computationally demanding and perhaps not even possible.

Preferences of decision makers can also be elucidated by other tools without expressing them in terms of mathematical functions. MADM methods such as ELECTRE, TOPSIS, AHP and ANP can quantify qualitative attributes and find the best selection(s) from a set of outcomes by eliciting the decision maker's preference. These methods can be used to evaluate the intangible factors in a decision method in a much simpler and effective way.

Among these, ANP is the method that can handle complicated decision problems with multiple stakeholders including dependencies among criteria and alternatives. It can decision problems in a network structure by means of influence projections. Although the methodology's mathematical evaluation may be overwhelming for large problems, its accompanying software package "Superdecisions [54]" enables assistance and flexibility in its application.

ANP is the generalized version of AHP which is a type of additive weighting method, developed by Saaty in 70's. AHP, and later ANP, has been very popular in the decision literature and has been widely utilized. Both methods are straightforward and easy to use and are incorporated in software packages that make their applications more convenient. The methods integrate subjective judgments with numerical data and can monitor the inconsistencies in subjective judgments.

In summary, for this research problem the MADM methods can be used to incorporate the intangible factors whereas the mixed integer programming can be used to find the best offshoring strategy with respect to minimization of costs. The results from an MADM model and an MIP model are often conflicting (ie. minimum cost strategy may result in maximum risk). In order to make a decision based on the economic criteria (considered in the MIP model) and the intangible criteria (considered in the MADM model), the solutions should be combined in a structural form to make an integrated decision.

This research develops a two-phase integrated decision approach for offshoring decisions. The two-phase decision approach consists of concurrent MIP and MADM model formulations, the multi-objective optimization problem and a sensitivity analysis. Figure 3-3 gives a schematic view of the decision process.

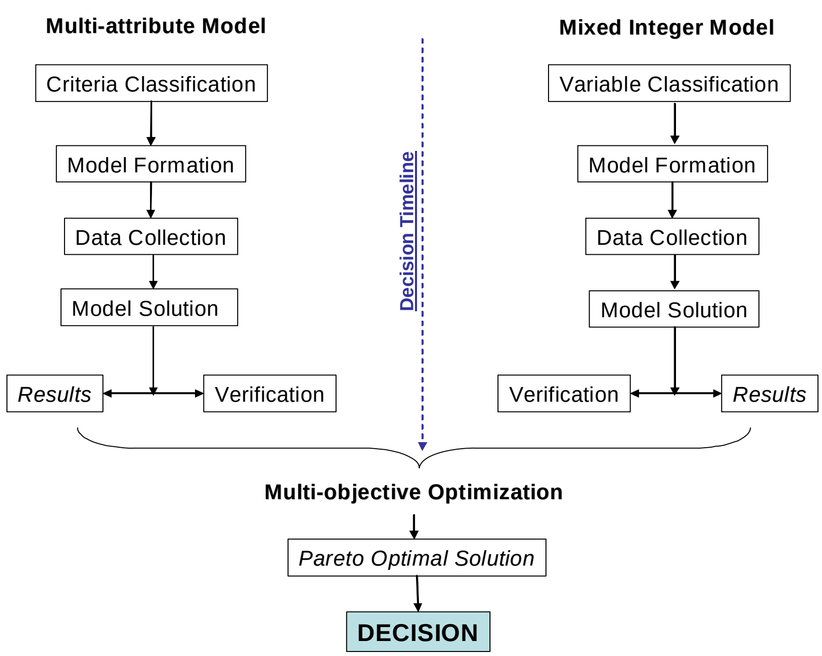

Figure 3-3. Two-phase Integrated Decision Approach

The MIP model includes quantitative data whereas the MADM model includes qualitative factors. These models are independent of each other, therefore can be formed concurrently. The results of the models are entered into a multi-objective programming problem that yields a set of Pareto optimal solutions. The decision maker decides on the best offshoring strategy by evaluating the tradeoffs.

These two phases are presented in detail by first giving an overview of the methodologies used and then describing the model implementation in offshoring decisions. Selection of the specific tools (MIP and ANP) is also justified. After the illustration of the two phases, the integration process is presented.

3.3 MIXED INTEGER PROGRAMMING

3.3.1 Background

Mixed integer programming is a generalization of linear programming in which some of the decision variables are constrained to be integers. Many production and location problems are solved as mixed integer programs due to the existence of fixed charges. These are incurred whenever the activity (i.e. production, transportation) is undertaken. Examples of fixed charges are setup costs, location rental costs and minimum order quantities. Furthermore, integer values can also enter into a linear programming model to deal with "if-then" constraints and piecewise linear functions. Piecewise linear functions can occur as a result of such situations such as price discounts depending on order quantities and cost reductions due to economies of scale and training.

A mixed integer program can be formulated as below:

$$\text{Minimize} \quad c^T x \tag{3-1}$$

$$\text{s.t.} \quad A_1 x = b_1 \tag{3-2}$$

$$A_2 x \le b_2 \tag{3-3}$$

$$l_i \le x_i \le u_i \quad i \in S \setminus P \tag{3-4}$$

$$x_j \text{ integer} \quad j \in P \subseteq S \tag{3-5}$$

P is the set of integer decision variables and *S* is the set of all decision variables. A_1 (A_2) represents the coefficient matrix and b_1 (b_2) represents the right hand side of equality (inequality) constraints. l_i and u_i represent the lower and upper bounds of the continuous variables. x is the matrix of decision variables.

Mixed integer programming problems are NP-hard (Non-deterministic Polynomial-time hard), meaning that many researchers believe that they do not have polynomial-time algorithms, therefore are complex problems which can only be solved in extensive computational time.

The complexity class NP (Non-deterministic polynomial time) is the class of languages that can be verified by a polynomial-time algorithm [55]. NP-hard is complexity class defined as a set such that for every decision problem in NP there exists a polynomial-time many-one reduction to that set. Briefly, a problem A is said to be reduced to another problem B if any instance of A can be easily rephrased as an instance of problem B.

Mixed integer programming problems are generally solved by using modified versions of branch and bound methods [56]. First, the linear relaxation of the problem (without the integer constraints) is solved to optimum. If the optimum solution happens to satisfy integer conditions, it is the optimal for the MIP problem. If not, additional linear inequality constraints (called cutting planes) are added to the system in such a way as to remove the suboptimal extreme point solution. There are several methods of building cutting planes including Gomory's cuts [57] and Lift-and-Project cuts [58]. Although MIP problems are difficult to solve, branch and bound algorithms have been successful in providing optimal solutions.

On the other hand, for large MIP problems optimality may be too difficult to obtain because of the computational complexity. In some cases, optimality may even be unnecessary due to the problem's nature. In these cases, heuristic methods are applied either to obtain a near-optimum solution or to accelerate the branch and bound method by reducing the number of iterations to approach the exact optimum. A well known heuristic is Pivot and Shift developed by Balas et al. [59]. It is an extension to general mixed integer programming of Pivot and Complement which is a heuristic for finding approximate solutions to binary programming problems. Tabu search and genetic algorithms are also widely used in developing general heuristics for MIP problems. A tabu search based method for binary MIP is presented by Lokketangen and Glover [60] whereas Kostikas and Fragakis [61] apply genetic programming to MIP by embedding the genetic run into the branch and bound process.

Mixed integer programming is applied to many real life problems: one of its biggest application areas is in supply chain management. In production planning, integer values are required to take into account setup times. Problems that are formulated mixed integer programming include lot sizing [62], production and staff scheduling [63, 64], site location [65] and transportation [66] problems. Supplier selection in supply chains is mathematically similar to site location and transportation problems. Due to the existence of both fixed and variables costs, the formulation of this problem is also structured as mixed integer programming. Total cost of production/ownership approach is also incorporated while modeling the decision mathematically.

3.3.2 Model

Possible alternative locations for manufacturing/services are considered as supply nodes and possible locations of product/service sales are considered as demand nodes. Each arc between the supply and demand points is represented by a variable denoting the volume of manufacturing/service supplied from the supply point to the demand point. In addition, a binary variable is associated with each supply node, representing the existence of manufacturing/service in that location. A general formulation for global supplier selection problem can be structured as an MIP model.

Indices:

I: Set of supply points - $i \in I$ represents a supply point

J: Set of demand points- $j \in J$ represents a demand point

T: Time horizon (annually divided: t = one year) - $t \in T$ represents a one year period

Decision variables:

x_{ij}^{t} = amount of production/service at supplier i and transported to location j (for consumption) at year t

z_i = binary variable associated with location *i*, 1 if location *i* is chosen for production, 0 otherwise

Parameters:

M = sufficiently big constant for the binary force constraints

D_j^t = total annual demand at location *j* at time *t*

v_i^t = variable cost of production/service by supplier *i* at time *t*

s_{ij}^t = transportation cost from supplier *i* to location *j* at time *t* including inbounda and outbound transportation

f_i^t = fixed cost of supplier *i* at time *t*

r_i^t = the discount rate for supplier *i* at time *t* (includes any discount that should be considered such as inflation, interest, depreciation etc..)

Objective Function:

minimize the net present value of total cost:

Minimize $$\sum_{i \in I} \sum_{t \in T} \left[\sum_{j \in J} v_i^t x_{ij}^t + s_{ij}^t x_{ij}^t \right] r_i^t + \sum_{i \in I} \sum_{t \in T} f_i^t r_i^t z_i \qquad (3\text{-}6)$$

Constraints:

- *Demand Constraint*

$$\sum_{i \in I} x_{ij}^t = D_j^t \qquad \forall \quad j \in J \text{ and } t \in T \qquad (3\text{-}7)$$

- *Binary Force Constraint*

$$\sum_{t \in T} \sum_{j \in J} x_{ij}^t \le M z_i \qquad \forall \quad i \in I \qquad (3\text{-}8)$$

- *Trivial Constraints*

$$x_{ij}^t \ge 0 \qquad \forall \ i \in I\,,\ j \in J \ \text{ and } \ t \in T \qquad (3\text{-}9)$$

$$z_i \in \{0,1\} \qquad \forall \ i \in I \qquad (3\text{-}10)$$

The objective minimizes the net present value of total cost discounted over the decision time horizon. The discount rate may include financial indicators like tax and interest as well as the economic factors such as inflation and exchange rate. The demand constraint ensures that the demands at locations are fulfilled. The binary force constraints ensure that if a supplier is not selected, there is no product flow from that supplier. Trivial constraints ensure the nonnegativity of product/service flow and assignment of 0-1 to the binary variables.

The parameters for the MIP model are obtained by using data collected from different sources. If the production and services are outsourced directly to a supplier without any investment, the company can rely on the data provided by the supplier. If there is significant amount of investment and offshoring is a long-term financially demanding process, then a cost analysis must be performed based on the reliable sources. Activity Based Costing (ABC) is a cost accounting methodology that is originally developed to allocate costs to products and services. ABC identifies the activities and consumed resources and determines the cost variables according to the relationship between activities, products/services and consumed resources. This technique is also utilized to estimate costs by using basic resource costs (i.e. electricity, labor) to develop the product/service cost.

The MIP model can be solved via various commercial solvers or by developing a solution algorithm specifically for the problem. In this research, the MIP models are sparse without many decision variables. Thus, there is no need to develop a specific solution algorithm, rather commercial solvers can be utilized. Hence, the ILOG Cplex 9.0 with C programming language interface is used to solve the MIP problem. Cplex uses branch and cut to solve MIP models [67]. It begins by solving the relaxation of the model: i.e., all integrality constraints and special order sets are ignored. It proceeds by introducing the integrality constraints one by one. Branching from a parent node occurs as bounds are modified and cuts occur as new constraints are added. As a result, the solution of the MIP model gives the optimal choice of alternatives and production/service distributions with respect to minimization of costs.

3.4 ANALYTIC NETWORK PROCESS

3.4.1 Background

In this research Analytic Network Process (ANP) is selected as the MADM method in the integrated two-phase methodology. As discussed, the ANP is an advanced decision making technique that is based on the fundamental principles of Analytical Hierarchy Process (AHP). In fact, AHP is a special case of ANP, where the elements are assumed to be independent of each other. ANP is structured on the same basis of AHP, but it does not assume independence between criteria and alternatives [68]. ANP can capture complex decision making problems by incorporating a feedback mechanism and attribute interactions as well as the hierarchical relationship of alternatives. Multiple expert and multiple criteria features of decision making problems are intelligently tied together to formulate a network of elements.

According to Saaty [69], there are three elements to a decision problem: goal, criteria and alternatives. Interactions between these three elements can be defined in a tree structure. Both AHP and ANP evaluate the alternatives with a bottom-to-top approach. AHP formulates decision models in a single hierarchy whereas ANP has a network structure with sub-networks where the criteria are divided into sub models. Dependencies between criteria and alternatives are handled with feedback mechanisms. In the sub-networks, the feedback mechanism ensures a more realistic reflection of the intrinsic complexity of organizational decisions. In general, the basic reasoning behind AHP and ANP are the same. Although the structure of the model is more complex in ANP, both are based on “comparative judgments.”

Intangible values are quantified using the proposition of ratio scales and the criteria are compared based on the priority theory. That is, a comparison between two elements is made according to the intensity (how much?) and dominance (which one?). The priorities of criteria determine the weight factors in the goal. The comparisons are made by experts/stakeholders. For a case with n criteria, $n(n-1)/2$ pair-wise comparisons are made with respect to a common attribute by each expert. The control mechanism for the consistency of judgments in the comparisons is the “inconsistency factor” which is calculated from the comparison matrix. The comparison ratios are entered in a comparison matrix and the priorities are obtained by calculating the eigenvector of this matrix. The priorities represent the conversion of the paired comparisons of the criteria into a ratio scale.

The steps for building an ANP model start with structuring the network that consists of hierarchies and dependencies. The goal is considered to be the root of the network, where the alternatives are assessed by their Benefit, Opportunity, Cost and Risk (BOCR) influences with respect to the goal. The combination of the goal and its relationship with the major criteria is called the "control hierarchy." Under each parent criterion (BOCR), sub-networks are built according to the specific conditions of the problem. These sub-networks are further divided into sub-criteria which are connected to different stakeholders. The feedback structure is essential to ANP and is the element that differentiates ANP from AHP. It represents interactions that converge toward the goal. Under sub-networks feedback loops can be added to stakeholders and criteria nodes. Once the network structure is completed, the decision maker (or makers) performs the paired comparisons between the attributes with respect to their parent criteria.

The fundamental scale of ANP is based on *absolute numbers* which is described as the ratio of ratio numbers. Absolute numbers are used to answer the basic question in all paired comparisons: how many times more dominant is one element than the other with respect to a certain criterion or attribute. Paired comparisons are always more precise than rating alternatives independent of each other. Rating and ranking alternatives separately without the knowledge of entire decision space will create biased solutions. If a person does not have a basis to judge things relatively, s/he cannot give accurate scores, values or rankings. For instance, when a person is asked how happy s/he is feeling at the moment, s/he will try to answer by comparing her/his feelings with past experiences and judgments. Such a comparison is made by first determining the dominance relation (more or less) and then identifying the intensity (how many times more or less).

A judgment for a paired comparison is made on a pair of elements with respect to a property they have in common. The smaller element is considered to be the unit and the decision maker estimates how many times more important, preferable, influencing or likely, more generally "dominant," the other is by using a number from the Fundamental Scale, as explained in Table 3-1.

Table 3-1. Fundamental Scale [70]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one element over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one element over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	An element is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Example of a Paired Comparison:

Problem: Comparing the sizes of a "Golf" ball, a "Tennis" ball and a "Soccer" ball. The comparison matrix is a positive reciprocal matrix (if $a_{ij} = A$, then $a_{ji} = A^{-1}$). In this case, only the judgments for the upper or lower diagonal of the paired comparison matrix are needed. An example is shown in Table 3-2.

Table 3-2. Paired Comparison Example

	Golf Ball	**Tennis Ball**	**Soccer Ball**
Golf B.	1	3	8
Tennis B.	1/3	1	5
Soccer B.	1/8	1/5	1

For upper diagonal judgments, the questions are:

With respect to size:

1- How much bigger is a tennis ball than a golf ball?

Judgment: Moderately bigger (3)

2- How much bigger is a soccer ball than a golf ball?

Judgment: Very strongly bigger (8)

3- How much bigger is a soccer ball than a tennis ball?

Judgment: Strongly bigger (5)

One should note that the lower diagonal judgments are the reciprocals. For lower diagonal, the questions will be:

1- How much smaller is a golf ball than a tennis ball?

Judgment: Moderately smaller (1/3)

2- How much smaller is a golf ball than an apple?

Judgment: Very strongly smaller (1/8)

3- How much smaller is a tennis ball than a soccer ball?

Judgment: Strongly smaller (1/5)

These kinds of comparisons require observation of sizes of the objects under consideration. On the other hand, many of the real life decision problems necessitate comparison of intangible values that are often subject to individual perspectives. For instance, instead of comparing the sizes of the sports balls, one can ask to compare the popularity of these three sports. Then, the judgments are based on subjective preferences as well as the data such as the number of people who watch each sport. If such subjectivity needs to be minimized, the comparisons should be done by multiple decision makers who have different perspectives and whose collective judgments will be combined to yield a more objective result. However if by the nature of the problem, the decision needs based on the preferences of the decision maker, subjectivity is needed and favored.

Inconsistency in Paired Comparisons:

If a tennis ball is deemed three times bigger than a golf ball and a soccer ball is five times bigger than a tennis ball, shouldn't a soccer ball be 15 times bigger than a golf ball? Why is the comparison value eight instead? Such inconsistency is natural in human thinking as long as it does not exceed certain values. For ANP judgments, inconsistency under a certain value does not yield a significant perturbation in the results. The consistency of a comparison matrix is quantified by a "Consistency Index" which is a measure of deviation of matrix from consistency. The formula for the consistency index is: $\mu \equiv \frac{\lambda_{\max} - n}{n-1}$ where $\lambda_{\max}$ is the principal (largest) eigenvalue and n is the dimension of the matrix [71].

Eigenvalues for the matrix $\begin{bmatrix} 1 & 3 & 8 \\ 1/3 & 1 & 5 \\ 1/8 & 1/5 & 1 \end{bmatrix}$ are 3.044, -0.022 and -0.022. Thus, $\lambda_{\max}$ is 3.044. The dimension of the matrix is 3. So, the inconsistency index is calculated as $\mu \equiv \frac{3.044-3}{3-1} = 0.022$.

"Random Index," on the other hand, is the expected average of consistency indices of random comparison matrices. The random index is evaluated approximately by simulating random matrices and taking the average of their consistency indices.

Table 3-3. Random Index [72]

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R.I.	0	0	.52	.89	1.11	1.25	1.35	1.40	1.45	1.49

As can be seen in Table 3-3, the expected random inconsistency of comparison matrices increases as the dimension (the number of elements compared) increases. Therefore, a better measurement to identify the inconsistency of a comparison matrix is its relative consistency that is determined by the "Consistency Ratio." The consistency ratio is the ratio of consistency index μ to the corresponding random index value. Inconsistency with a consistency ratio smaller than 10% is acceptable and will not have significant effects. If the inconsistency is larger than this value, the comparisons need to be repeated in closer attention.

An advantage of AHP and ANP over other multi-attribute decision making methods is that these methods offer sensitivity analysis, specifying the breakpoints where the alternative decisions dominate one another. The sensitivity analysis provides a tool to answer "what if" questions based on changes in criteria weights and risk factors. It also provides a measurement of sustainability and certainty of the final decision. Such an indicator suggests a scheme for the overall decision and the frequency with which the decision making technique should be repeated to check the optimality of the solution.

Another advantage of AHP and ANP is their ability to handle complex problems [73]. Complex decision problems consisting of dependent criteria and attributes are usually solved by utilizing ANP whereas AHP is used for simpler problems with a hierarchical decision structure. Application areas of ANP are numerous. Examples include R&D project selections [74], policy planning [75], financial crisis forecasting [76] and supply chain management [77].

An important of benefit of AHP and ANP are their ease of implementation [78]. Many of the other multi-criteria methods that are based on utility theory may be either too theoretical to apply or too complex to be appropriate in a corporate decision process. The paired comparison technique makes the methods easier to comprehend by decision makers.

AHP and ANP methods are sometimes criticized because of claims that the utility based methodologies are better in terms of theory [79]. A major criticism is the possibility of "rank reversal." Rank reversal occurs when different alternatives are added to the problem and the ranking of alternatives changes with this addition [80]. Another criticism is the large number of paired comparisons that should be performed in the model solution. Especially as the number of criteria increases, the number of paired comparisons escalates exponentially. The discussion on the theory and applicability of multi-criteria decision making methods can further be expanded [81] but is not pursued further in this research. Overall, the results of AHP and ANP have been accepted in many problems and its applicability is demonstrated

Here ANP is selected because of its advantages and its applicability to corporate decision making is demonstrated in many ways. The rank reversal and scale of paired comparisons are not major concerns for the problems in consideration because the decision problem is a strategic problem that does not require frequent computation and modification. Moreover, for the complexity and the dependencies of criteria in the decision problem in consideration, using utility based approaches is not practical, even if possible.

3.4.2 Model

In this research, the Analytic Network Process model is not used as a method to find the solutions for a decision problem, rather it is used as a tool to quantify the intangible factors that exist in an offshoring decision. As a result of offshoring, companies seek competitive advantage by reducing the cost of their production and services. According to an Accenture survey of more than 800 executives in the United States and Europe, cost savings are still a key offshoring benefit, but the additional business controls generated by offshoring are driving the trend [82]. Offshoring comes with uncertainties and risks. For instance companies that transfer operations overseas put their intellectual property and core competencies at risk.

Such intangible values involved in a decision model can broadly be classified into two groups: “Opportunities” and “Risks.” Opportunities represent the short and long term benefits that the company realizes as a result of the decision. Risks represent all the possible negative results that may be incurred as a result of the decision. The magnitude of the risks and opportunities that a company realizes is based on the supplier choice, the regions selected and the volume of production and services that are moved overseas. Obviously this magnitude varies depending on the execution of offshoring after the decision is made, but still a strategic offshoring decision should be made to minimize the possible risks and maximize opportunities by finding the best suppliers and the distribution of production/services.

The magnitude of risks and opportunities associated with the decision is found by an ANP model. The first step in building an ANP model is to identify the criteria with respect to which the alternatives will be evaluated. In the following, an example is shown for determining the criteria under risks. In this example risks are categorized into following criteria: operational, managerial and market risks. Each criterion can further be divided into sub-criteria that can independently be assessed. The elements of operational risks may be classified as quality, lead time, reliability and cost variance risks.

All of the criteria and sub-criteria can comprehensively be organized in a network structure. In this network, the criteria, sub-criteria and alternatives are connected to each other via arcs that represent the influence between the connected elements. An example is shown in Figure 3-4.

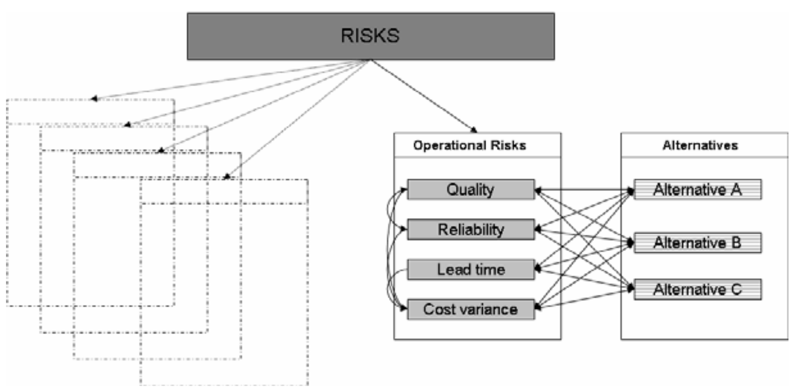

Figure 3-4. Example of an ANP Network

An arrow in a diagram pointing to a component means that its elements influence the elements in the component from which the arrow emanates [68]. For instance, in Figure 3-4 the level of reliability is influenced by alternatives (the choice of alternative) as well as the level of cost variance and quality. For many offshoring decisions, the evaluation criteria and their relationship to each other vary depending on the industry the company is in and the product/service nature that will be outsourced. Thus, the criteria, sub-criteria and the structure of the network should be considered for every offshoring decision separately.

After the formation of the network, the next step is to compare the elements based on their importance. The comparisons are performed as a result of expert analyses. The generic question is [70]: Given an element (in the same component or in another component) of the system or given a component of that system, how much more does a second element (component) of a pair influence that first element (component) with respect to a control sub criterion (criterion)? The format of the question is based on the relations in the network model. Priorities are derived from the paired comparisons by taking the matrix eigenvectors and consequently these priorities are input to a supermatrix. The columns are weighted by priorities of influence of corresponding components. Then the resulting column stochastic supermatrix is multiplied by itself with a limit power to obtain the priorities of alternatives with respect to upper level criteria. Their aggregation with the upper criteria weights gives the synthesized values of the end result which is a ranking of alternatives. As a result of standardization of alternative priorities, the solution to the problem can be obtained.

In offshoring decisions the paired comparisons should be based on company executives' opinions, literature survey, expert reviews [83] and real data from such databases as Countrywatch [84] and Sourceoecd [85]. Comparisons for country specific criteria may be evaluated based on newspaper articles, consultant reports and Internet search. Various reports are published to point out competitive indices for countries, which can be used as a basis for evaluating suppliers depending on their locations. Moreover historical economic data, such as inflation rates, can be used as an indicator for stability of resources. Supplier specific comparisons, on the other hand, need individuals who can assess the suppliers based on their experiences.

The ANP model gives opportunity and risk weights associated with each offshoring (supplier or in-house/offshore location) alternative. Alternatives are denoted in the set I = {i = 1, …, n}. The quantified risk associated with alternative *i* obtained from the ANP model is denoted as R_i whereas the opportunity is denoted as O_i.

3.5 INTEGRATION

Multi-attribute decision making methods may be used to determine the best alternative for a complex decision problem that includes intangible and tangible values. However, continuous variables such as production amounts cannot be included in a multi-attribute model. On the other hand, mathematical models give precise optimum answers by considering continuous and discrete decision spaces as well as production/service constraints. Yet, they cannot include intangible values that have complex interactive relations. This research combines the strengths of these two methods by integrating them to develop an approach based on multi-objective optimization.

3.5.1 Background

Most of the decision problems in real life have multiple conflicting objectives. Multiple objectives can be optimized by utilizing multi-objective optimization techniques that generate good solutions based on the relativity of conflicting objectives. The multi-objective optimization problem can be formulated as follows [86]:

Minimize $f(x) = (f_1(x), f_2(x), \cdots, f_p(x))$ over $x \in X$

where f_i is an objective function

Instead of a single optimum value, there is a set of best solutions for a multi-objective problem. When one or more objective functions are conflicting, the concept of "optimality" does not apply directly in the multi-objective setting. A useful replacement is the notion of *Pareto optimality*.

Definition 1. *A point* $x^* \in X$ *is said to be a Pareto optimal solution to the problem if there is no* $x \in X$ *such that* $f(x) < f(x^*)$.

The solution methods can be classified into two groups; Pareto techniques and non-Pareto techniques [87]. The non-Pareto techniques give a single solution whereas Pareto techniques give a set of Pareto optimal values by solving the objective functions iteratively.

A two-phase decision approach is developed by utilizing the MIP model to solve the quantitative objectives and the ANP model to quantify intangible factors. Pareto optimal set generation allows the decision maker to see the tradeoffs between the objectives and therefore it is preferred over single solution generation. Pareto optimization is chosen for this research to let the decision maker evaluate the tradeoffs between objectives and make a decision based on the sensitivity of the optimal decision to changing priorities.

The Pareto optimal solution set for a multi-objective problem can be generated using different algorithms. These algorithms are classified in three categories: enumerative, deterministic, and stochastic [88]. Stochastic methods include heuristic search algorithms such as tabu search, simulated annealing and evolutionary algorithms. Extensive research has been carried out in recent years in the area of evolutionary algorithms [89]. These algorithms utilize the Darwinian evolutionary theory to generate a near-to-optimal population by eliminating the unfit points and reproducing from the fit ones. The advantage of stochastic methods is their ability to find good solutions for large size problems in a reasonable amount of time. The disadvantage is that they do not guarantee optimal solutions and their performance depends on many factors such as the initial population and adjustment parameters.

On the other hand, deterministic algorithms guarantee optimal solutions and give solutions on the exact Pareto space. For instance, gradient based algorithms and branch and bound methods can provide exact Pareto values. Enumerative search algorithms are based on evaluating each possible solution from a given finite search space. For problems with a finite solution space, enumerative search algorithms can actually give the exact Pareto set. Computationally enumerative search algorithms are expensive, requiring exhaustive optimization of objective functions in many iterations.

Another classification of multi-objective optimization methods can be done based on the articulation of preferences [90]. “No articulation of preferences” methods generally combine the objective functions in an aggregate function called a global criterion. Examples are: weighted-sum, compromise programming and min-max methods. “A priori articulation of preferences” methods include preferences of the decision maker in the optimization approach. Lexicographic and hierarchical methods involve ordering of objectives according their relative importance. Many of the “no articulation of preferences” methods such as the weighted-sum method can also be modified with the preferences. “A posteriori articulation of preferences” methods such as the normal boundary intersection method and the normal constraint methods are designed for a posteriori articulation.

3.5.2 Model

After employing the MIP and ANP model, the challenge remains to integrate the solutions to come up with the best offshoring strategy. The solutions for the MIP and the ANP models are often conflicting since in most cases the low-cost alternatives are often the more risky ones which offer a minimal amount of opportunity. Multi-objective optimization is utilized to integrate these solutions to achieve the best offshoring decisions.

There are three objectives:

1- Quantitative values are input into an MIP model by decision variables x_{ij}^t representing production and service volumes supplied from an alternative location i to a demand location j at a time period t. z_i is the binary variable denoting the selection of an alternative location (or suppliers) that the operations may be carried. This model forms the skeleton of the multi-objective model (refer to the mathematical model Section 3-3). The cost objective is denoted as:

- **π_1(x)=** Minimize Total Cost

  [$\sum_{t \in T} \sum_{i \in I} \sum_{j \in J} C_{ij}(x_{ij}^t, z_i)$] , where I is the set of supply, J is the set of demand and T is the decision time horizon.

2- Risk indicates the likelihood of losing competitiveness as a result of offshoring. The ANP model gives the value of risks associated with each alternative $i \in I$ on a scale of 0 to 1, and is denoted by weight R_i. These weights are either normalized $(\sum_{i \in I} R_i = 1)$ or idealized $\max_{i \in I}\{R_i\} = 1$. The total risk of the offshoring decision depends on the alternatives chosen. If more risky alternatives are chosen for the offshore process, the risk level for the decision increases. The objective "minimization of risk" is denoted as:

- **π₂(x)** = Minimize Total Risk

  π₂(x) = min [$f_R(R_i, \sum_{t \in T} x_{ij}^t)$]

3- By offshoring (or by staying in-house) companies realize many opportunities such as market expansion and operational control. The ANP model gives the value of risk associated with each alternative $i \in I$ on a scale of 0 to 1, represented by the weight O_i.

   These weights are either normalized $(\sum_{i \in I} O_i = 1)$ or idealized $\max_{i \in I}\{O_i\} = 1$. Just like total risk, total opportunity of an offshoring decision depends on the alternatives chosen. The opportunity objective is denoted as:

- **π₃(x)** = Maximize Total Opportunity

  π₃(x) = [$f_O(O_i, \sum_{t \in T} x_{ij}^t)$]

Defining Total Risk and Total Opportunity:

The results of the ANP model gives the risk and opportunity weights associated with each alternative. Based on the weights of the alternatives chosen, the decision takes on a value of total risk and opportunity. The total risk and opportunity value that a decision takes cannot be simply defined as the sum of risk and opportunity weights of the alternatives chosen because this value not only depends on the alternatives but also depends on the nature of the risk and opportunity. For instance, if the risk involved in an offshore process compromises mainly the risk of losing intellectual property rights, doing business with an additional supplier will add more to the total risk. On the other hand, if the risk compromises mainly the risk of tardiness in production, working with diverse set of suppliers will mitigate the level of risk in the process.

In this study, the total risk and opportunity is defined with an analogy from the portfolio management literature in finance. In finance, the total risk of a portfolio is defined as the sum of systematic (nondiversifiable) and unsystematic (diversifiable) risks [91]. The unsystematic risk is the risk that can be "washed out" by diversification, such as organizational changes that affect only the stocks of a company. The systematic risk is the risk which cannot be diversified away, such as sudden fluctuations in interest rates and inflation.

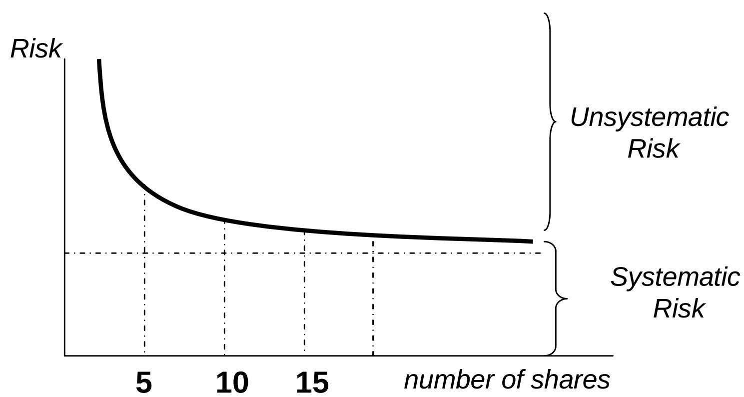

Figure 3-5. Portfolio Risk [92]

Analogous to the portfolio risk definition, as depicted in Figure 3-5, in this study risks (or opportunities) are defined as the sum of diversifiable and nondiversifiable risks (or opportunities). Diversifiable risks are risks that can be alleviated by distributing the production or services to multiple locations and suppliers. Risks related to lead time, macro-economic conditions (ie. interest and inflation) and quality are diversifiable. Diversifiable opportunities are opportunities that are elevated by distributing the production or services to multiple locations, such as opportunities for future product development, price reduction opportunities and quality enhancements. On the other hand, nondiversifiable risks are risks that add up as more locations are in the supply chain. These include intellectual property risks, implementation risks and management risks. Nondiversifiable opportunities are opportunities that reduce as the production or services are distributed. For instance, market expansion is an opportunity directly proportional to the company's share which is based on the volume of production and services in the region.

Within this framework, the total of diversifiable risks (or nondiversifiable opportunities) is defined as the sum of individual location risks (or opportunities) weighted by the volume of production and services at each location. The total of nondiversifiable risks (or diversifiable opportunities) is defined as the unweighted sum of individual location risks (or opportunities).

Once the total risk and opportunity functions are determined, a multi-objective problem is formulated consisting of the three objectives and the necessary constraints related to the offshoring decision. This multi-objective problem is characterized by the following:

- Preference articulation is very difficult without any information about the trade-offs between the objectives. Moreover, the preferences depend not only on the value of the objectives but also on the amount of production/services. Therefore, a method that can be solved without any prior preference articulation is needed.
- In order to show the decision maker the trade-offs, a Pareto optimal solution set needs to be generated. The Pareto optimal solution set can be plotted as a three dimensional graph with each axis representing one of the objectives. Visualization of the optimal set helps the decision maker to see the tradeoffs and make a sound decision based on preferences.

- The decision of offshoring usually consists of a small set of a limited number of location alternatives. Therefore, the multi-objective optimization problem is a small sized problem that does not necessitate the use of any heuristic optimization methods.
- The objectives for “risks” and “opportunities” have limits determined by the minimum and maximum risk and opportunity values of the alternatives. Moreover these bounds are numerically restricted due to the fact that risk and opportunity quantifications must be between 0 and 1. This feature puts bounds on the search space and creates computational advantage.

The preferences need to be elucidated a posteriori and due to the small size of the problem, exact methods are computationally efficient enough to solve such a multi-objective problem. Therefore two methods are selected to generate the Pareto front: weighted-sum and epsilon-constraint methods.

Weighted-sum method:

The weighted-sum method is a scalarization method that aggregates the objectives with associated weights and generates the Pareto optimal points by solving the aggregated objective. The weighted-sum method is a traditional multi-objective optimization method that is used for various applications. The multi-objective problem is converted into a scalar problem by constructing a weighted sum of all objectives. In the literature the weights are often used to represent preferences, however in cases without any preference articulation the weights can be used to generate the Pareto front. This also eliminates any problems that can come into play due to the deficiencies of using weights as preference indicators.

If each objective is denoted by min $F_i(x)$ s.t. $x \in X$ for i = 1, … , n

The weighted-sum approach solves the problem as follows:

$$\min \sum_i w_i F_i(x) \text{ s.t. } x \in X$$

Pareto optimal solutions are obtained by changing the weights. Minimizing the weighted-sum is a necessary condition for Pareto optimality if the feasible region is convex [93]. Moreover, if $w_i > 0$ for all *i*, minimizing the weighted-sum is a sufficient condition, guaranteeing that the solutions are always Pareto optimal [94].

If weighted-sum method is used for the multi-objective problem considered in this research, the cost objective function would dominate the aggregated objective function because of its relatively large value. In order to prevent one function's domination due to different orders of magnitude, transformations must be performed. There are various function transformation methods in the literature. Marler [90] presents an exhaustive review and comparison of these methods. As a conclusion, the author proposes that using the upper-lower-bound approach can improve the performance of the weighted-sum method and using this approach with Pareto-maximum values provides superior results. Therefore, this method is recommended as a function transformation approach. Moreover, using convex combination of weights is also recommended to facilitate a Pareto front with more uniformly scattered optimal points.

Epsilon-constraint method:

The epsilon-constraint method is not a scalarization approach; rather it is in a class called bounded objective function methods. It solves one of the objective functions (primary objective function) by adding the other objective functions into the constraint space. The Pareto optimal points are generated by changing the constraint limits of the objectives.

If the primary objective is denoted by min $F_s(x)$ and all other objectives are denoted by min $F_i(x)$; within the total constraint set $x \in X$ then the epsilon-constraint approach solves the problem:

$$\min F_s(x) \text{ s.t. } x \in X \text{ and } F_i(x) \le \varepsilon_i \text{ for } i \ne s$$

The point that minimizes the primary objective function is denoted by x_s^*.

Epsilon limit selection can be made by two methods that ensure the satisfaction of Pareto-optimality conditions. These are "primary-objective" and "pareto-maximum" methods. The primary-objective approach restricts the epsilons as [95]: $F_i^0 \le \varepsilon_i \le F_i(x_s^*)$ where the Pareto-maximum approach replaces $F_i(x_s^*)$ with the Pareto-maximum of F_i. F_i^0 represents the minimum of function *i* and $F_i(x_s^*)$ is the value of function *i* at x_s^*. The Pareto-maximum approach is found to give better results when compared to the primary-objective method, however the points found may sometimes be weak Pareto-optimal (not unique) [96].

In terms of computational efficiency and the quality of the results, both methods have advantages and disadvantages. The weighted-sum method can generate different optimal points at each iteration (by changing the weights) whereas the epsilon-constraint method encounters infeasibility or duplication in some iterations. The epsilon-constraint method does not need any normalization whereas the weighted-sum approach needs extra computation time due to the necessity for using transformation functions.

For the specific problem discussed in this research, the epsilon-constraint method is able to cover the constraint space with less iterations because of the distinct property that the two objectives have, specifically risks and opportunity objectives are limited by the maximum and minimum values of risks and opportunities of the alternatives. However research suggests [90] using the weighted-sum approach especially in cases with more than two objective functions because in these cases the epsilon-constraint method can result in infeasible problems and/or duplicate solution points, resulting in wasted computational time.

In this study, both the weighted-sum and epsilon-constraint methods are used to generate the Pareto optimal points. The risk and opportunity functions are on the same scale whereas the cost objective take on relatively large values that may dominate the aggregated objective function, requiring a transformation as discussed above.

Again in his thesis, Marler (pp.118) [90] compared different function transformation methods that can help in generating an approximation of the Pareto optimal set and concludes: "*Using the upper-lower-bound approach can improve the performance of the weighted sum method, and using this approach with a Pareto-maximum provides superior results. This is the most robust approach to function transformation and is recommended in conjunction with a convex combination of weights.*"

The upper-lower bound approach transforms the functions as [97]:

$$F_i^{trans} = \frac{F_i(x) - F_i^0}{F_i^{\max} - F_i^0}$$

x is the vector representing the evaluation point. $F_i(x)$ represents the value of objective function *i* at point **x**. F_i^0 is $\min_x \{F_i(x) \mid x \in X\}$ where X is the decision space. $F_i^{\max}$ is the Pareto-maximum and is defined as $\max_{1 \le j \le k} F_i(x_j^*)$ where *k* is the number of objective functions and x_j^* is the point that minimizes the j^{th} objective function.

In this research epsilon-constraint method is applied with Pareto-maximum bounds and the weighted-sum approach is applied with upper lower bound function transformation. The steps of multi-objective optimization algorithm are described below:

1. Define three objective functions: . $\pi_1(x), \pi_2(x), \pi_3(x)$

GoTo Step 2

2. Define the constraint space $x \in X$

GoTo Step 3

3. Find the Pareto-maximum of each objective function: $\pi_1^{\max}(x)$, $\pi_2^{\max}(x)$, $\pi_3^{\max}(x)$

GoTo Step 4

For weighted-sum approach:

4. Calculate the transformation ratios and transform the objective functions to

$\pi_1^{'}(x), \pi_2^{'}(x), \pi_3^{'}(x)$

GoTo Step 5

5. Set initial weights for the objective functions:

$\mathbf{w_1 = 0.05}$, $\mathbf{w_2 = 0.05}$, $\mathbf{w_3 = 1\text{-}(w_{1} + w_2)}$

GoTo Step 6

6. Solve the aggregated objective function $\min\{\mathrm{w}_1 \pi_1^{'}(x) + \mathrm{w}_2 \pi_2^{'}(x) + \mathrm{w}_3 \pi_2^{'}(x) \mid x \in X\}$ and store the results in the Pareto optimal set.

GoTo Step 7

7. If $w_2 \leq (1 – 0.05 - w_1)$

a. Increase w_2 by 0.05 and calculate $w_3 = 1\text{-}(w_{1} + w_2)$

b. Goto Step 6

Otherwise

c. Goto Step 8

8. Increase w_1 by 0.05 and set $w_2 = 0.05$ and calculate $w_3 = 1\text{-}(w_{1} + w_2)$

If $w_1 \leq 0.9$

a. GoTo Step 6

Otherwise

b. END

For epsilon-constraint approach:

4. Define $\varepsilon_2 = \pi_2^{\max}$ and $\varepsilon_3 = \pi_3^{\min}$

5. Keep the objective and constraints and add constraints:

a. $\pi_2(x) \leq \varepsilon_2$

b. $\pi_3(x) \geq \varepsilon_3$

Solve the optimization problem.

GoTo Step 6

6. If $\varepsilon_2 \geq \pi_2^{\min}$

a. If $\varepsilon_3 \leq \pi_3^{\max}$ increase ε_3 by 0.01 increment

b. Goto Step 5

c. Otherwise, decrease ε_2 by 0.01 increment

d. Goto Step 5

Otherwise

e. END

Once the weighted-sum and epsilon-constraint algorithms are applied, some of the Pareto optimal points in the Pareto front are obtained. By considering these non-dominated solutions, the decision maker can assess the tradeoffs between objectives and decide on the best decision that will fit the strategic and operational plans of the corporation. For visualization purposes, the decision maker may be assisted by plotting the Pareto set in a three dimensional graph where each axis represents one of the objectives. Furthermore, sensitivity analysis and utility elicitation may be performed to analyze the tradeoffs and make a final decision with respect to the preferences of the decision maker.

4.0 OFFSHORE OUTSOURCING EMPIRICAL STUDY: SIMA

SIMA Products Corporations is a private company which was founded in 1973 and as of 2006 operates in Oakmont, Pennsylvania [98]. SIMA is a leading innovator of consumer electronic accessories. It designs and creates consumer electronics and sells products to major retailers in the U.S. market, such as Best Buy and Circuit City. The company started as a small family business in the photographic accessories industry. Over the years, SIMA has developed a large supply network consisting of several suppliers around the world as well as its retail network, which has included not only category-killers like Circuit City and Best Buy, but also niche players such as Ricoh and local merchandisers.

SIMA is competitive in the consumer electronics industry characterized by very short product cycles, rapidly changing market opportunities, and a subtle balance of cooperation and rivalry with suppliers and retailers. Their business model is based on the early identification of niche market opportunities—typically targeted at highly sophisticated users of mainstream consumer electronics—that are often too small to be of interest to large consumer electronics companies. Once the market opportunity is identified, the product has to be designed and manufactured within a very short period of time. One of the paradoxes of the business is that if a product turns out to be really successful, it becomes attractive to SIMA's retailers, who may then see an opportunity to produce a similar product themselves, rather than to carry SIMA's product. Given that product life cycles are so short that a product's sales begin declining even before the patent is issued, patent protection is not an effective barrier to such threats. The only way to survive is to be ahead of the market, by knowing what to introduce beforehand, as well as by introducing new features rapidly—thus, even if the first generation of a product attracted "knock-offs," SIMA can offer a second generation with superior features. Table 4-1 presents major milestones in SIMA's history.

Table 4-1. SIMA Corp. Major Milestones

Date	Event
1973	SIMA is founded. Product focus is on photographic accessories.
1974	SIMA recieves the patent for FilmShield®
1984	SIMA engages Seidman & Seidman/BDO management consultants to develop a strategic plan for future
1985	Entrance to Camcorder and Video accessories industry
1985	SIMA develops a long-term strategic plan
1986	Irwin H.Diamond introduces a new line of video accessory products
1987	SIMA grows with 46.1% increase in staff size at head quarters office
1988	First outsourcing to a Taiwanese manufacturer
1990	Significant consolidation starts among competitors in the consumer electronics
1994	Entrance to home theater market
1995	Ilana Diamond becomes the new President of SIMA
1996	FilmShield XPF® is launched
1996	SIMA moves to Pittsburgh from Chicago
2002	SIMA acquires Shaumburg Corporation's wireless products (First Alert and Cherokee radio equipment lines)

SIMA is one of the few mid-size private companies that were able to maintain competitiveness in the industry. Over the last few years most of the competitors either went bankrupt or were acquired by big players in the industry. The driver behind the company's success has been its innovation business model that the company has kept as a core competence even while profit margins in the electronic equipment industry were under pressure and the rate of product obsolescence continued to accelerate.

The fierce price competition caused by the power shift in the supply chain, forced companies towards a search for less costly manufacturing opportunities. During the 1980s, the first signs of the offshore outsourcing trend were apparent with the rising manufacturing capabilities in Taiwan. The offshore outsourcing scheme became common in 1990s and today most consumer electronics items are manufactured outside the United States. SIMA was one of the earliest companies to outsource its manufacturing tasks to Taiwan in late 1980s. At that time, only the mature products that needed mass production were candidates for offshore outsourcing. Today, the competition is so strong that offshore outsourcing is necessarily considered for every product regardless of its phase in the product life cycle.

Working with offshore suppliers for manufacturing of products creates competitive advantages such as lower product costs and increased concentration on innovation. However it also creates many problems which may lead to monetary losses as well as withdrawals from the market. For instance, SIMA had to exit the remote control market because of an unreliable supplier even though the market in the U.S. had significant business opportunities. Past experiences showed that the suppliers in Hong Kong and Taiwan are usually more trustworthy in protecting the intellectual property and maintaining quality control. On the other hand, these suppliers cannot offer prices as low as the suppliers in China. Chinese suppliers have the advantages of economies of scale, low raw material costs and labor rates; however they tend to work with larger companies that can copy the innovative designs of SIMA. Another tradeoff is between product costs and engineering capabilities. In the past, SIMA has experienced many instances where the products failed only because of miscommunication and lack of technical expertise of suppliers. The market is very sensitive to price and at the same time customers demand innovation and superior design. Therefore, it is important to work with suppliers which can provide high quality engineering services while ensuring a competitive market price for the product. For SIMA, it is a big challenge to choose suppliers which can provide both low costs and the high innovative capability that the market seeks.

Although cost is an important determinant in supplier selection, it is only one of the factors that determine the success of the product. Through the past years, the bad and good experiences taught SIMA that measures that are not tangible like technology capability should be a consideration before starting a business with a supplier. SIMA has classified these qualitative variables under the criterion "experience" because experience seems to be the only standard for these variables. However, experience by itself cannot be easily measured and it does not reflect all of the intangible factors that should go into a supplier selection process. In this research, the qualitative and quantitative measures that should go into the supplier selection decisions of SIMA are investigated and an integrated systematic decision approach is illustrated for the selection of a supplier (offshore and inshore) that would manufacture a new product line designed by SIMA.

In the consumer electronic industry the product life cycles are short, usually ranging from six months to one year. A major challenge in supplier selection for a consumer electronic product is the demand fluctuations at each product life cycle phase. SIMA experienced several cases of their product becoming obsolete when big players entered the market with a similar product (often with a copied design) and reduced product prices. In the first phase where the product is launched and the demand grows, the most crucial thing is to protect the design from competitors.

Once the product is on the shelf for a certain length of time and is successful, it is inevitably copied and then price becomes the major factor in competition. Consequently the demand for the product changes drastically. Therefore, in this research a decision model is built for offshore supplier selection by assuming different demand volumes. The model shows how the decision changes depending on the demand volume. This enables the decision makers to conduct scenario analysis by considering possible outcomes.

As described in the methodology section, the decision approach is implemented in two phases. First, a mathematical model is formulated to evaluate the quantitative variables involved in the decision. This model finds the best supplier alternative(s) and the distribution of manufacturing among the suppliers with respect to the financial considerations. Later, the qualitative variables are identified and classified into criteria groups. The supplier alternatives are evaluated with respect to these criteria by constructing an ANP model. The results are later synthesized to generate the best strategy in terms of both quantitative and qualitative variables.

The process in consideration for offshore outsourcing is the manufacturing of High-Definition Multimedia Interface (HDMI) switchers. HDMI switchers are used to connect multiple devices such as play stations and DVD players to one HD (high definition) monitor. There are three product lines: 2x1 HDMI (with two inputs), 3x1 HDMI (with three inputs) and 5x1 HDMI (with five inputs). Four supplier alternatives are evaluated in terms of their monetary advantageousness as well as the risks and opportunities they engender.

4.1 MATHEMATICAL MODEL FOR SIMA CORPORATION

4.1.1 Model Formulation

The mathematical formulation is a supplier selection model with four possible supplier alternatives, one demand point and three products. The supplier alternatives are: Amberson (Taiwan), Function (U.S.A.), NTC (Hong Kong) and Belton (Peoples Republic of China). The real names of the suppliers have been disguised to protect the confidentiality. The products will be sold only in the U.S. market, thus there is one demand point and all of the manufactured products will be shipped to the U.S. The total demand is difficult to estimate before the product is launched because the demand can fluctuate depending on the product life phase. However, the proportions of sales for each product line can reliably be estimated based on the current market information. The mathematical model minimizes the total relevant cost incurred in product purchases from suppliers.

Assumptions:

- The product life cycle is short (less than one year) and therefore time variables (such as interest rate) are ignored.
- The capacities of the suppliers are adequate to meet total demand.
- The minimum quantity that can be ordered is 500 units.

Indices:

I: {i = 1,2,3.4} Set of supply points

P: {p = 1,2,3} Set of product types

Parameters:

M = sufficiently large constant for the binary force constraints

D = total demand for products

v_{ip} = quoted unit price of product p by supplier i

f_{ip} = fixed cost requested by supplier i for product line p

c_i = capital investment that supplier i needs

s_i = HDMI certification registration cost for supplier i

h_i = HDMI licensing cost per product

t_{ip} = transportation cost per unit of a product p from supplier i

r_i = tariff and other fees applied per unit of product shipped by supplier i

mo_i = minimum order quantity that supplier i requires

q_p = estimated percentage of product type p in demand

Decision variables:

x_{ip} = the amount of product type p coming from supplier i

z_{ip} = binary variable associated with product type p coming from supplier i, 1 if supplier i is chosen for manufacturing of product p, 0 otherwise

b_i = binary variable associated with supplier i, 1 if supplier i is chosen for any manufacturing

Objective function:

$$\text{Minimize} \qquad \sum_{i \in I}\left[\sum_{p \in P}\left(f_{ip} z_{ip} + (1 + r_i)(v_{ip} + t_{ip} + h_i)x_{ip}\right) + (c_i + s_i)b_i\right] \tag{4-1}$$

Constraints:

- *Demand Constraint*

$$\sum_{i \in I} x_{ip} = q_p D \qquad \forall \;\; p \in P \tag{4-2}$$

- *Minimum Order Constraint*

$$x_{ip} \geq mo_i z_{ip} \qquad \forall \;\; p \in P \text{ and } \forall \;\; i \in I \tag{4-3}$$

- *Binary Force Constraints*

$$x_{ip} \leq M z_{ip} \qquad \forall \;\; p \in P \text{ and } \forall \;\; i \in I \tag{4-4}$$

$$\sum_{p \in P} z_{ip} \leq M b_i \qquad \forall \;\; i \in I \tag{4-5}$$

- *Trivial Constraints*

$$x_{ip} \geq 0 \qquad \forall \ p \in P \text{ and } \forall \ i \in I \qquad (4\text{-}6)$$

$$z_{ip} \in \{0,1\} \qquad \forall \ p \in P \text{ and } \forall \ i \in I \qquad (4\text{-}7)$$

$$b_i \in \{0,1\} \qquad \forall \ i \in I \qquad (4\text{-}8)$$

4.1.2 Data Collection

The quantitative data are provided by SIMA based on the suppliers' quotes of unit prices, the minimum order quantities and the amount of capital required for manufacturing. The tariff and duty rates and transportation costs are taken as designated by the regulations. The data are depicted in Table 4-2.

Table 4-2. SIMA Quantitative Data

		$ Per Item	**Fixed Cost**	**Capital Cost**	**Certific. Cost**	**Trans. Cost**	**Tariff Rate**	**Min. Order Quant.**
Amber-son	**2X1**	$ 21	$ -	$ -	$ -	$ 1.90	3.04%	1,000
	3X1	$ 37	$ -	$ -	$ -	$ 1.57	3.04%	1,000
	5X1	$ 65	$ -	$ -	$ -	$ 1.57	3.04%	1,000
Function	**2X1**	$ 43	$ -	$30,000 total	$10,000 & 15 cents per unit	$ -	0%	2,500
	3X1	$ 45	$ -			$ -	0%	2,500
	5X1	$ 60	$ -			$ -	0%	2,500
NTC	**2X1**	$ 98	$ -	$30,000 total	$10,000 & 15 cents per unit	$ 0.86	3.04%	500
	3X1	$125	$ -			$ 1.62	3.04%	500
	5X1	$250	$ -			$ 1.62	3.04%	500
Belton	**2X1**	$ 15	$ 20,000	$30,000 total	$10,000 & 15 cents per unit	$ 1.22	3.04%	500
	3X1	$ 20	$ 20,000			$ 2.32	3.04%	500
	5X1	$ 50	$ 20,000			$ 2.32	3.04%	500

As indicated by SIMA, capacity is not a subject of consideration for the four alternative suppliers because demand usually does not exceed the amount a large supplier can supply. Belton requires SIMA to pay an extra tooling cost equivalent to $20,000 that will be used to buy new equipment for each product line. The capital cost includes all the costs incurred for additional resources and R&D involved in production. Amberson absorbs all of the capital cost (depreciation, maintenance etc.) whereas the other three suppliers ask for approximately $30,000 for capital. In this case regardless of the amount of products supplied, $30,000 needs to be paid.

LLC is the licensing agent responsible for administering the licensing of the HDMI specification, promoting the HDMI standard and providing education on the benefits of HDMI to retailers and consumers [99]. HDMI adopter manufacturers have licensing rights for their end products in return to registering with HDMI Licensing and cooperating with the HDMI standards and tests. The first HDMI product produced by a manufacturer in each device category must be tested at an HDMI Authorized Testing Center. The registration fee for being an HDMI adopter is $10,000 per year and an additional 15 cents is paid per unit sold. SIMA has a policy asking for HDMI certification for all of the devices they sell in the U.S. market. Since the life cycle of the product is not expected to be more than one year, $10,000 is listed as the certification cost and the quoted unit prices are increased by 15 cents for suppliers who are not registered with HDMI Licensing.

The transportation cost includes the ocean freight and land transportation of the product from the supplier. Function has agreed to ship the product with no charge. The same tariff rate applies to shipments whether they are from mainland China (PRC), Taiwan or Hong Kong. The tariff rate is 2.7% of total value (rounded to nearest dollar) of the shipment. An additional 0.21% merchandise processing fee and 0.125% harbor maintenance fee is charged for ocean shipments.

NTC and Belton do not specify any minimum order quantity; however Amberson and Function require a minimum order of 1,000 and 2,500 units, respectively.

4.1.3 Solution

The proportion of product sale for 2x1, 3x1 and 5x1 HDMI switchers are 50%, 30% and 20% respectively. The model is solved by inputting different demand values to obtain optimum solutions associated with each. This helps the decision maker understand the market conditions that affect the decision while providing a tool for scenario analysis.

If total demand is less than 2,500, the production volumes for 2x1, 3x1 and 5x1 are less than 1,250, 750 and 500 units respectively. Since none of the suppliers is willing to supply less than 500 units, 5x1 HDMI switchers cannot be supplied when the total order quantity is less than 2,500. Therefore even if real market demand is lower, it is assumed that SIMA will order at least 2,500 units.

If total demand is more than 12,500, the production volumes for 2x1, 3x1 and 5x1 exceed 6,250, 3,750 and 2,500 units respectively. In this case any supplier may be selected since order quantities exceed the minimum order quantity requirement of all suppliers. If total demand is between 2,500 and 12,500, selection of suppliers is restricted by the minimum order quantities. For example, if total demand is between 2,500 and 3,333 Function cannot be selected for any of the products and Amberson cannot be selected for manufacturing of 3x1 and 5x1 HDMI switchers due to the limitations of minimum order quantities. Table 4-3 presents the possible combinations for supplier selections for different intervals of demand Where “*” indicates possible selection and “-“ indicates that supplier cannot be selected for the corresponding product due to the minimum order quantity restrictions.

Table 4-3. SIMA Supplier Selection Possibilities

2x1 HDMI	**Minimum**	1,250	1,667	2,500	4,167
	Maximum	1,667	2,500	4,167	6,250
	Amberson	*	*	*	*
	Function	-	-	*	*
	NTC	*	*	*	*
	Belton	*	*	*	*
3x1 HDMI	**Minimum**	750	1,000	1,500	2,500
	Maximum	1,000	1,500	2,500	3,750
	Amberson	-	*	*	*
	Function	-	-	-	*
	NTC	*	*	*	*
	Belton	*	*	*	*
5x1 HDMI	**Minimum**	500	667	1,000	1,667
	Maximum	667	1,000	1,667	2,500
	Amberson	-	-	*	*
	Function	-	-	-	-
	NTC	*	*	*	*
	Belton	*	*	*	*
Total Demand	**Minimum**	2,500	3,333	5,000	8,333
	Maximum	3,333	5,000	8,333	12,500

Belton's unit price quotes are lower than that of Amberson, Function and NTC and Belton requires a lower minimum order quantity. When compared with NTC and Function, the only drawback of choosing Belton would be the tooling cost which is $20,000 per production line. Breakeven analyses are performed to determine how much production volume is needed in order for Belton to incur a total cost that is less than that of what Function and NTC.

Figure 4-1 illustrates that if production volume is more than 240 units, when compared to NTC, Belton's tooling cost for the 2x1 HDMI production line is recovered by its lower unit costs.

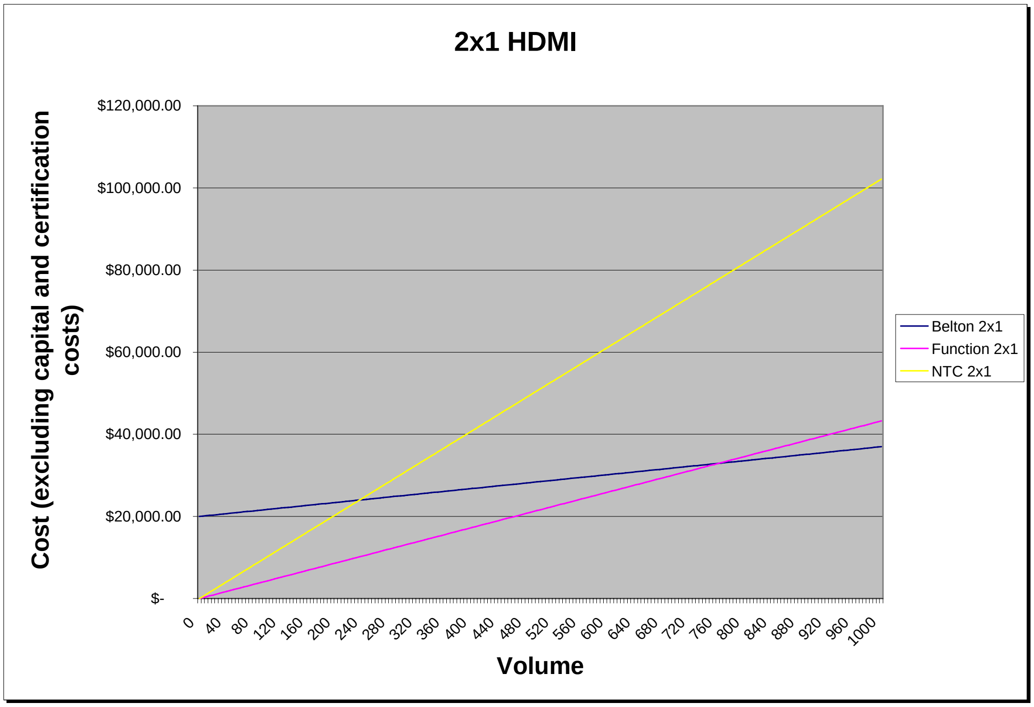

Figure 4-1. Breakeven Analysis: 2x1 HDMI- Belton, Function, NTC

Since 240 is less than the minimum order quantity required, Belton is always preferred over NTC regardless of the demand volume. Again, if the demand volume is more than 765 units, when compared to Function, Belton's tooling cost for the 2x1 HDMI production line is recovered by its lower unit costs. Since 765 is less than the minimum order quantity required, Belton is always preferred over Function regardless of the demand volume. As a result, Belton is preferred over Function and NTC independent of the volume of demand.

Figure 4-2 illustrates a similar breakeven analysis for 3x1 HDMI switchers. The extra tooling cost required by Belton is overcome at a breakpoint demand volume that is lower than the minimum order quantities. Therefore, Belton is always preferred over NTC and Function for 3x1 HDMI switchers. On the other hand, Figure 4-3 shows that Function is preferred over Belton for 5x1 HDMI switchers.

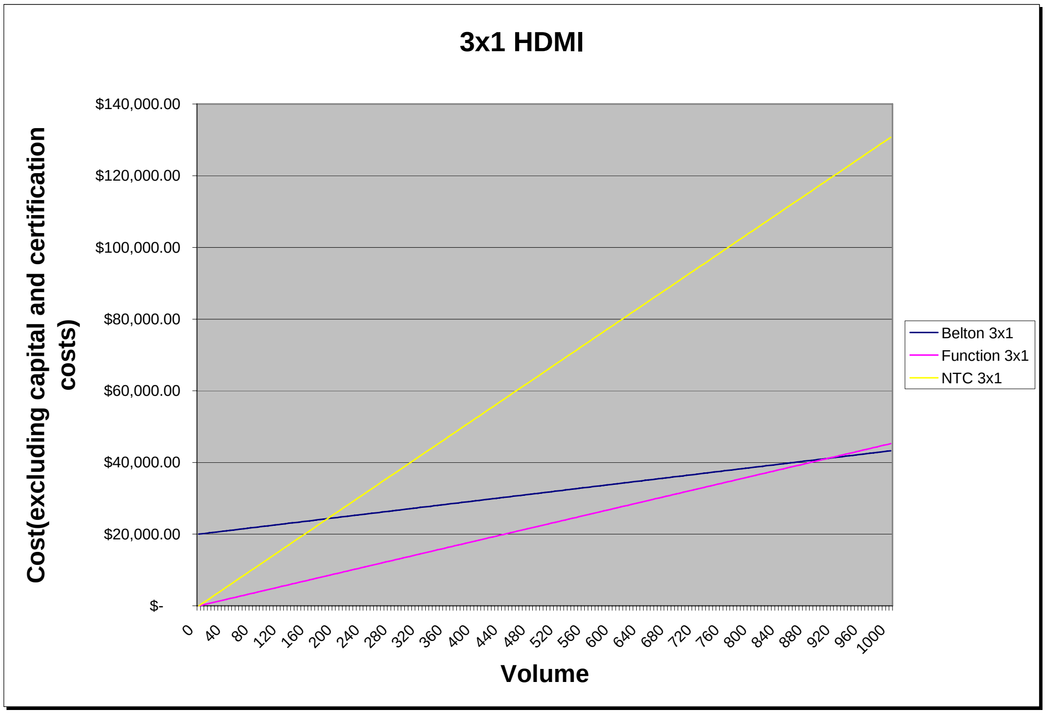

Figure 4-2. Breakeven Analysis:3x1 HDMI - Belton,Function, NTC

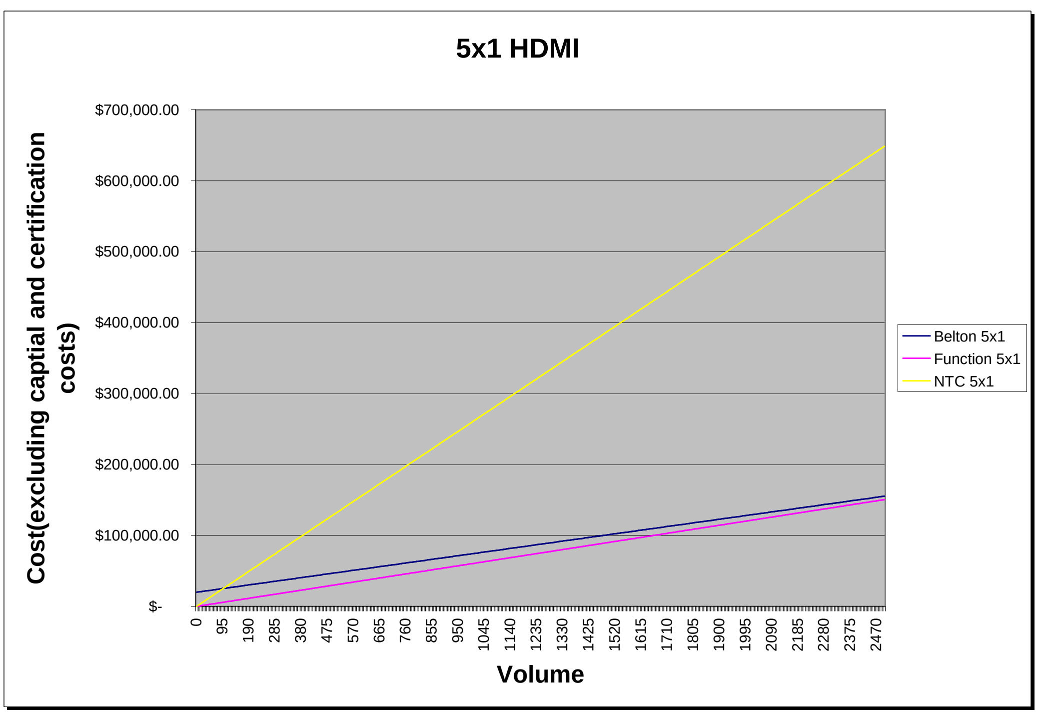

Figure 4-3. Breakeven Analysis: 5x1 HDMI- Belton, Function, NTC

However as illustrated in Figure 4-4, if all of the product order costs are aggregated the savings that Function can provide in 5x1 HDMI product line is not enough to recover the extra capital and certification costs required for other products. Therefore, the analyses reveal that in order to minimize total production costs, Belton are always preferred over NTC and Function for manufacturing of all of the products regardless of the demand volume.

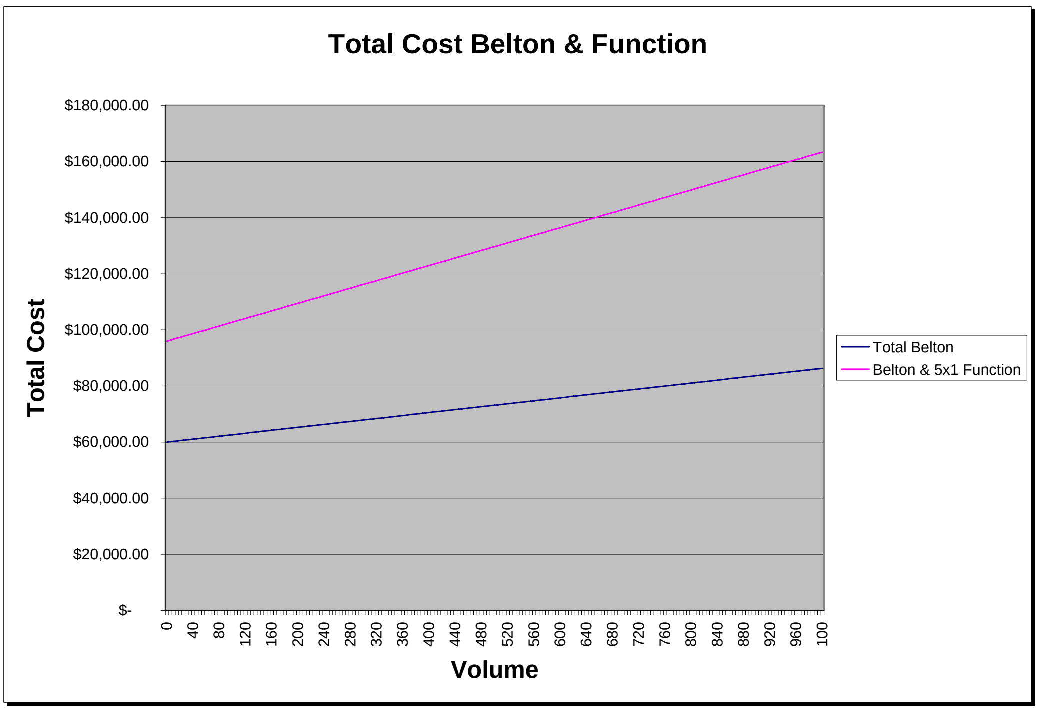

Figure 4-4. Breakeven Analysis: Aggregated Production- Belton,Function

Amberson is also always preferred over NTC because its unit prices for all of the three product lines are lower and does not have any extra fixed or capital cost requirements. It is also preferred over Function for 2x1 and 3x1 HDMI switchers but there is no strict preference for 5x1 switchers because the unit price quoted by Function is lower although there is a capital cost associated with it. As shown in Figure 4-5, Function is preferred for manufacturing of 5x1 HDMI switcher when the total demand exceeds 23,255 units.

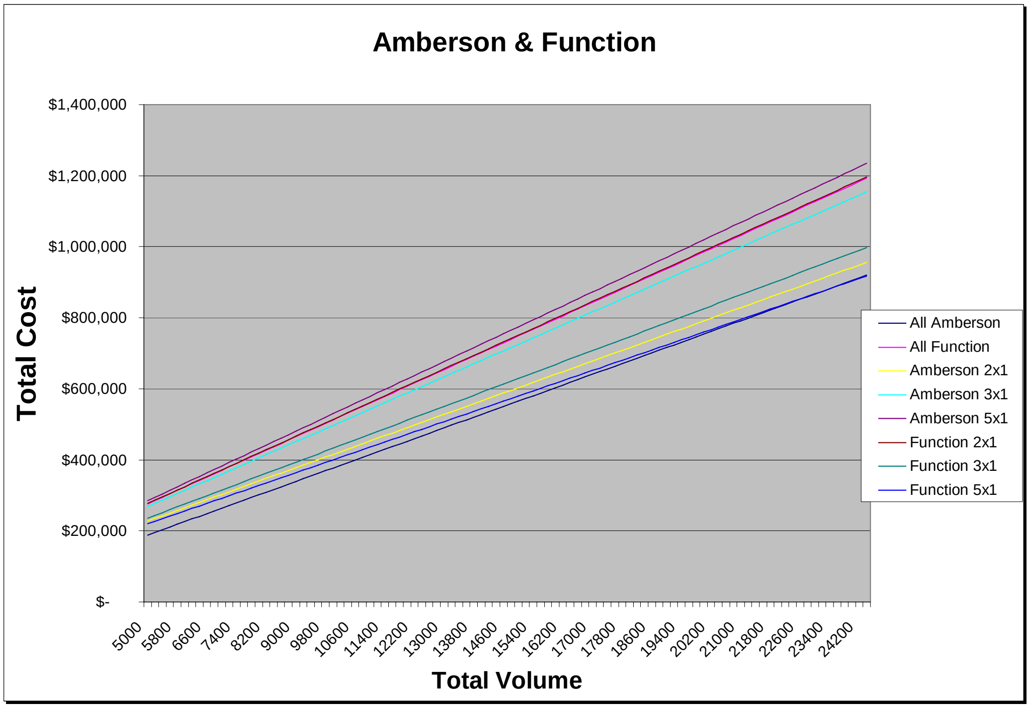

Figure 4-5. Breakeven Analysis- Amberson, Function

There is no dominant preference between Belton and Amberson, either. Although Amberson has higher price quotes, it has no fixed cost which may lead to a lower total cost for some demand points. The breakeven analysis for Belton and Amberson is depicted in Figure 4-6. When demand volume exceeds 8,873 Belton is preferred over Amberson. Since Belton is preferred also over Function, even though Function is preferred over Amberson for manufacturing of 5x1 HDMI switcher for high demand volumes, Function is dominated at all of the demand volumes.

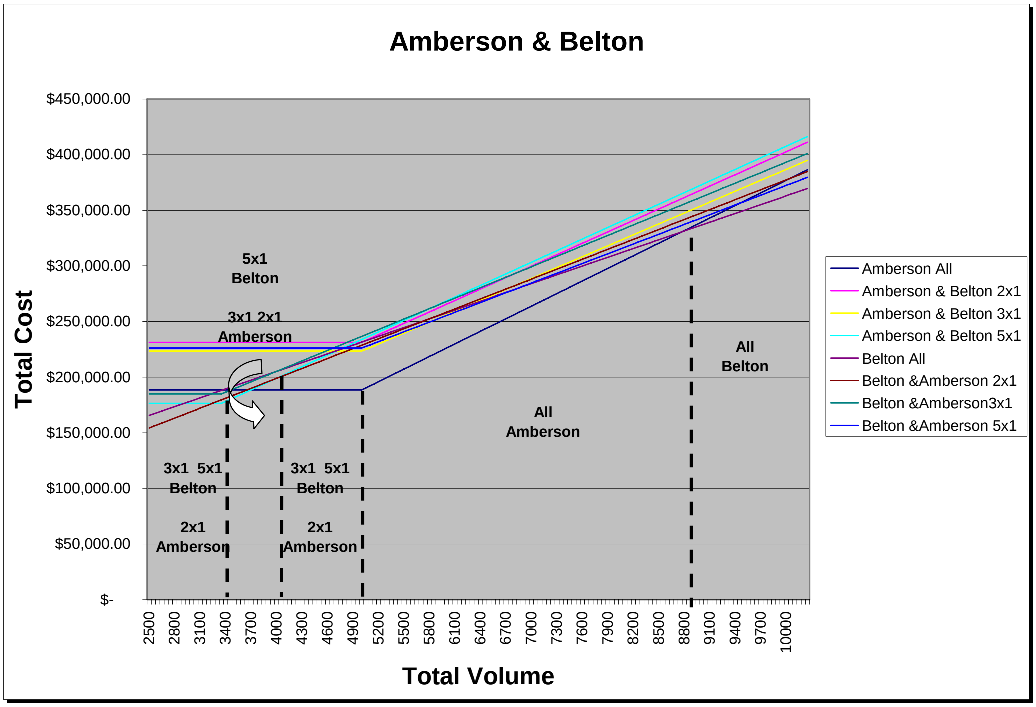

Figure 4-6. Breakeven Analysis- Amberson,Belton

When the mixed integer model is solved repetitively for different demand volumes, the optimization solutions confirm the breakeven results. If the total demand is higher than 2,500 manufacturing of 3x1 and 2x1 HDMI switchers is outsourced to Belton whereas manufacturing of 2x1 HDMI switchers is outsourced to Amberson. The first breakeven occurs when the demand for 3x1 HDMI exceeds 1,000 (total volume: 3,333). After this point Belton is preferred for manufacturing of 5x1 HDMI switchers and Amberson is preferred for manufacturing of 3x1 and 2x1 HDMI switchers. The second breakeven occurs when Belton's fixed cost for the 3x1 HDMI production line is overcome by its low unit price (total volume: 3,982). The distribution of product lines among Amberson and Belton again changes. The third breakeven occurs when the demand for 5x1 HDMI exceeds 1,000 (total volume of 5,000). After this point Amberson is selected for all of the product lines. Finally the last breakeven occurs when the fixed costs of

Belton are overcome by the low unit prices (total volume: 8,873) and Belton is preferred for manufacturing of all of the three products.

4.2 ANP MODEL FOR SIMA CORPORATION

The biggest challenge in decision making is measuring intangible elements and evaluating the preferences associated with them. In SIMA's history, most of the product failures occurred because of wrong supplier choices. The supplier either did not manufacture within the design specifications, or there were communication problems due to technical and organizational factors. On the other hand, a number of suppliers created opportunities for the future by proposing innovative product changes and jointly working with SIMA for the development of future products. Therefore, both the risks and opportunities involved in supplier selection should be assessed in making the best supplier choice.

4.2.1 Model Formulation

ANP quantifies intangible merits by forming a network of criteria, sub-criteria and elements and then comparing elements with respect to the sub-criteria and criteria. The implementation of the ANP model in SIMA was performed with a number of steps involving high level executives, engineers and purchasing specialists. The first step is to identify the criteria that influence the level of risks and opportunities involved in an overseas supplier relationship. This was done in a session where the decision makers (company executives and engineers) classified the criteria into two clusters: risks and opportunities. Under each cluster, the components affecting the decision are identified by the SIMA executives based on their experiences and priorities.

The relationships among the criteria, sub-criteria and alternatives are determined based on the direction of influence that one has on the others. Below are the descriptions of the criteria for which the risks and opportunities are calculated for each supplier. Figure 4-7 through Figure 4-12 show the structure of the decision network including the hierarchical structure and relationships. An arrow pointing into a component means that its elements influence the elements in the component from which the arrow emanates. The double arc arrows indicate that all of the sub-criteria under the criterion are influenced by and influencing all of the sub-criteria under the other criterion.

4.2.1.1 Risks for SIMA

1- Cultural Fit

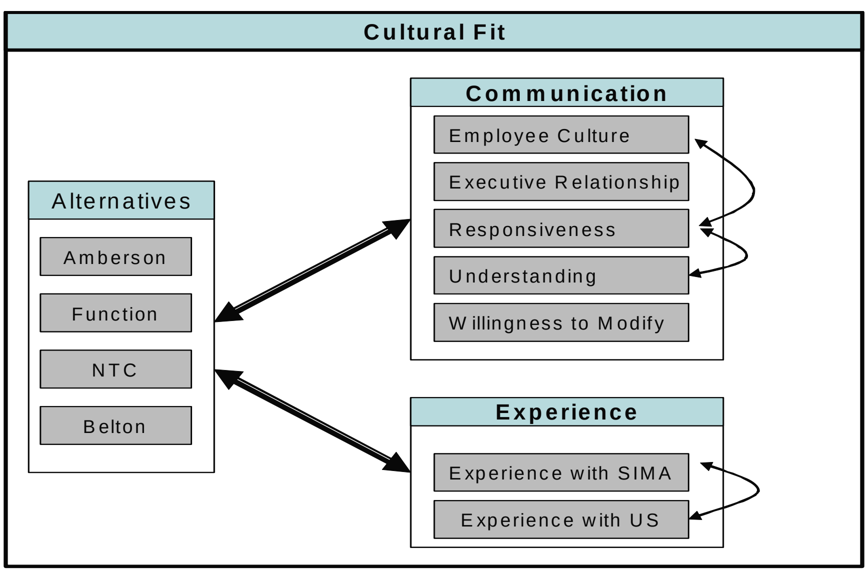

Figure 4-7. Criterion: Cultural Fit

a) Communication

i. *Understanding:* When SIMA requests changes in the product such as replacing a part of an electronic device, the supplier should be able to recognize that the reason behind this request is to make the product more marketable. If the supplier is having a hard time in perceiving the needs of the U.S. market and SIMA's efforts to modify product designs to fulfill these needs, then the risk of having delays in the product development increases.

ii. *Employee culture (western mind):* Organizational culture is an important indicator of how successful the relationship can be with a supplier. An Asian protocol is often characterized by multi-level, hierarchical organizational structure that may slow down decision processes.

iii. *Responsiveness:* Rapid response times to the requests made by SIMA are critical. The product life cycles are so short that any delay in the production process may result in loss of the entire market.

iv. *Executive relationships:* A close relationship between the executives generates trust at high levels. This is especially true when conducting business in the Far East where the president (or the CEO) of the company has direct command of the shop floor.

v. *Willingness to modify:* The supplier should be willing to modify the product in the direction of SIMA's request, even if the modification demands major work in the manufacturing process.

b) Experience

i. *Experience with U.S. companies:* Suppliers that have worked with U.S. companies should know the appropriate business procedures. Experience with other U.S. companies mitigates the risks that arise due to the cultural differences.

ii. *Experience with SIMA:* Suppliers who have worked with SIMA previously know SIMA's expectations and requirements. Also, the risks involved with these suppliers can be foreseen and action can be taken to prevent problems.

2- Technical Fit

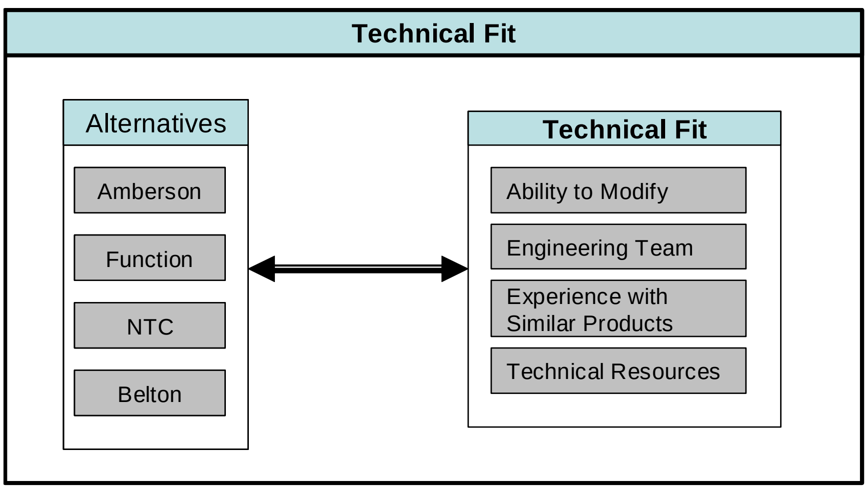

Figure 4-8. Criterion: Technical Fit

i. *Ability to complete modifications:* A supplier's technical expertise should be sufficient to perform product modifications.

ii. *Experience with similar product lines:* The more experience a supplier has with similar products, the less is the probability that manufacturing problems will appear.

iii. Technical resources (other than human capital): The technical resources and availability of equipment are important factors in determining the risks associated with a supplier.

iv. Engineering team/technical depth (human capital): The technical proficiency level of the engineering team also determines the success of the relationship.

3- Operations

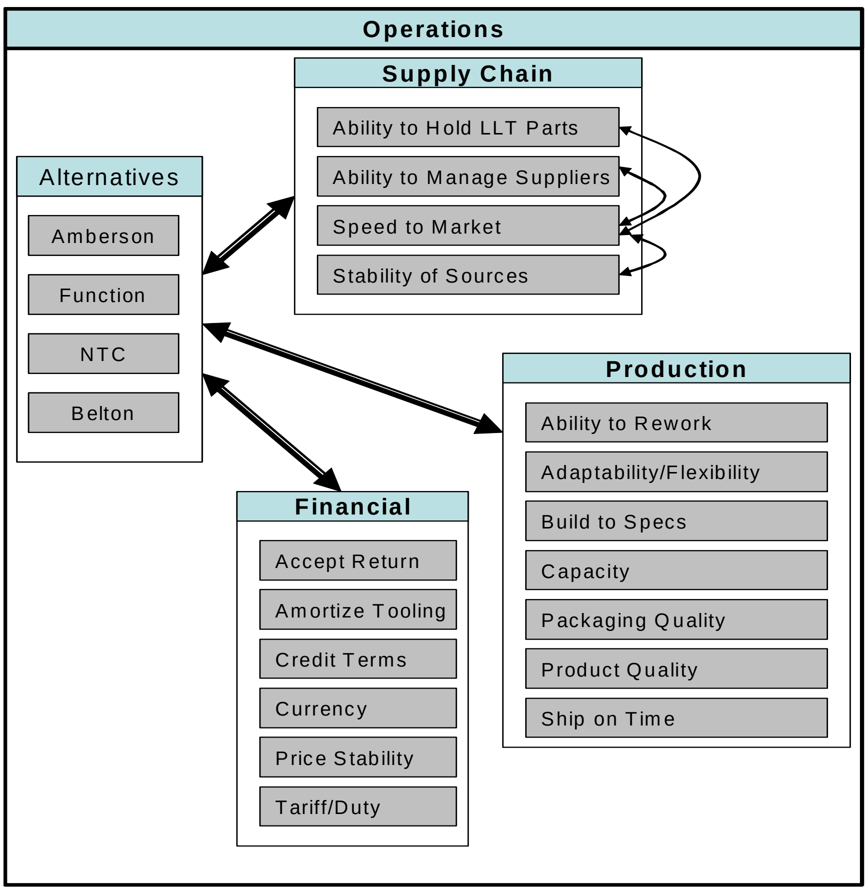

Figure 4-9. Criterion: Operational Risks

a) Financial

i. *Price stability*: If the supplier tends to increase prices, or as the economies of scale are achieved the supplier is not willing to lower the prices, the financial risks are higher.

ii. *Tariff/Duty:* The tariff and duty restrictions may exist for some regions for particular products. Moreover, the duty rates and taxes may change in some countries. By looking at the historical trends and the economic indicators, the risks associated with the location can be predicted.

iii. *Currency*: The potency of fluctuating currencies will elevate the risk factors. There is no currency related risk currently, but the criterion is included for future problems.

iv. *Credit Terms:* The supplier's attitude toward the credit term agreement is a factor in financial risks.

v. *Acceptance of returns:* Once the product is in the market, product returns will occur due to defects and other miscellaneous reasons. Risks are lower if a supplier is willing to accept returns.

vi. *Amortization of tooling:* The way the supplier calculates the costs is important. For instance, the tooling amortization may be reflected on the future prices, in which case SIMA will be paying extra money.

b) Production

i. *Quality:* The level of product quality that the supplier offers may be predicted by evaluating the existing or previous products. Poor quality is always a big risk in the U.S. market.

ii. *On time shipment:* In a market environment with very short life cycles it is important to work with a supplier that can ship products on time without any delays.

iii. *Building to specifications:* A supplier that does not manufacture products according to the exact design specifications creates the risk of losing market share due to unsatisfactory product features.

iv. *Adaptability/ Flexibility*: A supplier who has the technical capability and resources to adapt to last minute changes in design and/or product timeline mitigates the risks considerably.

v. *Packaging quality:* The packaging quality is an important factor for a product to be successful in the market.

vi. *Capacity:* The sufficiency of the supplier's maximum capacity for the forecasted demand.

vii. *Ability to rework:* A supplier needs to be able to rework returned products.

c) Supply Chain

i. *Speed to market:* It is essential that the product is launched on time. New and innovative products are usually launched before Christmas in order to benefit from consumption boost in that period. Moreover, if a product's launch is late, the risk of having a competitor launching the same product is higher.

ii. *Stability of sources (their sources):* The stability of a supplier's sources for raw material and energy is important to ensure the continuity of production.

iii. *Ability to manage suppliers (their own):* A supplier should be able to manage its own suppliers to eliminate unexpected delays.

iv. *Ability to hold long lead time parts:* The suppliers that can hold parts with long lead times are preferred because holding these parts reduces the risk of interruption in manufacturing.

4- IP Protection

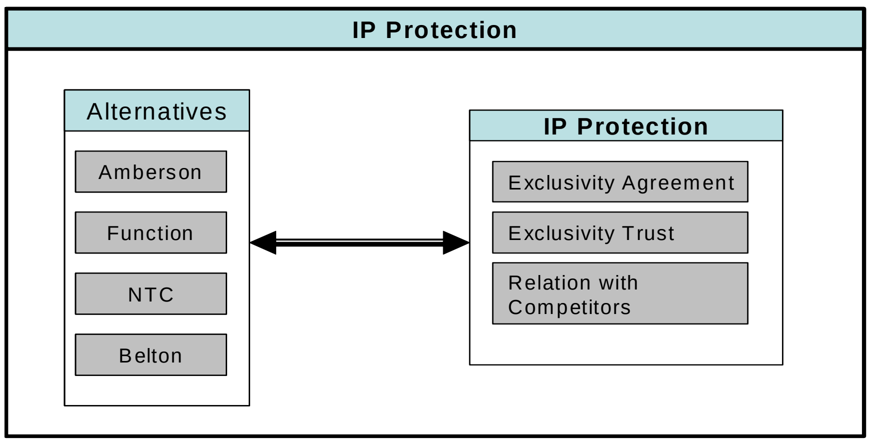

Figure 4-10. Criterion: IP Protection Risks

i. *Exclusivity agreement:* SIMA owns the design of its products that are usually innovative and unique in the market. Therefore, it is important to maintain exclusivity with the supplier. If the supplier starts working with another consumer electronics company, it is very likely that SIMA's design will be copied by others.

ii. *Exclusivity trust:* Exclusivity agreement is not always the solution because the regulations in some countries may not be enforced fully. In this aspect, trust plays an important role in ensuring protection of the intellectual property.

iii. *Relationship with potential competitors:* Even though previous experience with U.S. companies is preferred for better communication, working with a supplier who is currently in a relationship with other U.S. companies creates many risks in terms of intellectual property protection. Suppliers who do business with large U.S. consumer electronic companies are especially risky.

5- Infrastructure

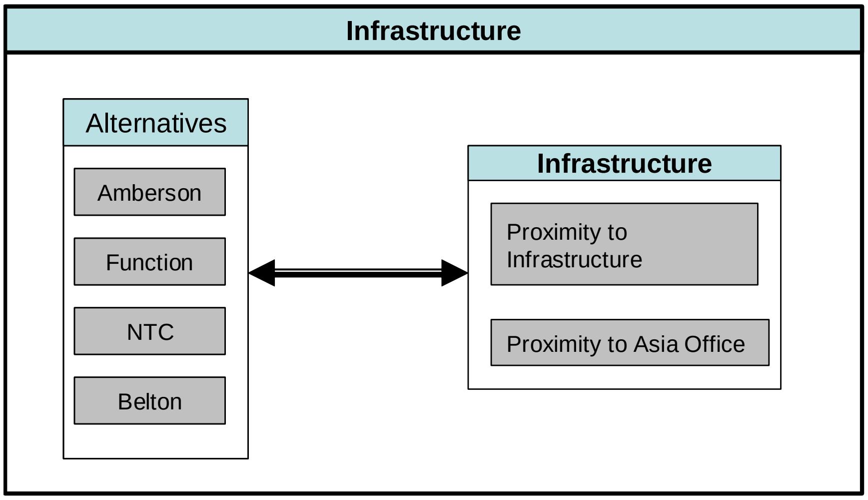

Figure 4-11. Criterion: Infrastructure Risks

i. *Proximity to infrastructure:* The ease of access to the supplier's location is important for the transportation of products. Suppliers that are distant from major transportation systems will require longer lead times for shipping the products to the U.S.

ii. *Proximity to Asia Office:* SIMA has an Asia office that serves to control and monitor suppliers. A supplier's proximity to this office makes the control process easier.

4.2.1.2 Opportunities for SIMA

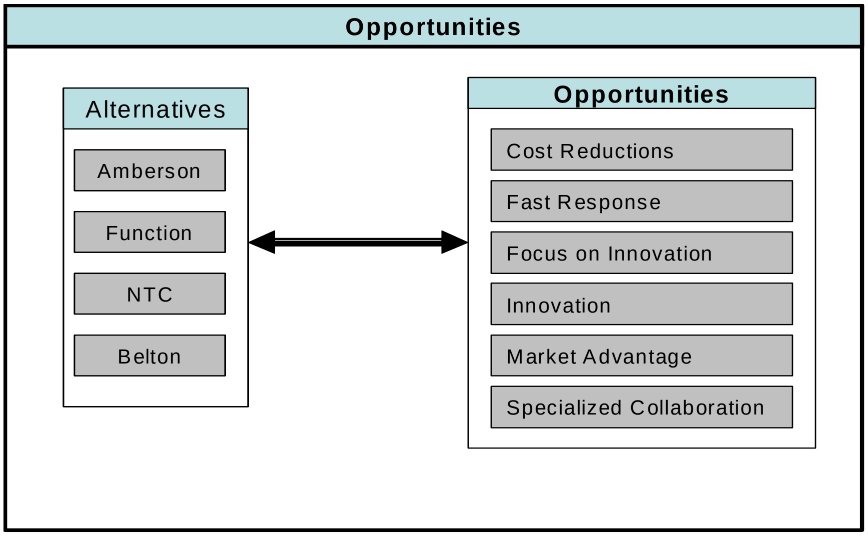

Figure 4-12. SIMA Opportunities

i. *Innovation – future product development*: Instead of finding a different supplier for each product, working with the same supplier for similar products is preferred. Suppliers that can support R&D for future products are preferred.

ii. *Roadmap for cost reductions:* As economies of scale are achieved, the cost of production decreases. Suppliers who tend to adjust the product price to the reduced costs are preferred.

iii. *Potential specialized collaboration:* SIMA prefers working with suppliers that may provide the opportunity for specialized collaboration. Specialized collaboration occurs when the supplier agrees to invest in technical resources for future innovation. In turn, SIMA gives the supplier a profit share.

iv. *Market advantage to supplier location:* For some products, U.S. consumers may be sensitive to the location where the product is manufactured. For instance, consumers may not be willing to purchase products imported from certain countries due to general perception about quality defects.

v. *Rapid market response:* Suppliers that monitor the U.S. market and develop new ideas create opportunities for the product development. These suppliers also create a mutually beneficial business environment based on trust.

vi. *Focus on innovation:* Some suppliers have an innovative culture where the engineers not only comply with the product design but also criticize it and propose modifications that can make the product more successful.

4.2.2 Paired Comparisons

The paired comparisons were performed by the executives, engineers and supplier specialists by assessing the ease of communication and skill level of one supplier to an alternative one. For instance, the responsiveness of the suppliers can be distinguished by observing their promptness in replying to emails and phone calls. At the same time SIMA's Asia office manager visits the suppliers to examine their technical capabilities.

Before the paired comparisons are performed, the decision makers were instructed about the fundamental scale of ANP, the ratio scales and the implications of comparisons. A Microsoft Excel spreadsheet was prepared with clear directives on what each comparison matrix means and how the decision maker should approach it. The decision makers requested that the comparisons under risks be done in a positive view. This means if the questions are asked in the direction of "how much better is A to B" instead of asking the traditional question "how much worse is A to B." These comparisons were later converted by taking reciprocals to calculate risk levels of the suppliers. An example is shown in Figure 4-13 through Figure 4-15.

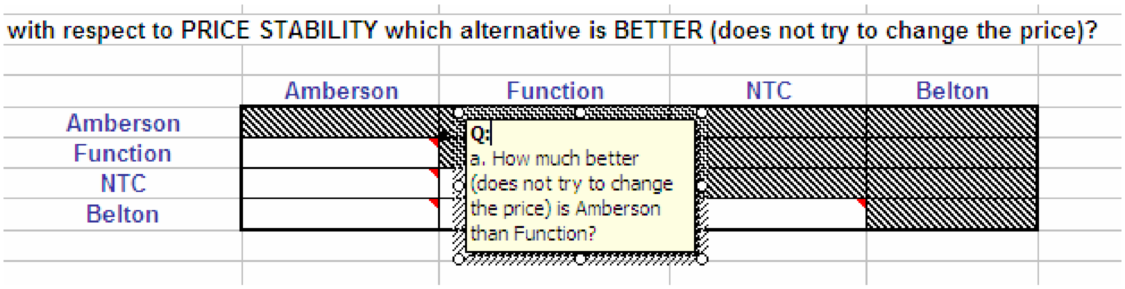

Figure 4-13. Paired Comparison Questions: Price Stability

with respect to PRICE STABILITY which alternative is BETTER (does not try to change the price)?

	Amberson	Function	NTC	Belton
Amberson				
Function	6			
NTC	6	1		
Belton	2	1/3	1/3	

Figure 4-14. Paired Comparisons with Positive View: Price Stability

with respect to PRICE STABILITY which alternative is WORSE (try to change the price)?

	Amberson	Function	NTC	Belton
Amberson				
Function	1/6			
NTC	1/6	1		
Belton	1/2	3	3	

Figure 4-15. Paired Comparisons Coverted: Price Stability

The decision makers performed paired comparisons in 81 matrices: 6 under "infrastructure risks," 7 under "IP protection risks," 9 under "technical fit risks," 16 under "cultural fit risks," 30 under "operations risks," 10 under "opportunities" and 3 cluster comparisons. Cluster comparisons are performed between clusters of sub-criteria with respect to the associated criteria. The inconsistency ratios are calculated for each comparisons matrix. It was found that 10 of these comparisons were unacceptably inconsistent, meaning their inconsistency ratio exceeded 10%. The decision makers were asked to repeat the inconsistent comparisons by re-evaluating their judgments.

The comparisons are made among alternatives with respect to the specified criteria and then among the criteria with respect to the alternatives. For instance the suppliers are compared with each other with respect to infrastructural risks to determine the level of risk that each alternative contributes. At the same time proximity to infrastructure and proximity to Asian office are compared to each other with respect to alternatives because the weight of a criterion in determining the decision depends not only on its importance with respect to the goal but also on its significance with respect to the alternatives. The significance may be different for different alternatives, i.e., if a supplier is in the U.S. the criterion "proximity to Asia office" loses its significance because the U.S. supplier is directly in relationship with SIMA rather than its Asia office. If such a difference is not taken into consideration, the U.S. supplier will incorrectly have an inferior risk rating because of its distance to the Asia office.

Example for Paired Comparisons: Infrastructure Risks

As indicated in Figure 4-11 there is a two way influencing effect between the two sub-criteria under infrastructure risks and the alternatives which leads to six comparison matrices. With the comparisons worded negatively, examples are given in Table 4-4 through Table 4-9.

1. With respect to "Proximity to Infrastructure," which alternative is worse (harder to access by main transportation systems)?

Table 4-4. Paired Comparisons: Proximity to Infrastructure

	Amberson	Function	NTC	Belton
Amberson				
Function	1			
NTC	1/6	1/3		
Belton	1/3	1	1	

Consistency Ratio: 0.080

2. With respect to "Proximity to Asia Office," which alternative is worse (harder to access)?

Table 4-5. Paired Comparisons: Proximity to Asia Office

	Amberson	Function	NTC	Belton
Amberson				
Function	1/8			
NTC	1	6		
Belton	1	6	1	

Consistency Ratio: 0.002

3. With respect to "Amberson" which criterion is more important?

Table 4-6. Paired Comparisons: Infrastructure Risks w.r.t. Amberson

	Prox. Infrastructure	Prox. Asia Office
Prox. Infrastructure		
Prox. Asia Office	1	

Consistency Ratio: 0

4. With respect to "Function" which criterion is more important?

Table 4-7. Paired Comparisons: Infrastructure Risks w.r.t. Function

	Prox. Infrastructure	Prox. Asia Office
Prox. Infrastructure		
Prox. Asia Office	1/6	

Consistency Ratio: 0

5. With respect to "NTC" which criterion is more important?

Table 4-8. Paired Comparisons: Infrastructure Risks w.r.t. NTC

	Prox. Infrastructure	**Prox. Asia Office**
Prox. Infrastructure		
Prox. Asia Office	1	

Consistency Ratio: 0

6. With respect to "Belton" which criterion is more important?

Table 4-9. Paired Comparison: Infrastructure Risks w.r.t. Belton

	Prox. Infrastructure	**Prox. Asia Office**
Prox. Infrastructure		
Prox. Asia Office	1/6	

Consistency Ratio: 0

In addition to alternative and criteria comparisons, cluster comparisons are done between clusters with respect to the criteria. For instance, under operational risks there are three clusters: financial, production and supply chain. These clusters are compared to each other according to their weight on the valuation of operational risks.

Table 4-10. Cluster Comparison w.r.t. Operational Risks

	Financial	**Production**	**Supply Chain**
Financial			
Production	1/3		
Supply Chain	1/3	1	

The table above indicates that production and supply chain risks are three times more influential than financial risks in determining the value of overall operational risks. The derived weights from cluster comparisons are used to weight the priorities of sub-criteria under the corresponding clusters to calculate the overall risk.

4.2.3 Synthesis

First, for each comparison matrix the priorities are calculated by taking the eigenvectors.

Table 4-11. Infrastructure Risks Priority Calculation

	Amberson	Function	NTC	Belton	Eigenvector
Amberson	1	1	6	3	0.1047
Function	1	1	3	1	0.1675
NTC	1/6	1/3	1	1	0.4409
Belton	1/3	1	1	1	0.2869

Later, under each cluster a stochastic supermatrix is formed where columns are the priorities associated with all of the comparison matrices under that cluster. In the supermatrix the cells that do not represent any influence are assigned zero. The limiting power of the supermatrix is a stabilized matrix with identical columns where elements are the priorities of the alternatives with respect to the cluster criteria. The supermatrix of infrastructure risks is shown in Table 4-12 as an example.

Table 4-12. Supermatrix: Infrastructure Risks

Cluster		**Alternatives**				**Infrastructure**	
Infrastructure Risks		**Amberson**	**Function**	**NTC**	**Belton**	**Prox.Infra.**	**Prox.Asia**
Alternatives	**Amberson**	0	0	0	0	0.1047	0.0993
	Function	0	0	0	0	0.1675	0.6879
	NTC	0	0	0	0	0.4409	0.1064
	Belton	0	0	0	0	0.2869	0.1064
Infrastructure	**Prox.Infra.**	0.5	0.143	0.5	0.143	0	0
	Prox.Asia	0.5	0.857	0.5	0.857	0	0

These priorities are multiplied by the associated cluster weights obtained from the paired cluster comparisons. The weighted sum in normalized form gives the overall risk and opportunity priorities of the alternatives. Table 4-13 shows how the values of risks corresponding to alternatives are calculated.

Table 4-13. Calculations for Risk Priorities

Control Criterion CC *Normalized*	*Cultural Fit* limiting CC 0.11466	0.11466	*Technical Fit* limiting CC 0.40406	0.40406	*Operations* limiting CC 0.19826	0.19826
Alternatives	*Idealized*	*(CC x Ideal.)*	*Idealized*	*(CC x Ideal.)*	*Idealized*	*(CC x Ideal.)*
Amberson	0.4399	0.0504	0.0923	0.0373	0.2034	0.0403
Function	0.6309	0.0723	0.3118	0.1260	0.6410	0.1271
NTC	1.0000	0.1147	1.0000	0.4041	1.0000	0.1983
Belton	0.3122	0.0358	0.2739	0.1107	0.2250	0.0446

Control Criterion CC *Normalized*	*IP Protection* limiting CC 0.21483	0.21483	*Infrastructure* limiting CC 0.06819	0.06819		
Alternatives	*Idealized*	*(CC x Ideal.)*	*Idealized*	*(CC x Ideal.)*	***SUM***	***Normalized***
Amberson	0.3067	0.0659	0.1797	0.0123	0.2062	0.1121
Function	1.0000	0.2148	1.0000	0.0682	0.6084	0.3308
NTC	0.2534	0.0544	0.3372	0.0230	0.7944	0.4319
Belton	0.0964	0.0207	0.2695	0.0184	0.2302	0.1251

The opportunity merit is formed of only one cluster, therefore the priorities calculated from the limiting supermatrix are directly the opportunity priorities of the respective alternatives. The limiting supermatrix's columns corresponding with the alternatives are:

- Amberson: 0.24442 Normalized: 0.4888
- Function: 0.07983 Normalized: 0.1597
- NTC: 0.03975 Normalized: 0.0795
- Belton: 0.13599 Normalized: 0.2720

Employing the mathematical notations, the risk and opportunity weights can be expressed as:

$R_1 = 0.1121$ $R_2 = 0.3308$ $R_3 = 0.4319$ $R_4 = 0.1251$

$O_1 = 0.4888$ $O_2 = 0.1597$ $O_3 = 0.0795$ $O_4 = 0.2720$

4.3 INTEGRATED MODEL FOR SIMA CORPORATION

There are three objectives: minimizing total costs, minimizing total risks and maximizing total opportunities. Minimization of the total cost is modeled and illustrated in Section 4.1. The other objectives are based on intangible values and can be defined by making use of the results of the ANP model. For SIMA, risks arise mainly due to the risk of losing the intellectual property (design of product). Difficulties in communication and management also play an important role in determining the level of risk. These types of managerial and IP risks are nondiversifiable because the existence of multiple suppliers means the probability of having a competitor copying the design and incurring communication problems increases. Thus, it is reasonable to assume that total risk of the decision is defined by is the sum of the risks associated with each selected supplier and the objective "minimization of total risks" can be denoted as:

$$\boldsymbol{\pi_2}(\mathbf{x}) = \min \sum_{i \in I} \left(R_i b_i \right).$$

In general, SIMA perceives opportunity as the potential for working with the same supplier for innovative modifications to the same product and for development of future products. In an interview the CEO of SIMA clearly stated "It is always better to work with suppliers that we have dealt with before. Especially anything that is a new technology; i.e., a new product from ground up should be developed with a long term supplier." Based on this perception it is reasonable to assume that working with different suppliers increases the chances for building trustworthy relationships for future products. Therefore, the opportunities can be classified as diversifiable, meaning that the total opportunity is defined as the sum of individual opportunities of the selected suppliers. The objective of maximizing total opportunity can be denoted as:

$$\boldsymbol{\pi_3}(\mathbf{x}) = \max \sum_{i \in I} \left(O_i b_i \right).$$

Since the total risks and opportunities are defined as the sum of individual risk and opportunity values the direction of optimality is easy to foresee. No matter what the demand is, maximization of total opportunities requires working with as many suppliers as possible, while minimization of total risks requires choosing only that one supplier with the minimum associated risk.

The ranking of risks (from least to most risky) and opportunities (from most to least opportunistic) is the same: Amberson, Belton, Function and NTC. In order to minimize total risks, only Amberson should to be chosen as the outsourcing supplier. However if demand does not exceed 5,000 units, some part of production needs to be outsourced to Belton because Amberson’s minimum order quantity requirement is not fulfilled for some product types. Since diversifying to two suppliers is much riskier, in order minimize the total risk Belton is selected for manufacturing of all of the products. If the total demand exceeds 5,000, then the minimum order quantity restrictions are not binding and all of manufacturing is outsourced to Amberson.

In order to maximize total opportunities, supplier selection should be as diverse as possible which leads to distribution of production as much as possible subject to meeting minimum order quantities. If demand is less than 5,000, the minimum order quantities of Amberson, NTC and Belton can be satisfied thus the opportunity objective is maximized by distributing production to these three suppliers. Once demand exceeds 5,000 all of the supplier minimum order quantities can be satisfied and maximum opportunity is achieved by selecting all four of the suppliers. Obviously, selecting multiple suppliers results in considerable cost and risk growth.

The multi-objective problem is solved by utilizing the epsilon-constraint multi-objective optimization method with Pareto maximum bounds. For solving the opportunity objective, a set of constraints needs to be added in order to ensure that binary variable associated with selection of the supplier is 0 if there is no production. The set of constraints is:

$$\sum_{p \in P} x_{ip} \geq mo_i b_i \qquad \forall \qquad i \in I \tag{4-9}$$

Considering the breakeven points for cost, risk and opportunity objectives, the tradeoff analysis is performed in three segments:

1. Demand between 2,500 and 5,000;

2. Demand between 5,000 and 8,873; and

3. Demand more than 8,873.

Since the ranking of supplier alternatives in terms of opportunities, risks and costs does not change within the segments, the solution set (selected suppliers) is the same independent of the demand within each segment. Figure 4-16 through Figure 4-18 depict the Pareto optimal points for selected demand volumes. These Pareto optimal points illustrate the best supplier selections and the tradeoffs between objectives. The tradeoffs between objectives may be evaluated by the decision maker within the framework of the company's goals and competitive advantages.

1- Demand between 2,500 and 5,000 units

To illustrate tradeoff characteristics in this region the multi-objective problem is solved for a demand of 4,600 units and the results are presented in Figure 4-16.

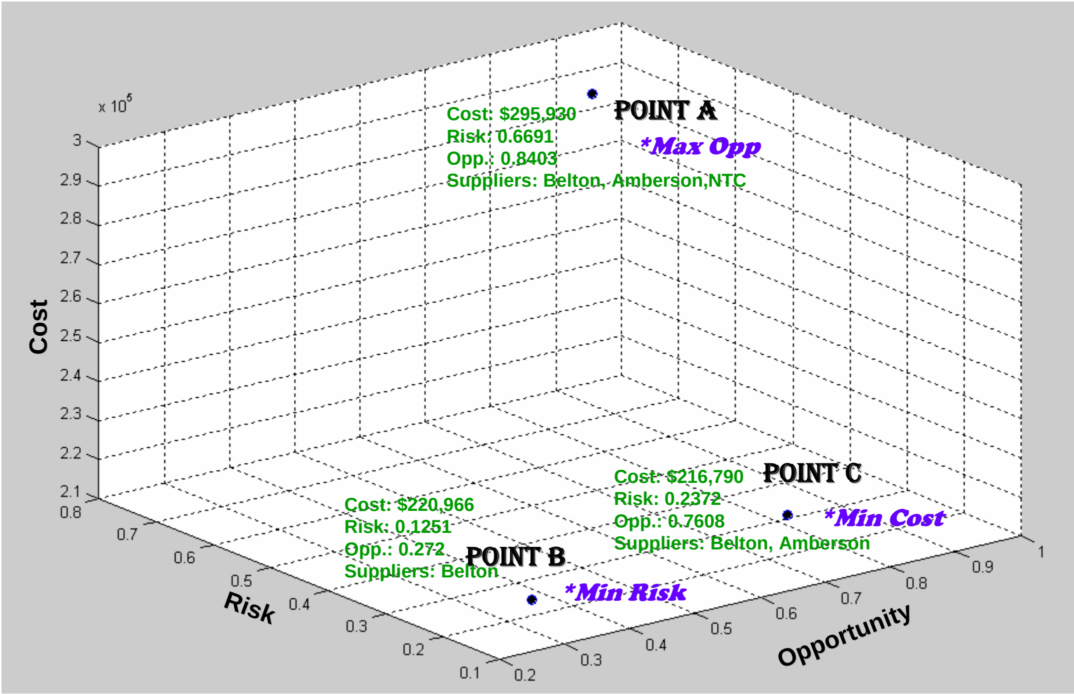

Figure 4-16. Pareto Front Points for Demand = 4,600 units

The Pareto points are the utopia points for two reasons. First, the minimum order quantity limits the number of combinations for supplier selection. Second, the total risk and opportunity values can take on distinct values because they are defined as the sum of individual risk and opportunity values.

At point "A" maximum opportunity is achieved by working with three different suppliers however the costs and risks elevate drastically at rates of 37% and 400% respectively. Therefore, unless opportunity is a very important priority, it is not reasonable to select decision point "A." Minimum cost is ensured at point "C" by selecting Belton and Amberson and distributing the production by minimizing the cost objective. Furthermore, by slightly letting the total cost increase approximately 2%, the total risk of business can be decreased by approximately 50% while the total opportunity decreases by approximately 65% at point "B." Since by sacrificing a little from cost objective considerably reduces risks and increases opportunities, such a sacrifice is reasonable to make. Therefore, the decision points “B” and “C’ are credible alternatives. The final decision of choosing whether to outsource to only Belton or to both Belton and Amberson may be made by assessing the company’s values, past experience and the decision maker’s opinions.

A more theoretical approach is to elicitate utility functions associated with each objective. Utility is defined as a measure of happiness (preference) represented on a scale of 0 to 1 where 1 represents the maximum preference and 0 represents the minimum preference. An efficient method to elicitate utility functions is the certainty equivalent method which finds the utilities by asking the decision maker his/her preferences in situations where binary choices are presented between a sure amount and a simple gamble [100]. For instance in this case, in order to elicit the utility function for “cost” a decision maker is asked to pick the best option in consequent situations such as “choosing between a sure amount of cost $250,000 in total cost to a 50-50 chance of incurring a cost of either $200,000 or $300,000. As a result, the utility functions associated with each objective are derived representing the amount of utility (between 0 and 1) for the objective values. The utilities for the alternatives are calculated by adding the utility for the corresponding objective values and the final decision is made by choosing the alternative which gives the maximum total utility.

2- Demand between 5,000 and 8,873 units

To illustrate tradeoff characteristics in this region the multi-objective problem is solved for a demand of 7,000 units and the results are shown in Figure 4-17.

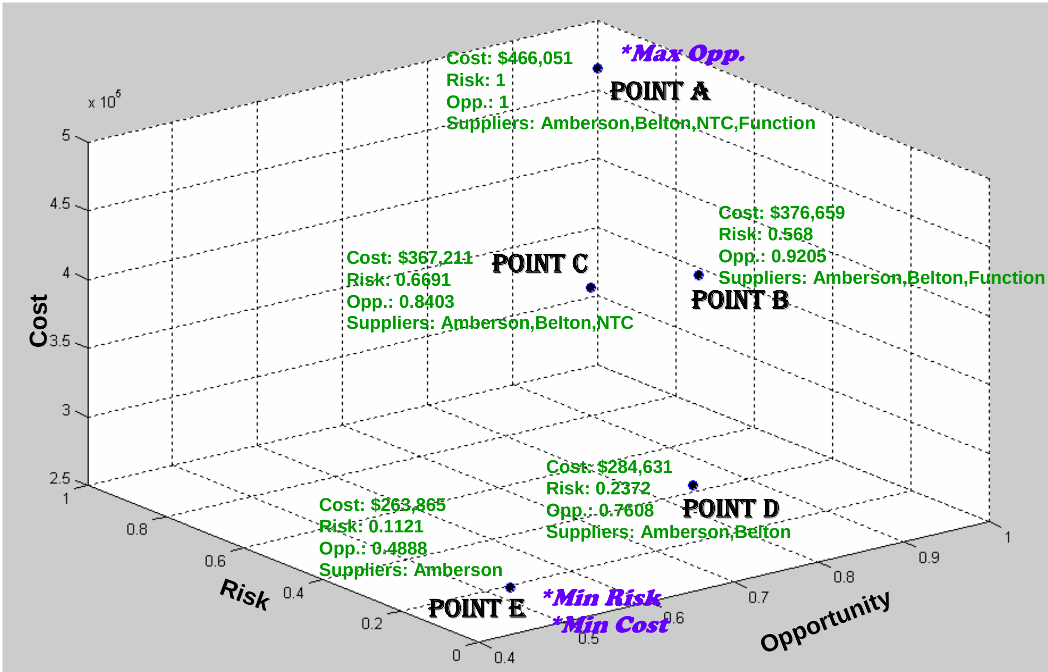

Figure 4-17. Pareto Front Points for Demand = 7,000 units

If total demand is less than 8,873 units, outsourcing manufacturing of all of the products to Amberson results in minimization of both total risks and costs. If additional opportunity is desired, then some of the production may be outsourced to Belton. Unless opportunity is an important priority for the company, decision points “A,” “B” and “C” are not credible because these points increase costs and risks significantly by approximately 100% and 200% respectively while providing comparably little increase in total opportunity value. The decision makers should concentrate on assessing the tradeoffs between whether selecting only Amberson (Point E) or both Amberson and Belton (Point D).

3- Demand more than 8,873 units

To illustrate tradeoff characteristics in this region the multi-objective problem is solved for a demand of 10,000 units and the results are depicted in Figure 4-18.

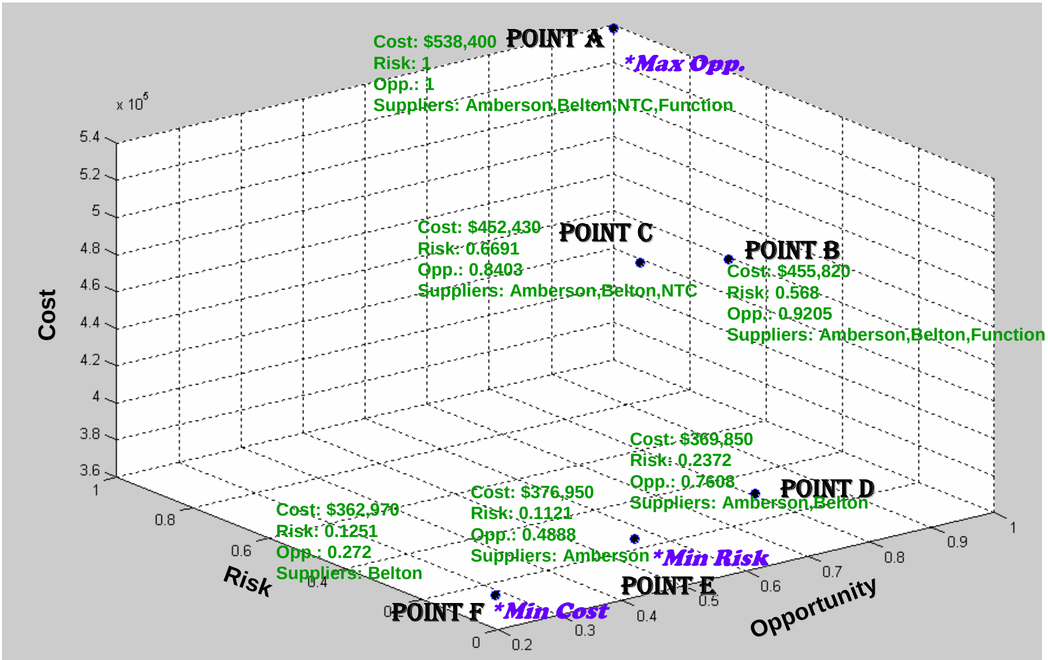

Figure 4-18. Pareto Front Points for Demand = 10,000 units

Unless opportunity has a very important priority, decision points “A,” “B” and “C” are not credible because both costs and risks significantly increase to gain minimal growth in opportunities. The decision makers need to evaluate the tradeoffs between points “D,” “E” and “F” to realize a final decision. Points “E” and “F” do not have considerable differences whereas point “D” incurs higher costs and risks in return for increasing opportunities.

4.4 INSIGHTS

In conclusion, the analysis shows that the decision “selecting both Amberson and Belton” is on the Pareto front regardless of the volume of demand. In addition, “selecting Amberson” always reduces risks and it is also the best decision in terms of reducing costs if the demand volume is low. On the other hand, "selecting Belton" does not increase risks considerably while offering the lowest total cost if the demand volume is high. One recommendation is for SIMA to outsource to Amberson if demand is low and then start shifting production to Belton as demand increases. The final decision depends on SIMA's corporate values and the decision makers' perspectives and experience.

This empirical study leads to broader insights on the process of offshore outsourcing decisions and the value of employing an integrated decision model that can incorporate tangible and intangible values. As a result,

- A comprehensive analysis shows that some of the supplier alternatives can be eliminated from consideration. In this case, NTC and Function are eliminated from the decision space regardless of the demand volume. Reducing the number of alternatives that have to be dealt with ensures both a less complex and a more accurate decision process.
- By exploiting the variations in the optimal decision as the parameters change, a decision can be made based on the product's entire life cycle rather than solely on the present values. This allows the company to establish a strategic action plan which may be executed according to the changing business conditions. For instance, SIMA's action plan may be to outsource to Amberson with a contractual agreement that can allow production to shift to Belton as the product goes through later product life phases. Another action plan may be to negotiate with Amberson so that it can maintain its advantageous status by lowering product prices towards the maturity and declining phases of the product.
- The integrated decision model developed incorporates both tangible and intangible variables and gives multiple optimal decisions while presenting the tradeoffs between

these decision points. These results not only provide answers for the company but also can be used as a basis of negotiation with the suppliers during offshore outsourcing relations. If negotiations are only based on costs, a win-win situation cannot be achieved because changing the unit price favors one side while hurting the other side. Instead, other variables such as operational and managerial considerations may be included in the negotiation process to achieve a win-win situation. The results of this analysis explicitly demonstrate this argument both to the suppliers and to SIMA.

5.0 CAPTIVE OFFSHORING EMPIRICAL STUDY: XYZ

The second empirical study is also based on a real case for a global corporation that requested confidentiality. Hence, the company is referred by the name "XYZ" and the product is referred as a "perishable food product" without giving the actual names. XYZ is a global U.S.-based company that produces and markets perishable food items in different regions of the world. Over the years, the company's international setting has allowed the operations to expand and diversify in terms of both volume and quality. Recently, the consequences of globalization began to put extra pressure on the market competition, forcing the company executives to seriously consider transferring some of its operations overseas. At the present time, the production for the North American consumer market takes place in the U.S. by utilizing the latest technologies in agriculture and processing. However due to the increasing cost of labor and transportation, and pressure from the market to hold prices steady, the company has given serious thought to cost reduction strategies. Offshoring became an attractive option for management to maintain the company's market share by transferring a part of the manufacturing facility offshore with contractual agreements supported by regional investments.

Offshoring from the U.S. is being considered for the front-end portion of the production process where the raw materials are converted to a semi-finished product. The process that is in consideration for outsourcing is divided into two parts: Raw Food Production (RFP) and Semi-finished Food Production (SFP). Figure 5-1 depicts a representation of the front end process that is in consideration for offshoring.

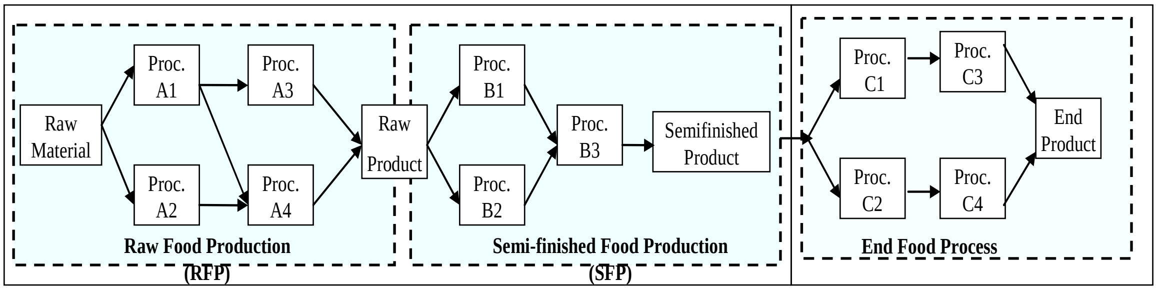

Figure 5-1. Representative Process Flow - XYZ

There are four alternative offshore locations (whose names are not disclosed to maintain confidentiality). The countries are referred with the regional names; remaining in-house in the U.S. is also included as an alternative to incorporate the decision of whether or not to outsource. The alternatives are:

1. Outsource the process to an Asian location
2. Outsource the process to a Middle Eastern location
3. Outsource the processes to an Eastern European location
4. Outsource the process to a South American location
5. Remain in the U.S.

Since the quality of a perishable food product is important, offshore outsourcing with a subcontractor is not an option. Instead, investment will be made (possibly with a third party venture) in the region and the semi-finished product processed at the destination will be directly imported to facilities in the U.S. and Western Europe where the product will be further processed and sold under the company's brand name.

5.1 COST ANALYSIS

Cost of production plays a major role in assessing alternatives for offshoring. In most of the global supplier and location selection cases, costs are evaluated on the basis of price quotes that are typically provided by vendors. This technique may be fairly accurate for consumer items whose production will not require a capital investment. However, it is not recommended for long term offshoring practices that require considerable investment because the analyses based on these values, may be biased not only due to the vendor's willingness to increase profit margins, but also because of the possibility that the computational tools that the vendor uses in the calculation of product costs may not be sufficiently accurate enough. Most vendors would prefer escalating the depreciation rates, thereby augmenting the overhead, which will result in an over-estimation of product costs. As in the case of XYZ, the offshoring process may not be done through a contractual agreement and in such cases it is not correct to base the decision on vendor quotes, as these quotes may be for lower quality products and may not reflect the real costs that will be incurred. A more dependable and consistent way for cost assessment is analyzing the alternatives by calculating the associated product costs through a set of tools based on the actual core parameters, such as labor wages and inflation rates that can be obtained from objective data sources. From this standpoint, Activity Based Costing (ABC) is a valuable methodology that can appropriately be utilized for an unbiased offshoring decision.

5.1.1 The Activity Based Costing Technique

Product costs can be divided into two major groups: direct and indirect costs. Direct labor (DL) and direct material (DM) costs are considered to be the direct costs, i.e., costs that can be traced directly to the product or process. The remaining costs are grouped as indirect costs such as overhead (OH) costs, making them difficult to trace to the products or processes. It is the significant increase of automation in the manufacturing process (and subsequently the reduction in direct labor) that has led to recognition of the importance of OH costs. Prior methods to allocate OH to products and processes were based on a particular volume-based metric such as DL content and became inappropriate in this new highly automated manufacturing environment. ABC which was first defined by Burns and Kaplan in 1987 [101] is an alternative method for allocating OH costs to products. ABC not only provides a new method for OH cost allocation, but also encourages accountants and engineers to identify and study the OH cost drivers. ABC is based on three major premises:

- cost objects consume activities,
- activities consume resources, and
- this consumption of resources drives costs.

The five steps of ABC process are:

1. identify major cost pools and drivers;
2. identify major activities;
3. link activities to output;
4. develop cost of activities; and
5. determine product cost.

A detailed flow chart for implementing ABC is shown in Figure 5-2.

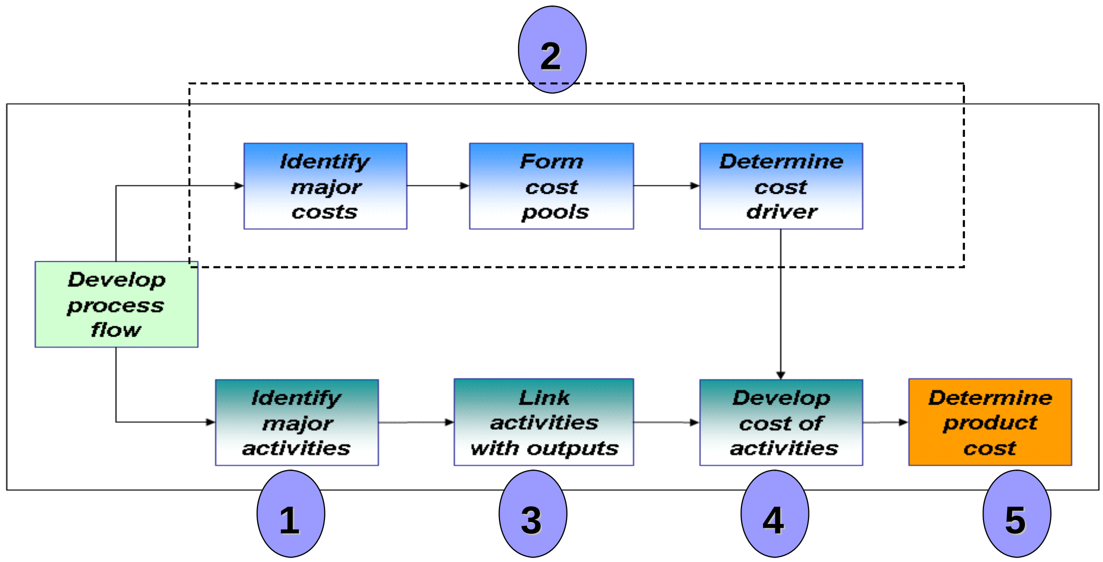

Figure 5-2. Activity Based Costing [102]

To fully understand product costs, it is best to study these costs across the product life cycle. Life cycle costing (LCC) and ABC can be readily integrated together as a powerful tool to study the product cost accumulation [103, 104]. In this study, ABC is utilized to estimate production and service costs and the LCC tools are used in formulating the MIP's objective function which minimizes the total cost over the decision horizon of offshoring.

5.1.2 Application of ABC

The costs are divided into three main groups: Direct Labor, Direct Material, and Overhead. Other fixed costs such as capital investments that cannot be traced to the product are handled separately from the ABC analysis and will be included in the next steps of the decision model. The direct costs are easily traced to the product whereas overhead costs are traced by utilizing the ABC approach.

1- Identify major activities

In the RFP stage the raw product is produced each season, going through a series of processes: land preparation, pre-fertilization, irrigation, fertilization, seedling, transplantation, weed protection, fumicide application, insecticide application, crop protection, train vines, harvesting and hauling. The raw food product goes through different processing machines during SFP and is converted to a semi-finished product that can be shipped to North America and Western Europe where it will be further processed to the final product. SFP is a mostly automated process that includes: water treatment, sorting, heating, finishing, waste recovery, evaporation, sterilization, filling (packaging) and loading.

In both stages there is a certain order for each activity; e.g., irrigation must be done before seedling and sterilization before packaging. In general, the order of activities does not change but the number of repetitions for a given activity may differ based on the climate and soil conditions. For instance, irrigation times are longer in warmer climates and amounts of pesticides vary based on the disease vulnerabilities. By the same token, the processing practices change depending on the region's economic conditions and technology. In the U.S. and Europe, most of farming is mechanized whereas, in Asia and the Middle East, manual work is more cost effective. Specifically, labor costs are relatively low in Asia and Middle East and when compared with the cost of machine depreciation, manual resources are more profitable. Another reason is the unavailability of modern machines due either to low purchasing power or the lack of expertise. For this analysis, the most cost effective practices are selected for each region and the product costs are estimated based on these "best" practices.

2- Identify major cost pools and drivers

In the ABC analysis, the cost pools and drivers are determined by categorizing the production costs into probable cost pools after a detailed articulation of the processes. RFP costs can be categorized into four pools: land, labor, input and machine expenses. From each cost pool, the cost drivers are determined and overhead rates are derived depending on the relationship between the cost drivers and cost pools. For instance, the driver for the cost pool “land” is the size of the farm and the associated overhead rate is the rent paid for the farm which can be expressed in $/acre. The overhead rates are based on the region’s economic conditions and these differences lead to differentiations in the product cost. The cost drivers corresponding to the cost pools are land size (acre), manual and operator labor hours (hour/acre), input amount (pound/acre) and machine hours (hour/acre), respectively. Although land is a fixed expense, it is traced to the product by considering the amount of production per unit of land.

In SFP, the cost pools are: raw material, labor, energy, package, maintenance and repair and fixed expenses. Although the fixed expenses in the RFP stage are traced to the product, the fixed expenses in SFP stage such as capital investment are not traced to the product. This is because in SFP stage products are shipped outside unlike the RFP stage where products are directly transferred to processing. Consequently, tax rates become a part of the cost calculation, and fixed expenses in the SFP stage are included in the cost objective by adjusting it with the tax rate percentages. Therefore, fixed expenses are excluded from the ABC analysis but are put into the decision model built in the next stage. The cost drivers corresponding to the cost pools are: raw material amount (tons), manual and operator labor time (hours/ton), energy usage (gallon or kWh / ton), package capacity (tons/package) and throughput (tons/year).

3- Link activities to output

The activities are linked to the output by determining the amount of time and material each activity consumes for processing one ton of product. As an example, in the U.S., pre-fertilization is done by machines and the average duration to prepare an acre of land is about 2.15 hours. In Asia, 22.5 machine (with less technology) hours and 48 man hours are needed to pre-fertilize one acre of land. The output is linked to the activity by dividing the hours/acre ratio by the yield (tons/acre) which gives the amount of time spent to produce a ton of product (hours/ton). For processing machines, the cost of product is traced by determining the usage capacities (hours/ton). The overhead costs are very high for these types of automation dependent operations. The utilization of these machines is taken into consideration in order to allocate energy, water and other overhead costs to the product. For activities involving material input, the link to the output is determined by the amount of material the activity consumes for the specific work. The link for activities such as loading and packaging are determined according to the average loading times and package capacities.

4- Develop cost of activities

Activity costs are developed in two steps. First, the costs are calculated by evaluating the cost components based on the activity-output relationship and the overhead rates. Direct costs are calculated by multiplying the time/output ratios with $/time amounts. Indirect costs such as the depreciation of farm equipment and utility expenses are allocated based on their consumption by the activities. Depreciation is included in the ABC analysis of the RFP stage but excluded from the ABC analysis of SFP stage. The reason is that the RFP stage is outsourced to a third party vendor which will set the price of the product by adding depreciation costs whereas the SFP stage will be transferred offshore and the costs should be calculated more precisely for tax purposes. Thus, depreciation is allocated to product costs in RFP stage, but considered as a fixed cost in the SFP stage.

The depreciation life of equipment in the RFP stage is assumed to be five years and salvage values are considered based on the market value of second hand equipment. Capital Recovery is calculated by using

$$\text{CRF (capital recovery factor)} = \frac{r}{(1-(1+r)^{-T})} \quad (5\text{-}1)$$

$$CR = ((P\text{-}SV) \times CRF) + SV \times r, \quad (5\text{-}2)$$

where r represents interest rate, T represents depreciation life, P represents price and SV represents the salvage value. The capital recovery is traced to the activity by the amount of time the equipment is used.

In the second step, the costs are adjusted by using the conversion rates such as concentration percentages and process weight ratios. As mentioned before, yield is used in the RFP stage to trace the cost of farming activities to the product. In the SFP stage shrinkage and evaporation occur as the product goes through processing machines and the weight of the product decreases with each subsequent process. For example, during the heating and finishing processes, water is evaporated from the product; therefore a ton of product entering the machine comes out concentrated and, hence, weighing less than a ton. Throughout the calculations the variable costs are adjusted to the cost of the final product by considering the ratios of input/output at each machine. Conversion ratios are different for each country depending on the concentration level of the harvested food and the production efficiency of the machines used.

5- Determine cost of product

Finally, costs of activities are added together to determine the overall cost of the product. A number of factors are taken into consideration in cost calculations. One of the factors that affect the allocation of asset costs is the scale of the farm that a single producer owns. For example, depreciation rates for farming equipment in Asia and the Middle East are much higher than in the U.S. and Europe because the farm equipment is owned by individuals with small farms.

The feasibility of practices is assessed with respect to the economical and social constraints in each region. The SFP stage is mostly automated everywhere in the world because processes require sterilization and therefore are machine intensive. Conversely, almost all of the activities in the RFP stage can be performed both manually and mechanically. For instance harvesting can be done both manually by hand picking and mechanically by using harvesting equipment. In developing countries, agriculture is done mostly manually because the farms are often owned by individual people who do not have purchasing power to afford mechanical devices. Moreover, the labor wages are so low that it is more cost effective to utilize manual work instead of mechanical work. In contrast, farms in the U.S. and Europe are cultivated by large companies which operate large acres of area. In this case, the mechanical practices are more efficient since the machine expenses can be distributed over a larger amount of product. In this study, costs associated with each activity in each region are evaluated for two scenarios: manual work and machine intensive work. Then, the least costly practice is selected and used for calculating the overall product cost in the region. For instance, for Asia the harvesting cost is calculated for both manual and mechanical work. Since the cost of performing the job manually is less than mechanical harvesting, manual harvesting is selected as the best practice and the cost for manual harvesting is considered in the analysis.

Another factor that needs to be considered for the cost calculations is the yield and quality of the harvested products. Climate and soil conditions affect the productivity of farms as well as the product's quality which is represented by the ratio of solid to liquid in the product. The more solid the product has, the better its productivity. So, even if production in a specific area is less costly for some regions, poor productivity can result in higher costs.

5.1.3 Illustration

Table 5-1 shows the activity based costing calculations for the RFP stage in Eastern Europe. The data for cost drivers such as fertilizer prices, hourly wages and land rents are collected from public and corporate databases [105]. Consumption of resources is calculated based on agricultural publications, corporate knowledge and the countries' productivity conditions (labor and soil productivity). Costs for each activity are calculated by multiplying the amount of consumed resource by the cost driver. As mentioned before, the operator and manual labor as well as the machine operation times are determined by selecting the best practices (the least costly methods) for each operation. For Eastern Europe the best practice for all of the activities is found to be an automation intensive operation. Calculations for consumed resources and cost drivers are explained in the next section.

Table 5-1. ABC Calculations for E.Europe (RFP state)

Cost Pool	**Cost Comp.**	**Cost Driver**	**Unit**	**Cons. Res.**	**Unit**	**Cost**	**Unit**
Land	Land Rent	$150	USD/acre	0.0238	acre/ton	$3.57	USD/ton
	Land Overhead	$44.12	USD/acre	0.0238	acre/ton	$1.05	USD/ton
Labor	Operator Labor	$4.00	USD/hour	0.244	hour/ton	$0.97	USD/ton
	Manual Labor	$3.00	USD/hour	0.822	hour/ton	$2.47	USD/ton
Input	Pre-fertilizer	$0.12	USD/gallon	4.28	gallon/ton	$0.51	USD/ton
	Water	$7.50	USD/acin	0.72	acin/ton	$5.40	USD/ton
	Seed	$2.65	USD/thou.	0.45	thou./ton	$1.19	USD/ton
	Fertilizer	$0.39	USD/ton	1.26	pound/ton	$0.49	USD/ton
	Herbicide	$68.22	USD/ounce	0.05	ounce/ton	$3.57	USD/ton
	Fumicide	$0.44	USD/gallon	0.93	gallon/ton	$0.41	USD/ton
	Insecticide	$4.39	USD/pound	0.34	pound/ton	$1.48	USD/ton
	Protectant	$0.26	USD/pound	0.48	pound/ton	$0.12	USD/ton
Mach. Over-head	Land Preparation	$18.93	USD/hour	0.05	hour/ton	$0.96	USD/ton
	Pre-fertilization	$43.41	USD/hour	0.003	hour/ton	$0.14	USD/ton
	Irrigation Pipe Setup	$8.59	USD/hour	0.06	hour/ton	$0.51	USD/ton
	Irrigation Pipe Operation	$0.10	USD/acin	0.72	acin/ton	$0.07	USD/ton
	Fertiliza-tion	$7.04	USD/hour	0.005	hour/ton	$0.04	USD/ton
	Transplanta tion	$5.62	USD/hour	0.01	hour/ton	$0.05	USD/ton
	Weed Protection	$6.59	USD/hour	0.031	hour/ton	$0.20	USD/ton
	Fumicide Application	$11.00	USD/acre	0.0238	acre/ton	$0.26	USD/ton
	Insecticide Application	$12.00	USD/acre	0.0238	acre/ton	$0.29	USD/ton
	Crop Protection	$2.00	USD/acre	0.0238	acre/ton	$0.05	USD/ton
	Train Vines	$4.69	USD/hour	0.005	hour/ton	$0.03	USD/ton
	Harvesting	$199.35	USD/hour	0.0226	hour/ton	$4.51	USD/ton
	Hauling	$59.63	USD/hour	0.0226	hour/ton	$1.35	USD/ton
Profit (10%)						$2.97	
Total						$32.66	USD/ton

1- Land and Overhead:

i) Land Rent

- Cost driver: Land rent is 150 USD/acre.
- Consumed resource: The production yield (which depends on soil and climate conditions) is estimated to be 42 tons/acre. Therefore the consumed resource for a ton of product is 0.0238 acre/ton.

ii) Land Overhead

- Cost driver: Land overhead includes insurance and assessment costs. Insurance is estimated to be 27.30 USD/Acre and average assessment cost is 16.80 USD/ton. According to the yield, consumed resource is .0238 acre/ton.
- Consumed resource: As described above, the consumed resource for a ton of product is 0.0238 acre/ton.

2- Labor*:*

i) Operator Labor

- Cost driver: The hourly wage for an operator is 4.00 USD/hour.
- Consumed resource: Operator labor is needed for the activities: land preparation, pre-fertilization, irrigation, fertilization, transplantation, weed protection, fumicide application, insecticide application, crop protection, train vines, harvesting and hauling. The duration for an operator to complete a job is calculated by summing all operation times of all the machines used for that activity. An example: pre-fertilization requires the utilization of machines: a subsoiler, a ditcher, a triplane, two discs and a mulcher. Their operation durations are 0.61, 0.15, 0.24, 0.32 and 0.2 hour/acre respectively. The total is

1.72 hours/acre. With 25% setup time added, the total pre-fertilization operator duration is estimated to be 2.15 hours/acre. The same calculations are performed for each activity. The total amount of time needed for an operator to complete an acre is 10.24 hours. Since 0.0238 acre is needed for a ton of product, the consumed resource is determined as (10.25 x 0.0238) = 0.244 hours/ton.

ii) Manual Labor

- Cost driver: The hourly wage for manual labor is 3.00 USD/hour.
- Consumed resource: Manual labor is needed for transplanting, weed protection, harvesting and hauling. The total amount of time needed for a worker to manually complete an acre is 34.56 hours. Since 0.0238 acre is needed for a ton of product, the cost driver is determined as (34.56 x 0.0238) = 0.822 hours/ton. The manual labor times are calculated based on the productivity of a man working on a farm. An example: for manual labor eight men can pre-fertilize an acre of soil in six hours. Thus, 48 hours of manual work is needed to pre-fertilize an acre. Since automation is used in Eastern Europe, there is no manual work for pre-fertilization.

3- Input:

- Cost driver: There is a variety of input materials: pre-fertilizer, water, seed, fertilizer, herbicide, fumicide, insecticide and protectant. Prices and the amounts needed for an acre of land are identified.
- Consumed resource: The consumed amounts per acre are converted to per ton by considering the yield of the farm. An example: the pre-fertilizer price is 0.12 USD/gallon

and 180 gallons of pre-fertilizer are needed for an acre of soil. Therefore, (180 x 0.0238) = 4.28 gallons are consumed per ton of product produced.

4- Machine Overhead:

- Cost driver: The cost drivers for the machine overhead are calculated by including depreciation, repair and setup costs, fuel, lube, insurance and tax expenses of each machine operated. An example: in pre-fertilization, the subsoiler's capital recovery is calculated to be 3,981 USD/year. Insurance is 84.60 USD/year and taxes are 127.80 USD/year. The insurance and taxes are calculated by taking a fixed percentage of the capital recovery [106]. Estimating that the machine will be used for 366 hours (calculated from the farm size) per year, the sum of capital depreciated, insurance and taxes per hour is calculated to be 11.46 USD/hour. Adding the fuel, lube, set-up and repair costs, and the total is 18.91 USD/hour. The same calculations are performed for every machine utilized in the process. Then the weighted average of hourly costs of all of the machines is calculated to determine the average hourly cost for the whole activity. An example: The usage of subsoiler for pre-fertilization is 0.61. The ratio is determined for other machines and the weighted average is calculated as: [(0.61 x 18.91) + (0.15 x 10.04) + (0.24 x 15.91) + (0.34 x 26.42) +(0.2 x 9.81)] / 1.72 = 18.93 USD/hour.
- Consumed resource: Consumed resource for each activity is calculated by summing up the machine operation times involved in the activity. An example: pre-fertilization requires the utilization of machines: a subsoiler, a ditcher, a triplane, two discs and a mulcher. Their operation durations are 0.61, 0.15, 0.24, 0.34 and 0.2 hours/acre respectively. Adding 25% setup time, the total operation duration is calculated to be 2.15

hours/acre. Considering the yield of 0.0238 acre/ton, (2.15 x 0.0238) =0.05 hours/ton is the total consumed resource for pre-fertilization.

Table 5-2 shows the activity based costing calculations for the SFP stage in Eastern Europe. The SFP stage is mostly automation intensive, thus the best practice is the same for all countries.

Table 5-2. ABC Calculations for E.Europe (SFP stage)

Cost Pool	Cost Component	Cost Driver	Unit	Cons. Res.	Unit	Alloc. Cost	Unit
Raw Material	Raw Food Product	$32.66	USD/ton*	6.30	Ton*/ton	$205.80	USD/ton
	Package	$35.10	USD/pack.	0.76	pack./ton	$26.63	USD/ton
Direct Labor	Grading	$5.00	USD/hour	0.105	hour/ton	$0.53	USD/ton
	Conveying	$5.00	USD/hour	0.105	hour/ton	$0.52	USD/ton
	Sorting	$5.00	USD/hour	0.126	hour/ton	$0.63	USD/ton
	Filling	$5.00	USD/hour	0.0125	hour/ton	$0.06	USD/ton
	Loading	$5.00	USD/hour	0.05	hour/ton	$0.25	USD/ton
Energy	Water Treatment	$0.58	USD/m^3	3.59	$M^{3/}$ton	$2.08	USD/ton
	Heating	$0.026	USD/kWh	552.58	kWh/ton	$14.37	USD/ton
	Finishing	$0.026	USD/kWh	0.82	kWh/ton	$0.02	USD/ton
	Waste Recovery	$0.026	USD/kWh	60.49	kWh/ton	$1.57	USD/ton
	Evaporation	$0.026	USD/kWh	320.29	kWh/ton	$8.33	USD/ton
	Sterilization	$0.026	USD/kWh	36	kWh/ton	$0.93	USD/ton
Maint. Repair	Labor	$5.00	USD/hour	0.2316	hour/ton	$1.16	USD/ton
	Operation	$49.00	USD/hour	0.0945	hour/ton	$4.63	USD/ton
TOTAL						$267.50	USD/ton

ton is used for the raw product, whereas Ton indicates the weight of end product.*

1- Raw Material:

i) Raw Food Product

- Cost driver: The raw food product costs are taken from the results of the ABC analysis of the RFP stage. In Eastern Europe the cost of raw product with the addition of 10% profit for the farmer, is 32.66 USD/ton.

- Consumed resource: During processing, the raw product loses water, leaving concentrated solid as the end product. As a result, 15.87% weight of the raw input yields in the end. Thus (1/0.1587) = 6.3 tons of raw product is needed to get 1 ton of end product.

ii) Packaging

The end product is sterilized and packed into large containers that can store the food production while transported to overseas.

- Cost driver: The package cost is 35.10 USD/package.
- Consumed resource: Each package can be filled with 1.32 tons of end product. Thus the consumed package resource is (1/1.32) = 0.75 packages/ton.

2- Direct Labor:

- Cost driver: The hourly wage for an employee working in a processing plant is estimated to be 5.00 USD/hour.
- Consumed resource: The amount of time required for each activity is calculated based on the duration of each operation. The durations are adjusted to the amount of the end product by considering the amount of product lost through each machine. An example: in sorting, a worker monitors the raw material as they go through a belt to see if there is any damaged or unripe product; 50 tons of product can be sorted by a person in an hour. Thus the consumed time is 0.02 hours/ton of raw product. There is a yield of 15.87% and also 1% of the raw product is lost during sorting. Therefore the consumed time is (0.02 x 0.1587 x 0.99) = 0.126 hours/ton of end product.

3- Energy:

i) Electricity

- Cost driver: Electricity costs are calculated by determining the price in each region.
- Consumed resource: The amount of electricity consumed by each machine depends on the operations. An example: for the evaporation process, 84% of the raw material weight which consists of water is evaporated to get the concentrated product. The product enters the process at 74 degrees Celsius temperature. In order for water to evaporate, enough energy must be used to raise the temperature to 100 Celsius and then convert liquid to vapor. The specific heat of water is 4.184 kJ/kg.C. Thus (4.184 x 1000 x (100-74)) = 108.78 megaJoules (MJ) of energy is consumed to raise the temperature to 100 Celsius. To evaporate 84% of it, (334.72 x 1000) = 334.72 MJ of energy is consumed (to make vapor from one ton of water). The sum is 443.50 MJ which is converted to 123.19 kWh. Since there is a recovery factor of 50%, a total of (123.19 x 0.50 x 0.84) = 51.66 kWh of energy is consumed for each ton of raw product entering the evaporation process. The end product yield is 16%, so the energy needed is adjusted to the end product by dividing it by 0.16. As a result, 320.29 kWh energy is consumed for each ton of end product produced.

ii) Water

- Cost driver: Water is listed in the energy category rather than an input, because it is consumed for washing the product. The price of water used for processing is 0.58 USD/m^3.

- Consumed resource: 0.57 m^3 water are used to wash a ton of entering product; 6.3 tons of raw product is needed to get one ton of end product. Thus, (0.57 x 6.3) 3.59 m^3 water is consumed for one ton of product.

4- Maintenance and Repair:

i) Labor

- Cost driver: The hourly operator wage rate is 15 USD.
- Consumed resource: Data from an existing plant indicates that labor cost for maintenance and repair is 75,000 USD/machine for a plant working 85 days per year with a capacity of 400 ton/hour full shift. The amount of product processed in this plant is calculated to be (85 x 24 x 400) = 816,000 tons with a yield of (816,000 x 0.1587) = 129,507 tons of end product. Thus, (75,000 / 15) = 5,000 hours of labor is used to produce 129,509 tons. (5,000 / 129,507) = 0.0386 hour/ton is needed for maintenance and repair. There are six machines; therefore total of (0.0386 x 6) = 0.2316 hour/ton is consumed.

ii) Operation

- Cost driver: Operation cost for maintenance and repair is recorded as 100,000 USD/machine for the same plant which operates (85 x 24) = 2,040 machine hours per year. Thus the cost per machine hour is 49 USD.
- Consumed resource: Since 2,040 hours per machine per year is needed to produce 129,507 tons of end product (2,040 / 129,507) = 0.016 hours is consumed for a ton of end product. There are six machines, so (0.016 x 6) = 0.0945 machine hours per ton is consumed. The outcome of the ABC analysis for all of the regions is summarized in Table 5-3.

Table 5-3. Estimated Costs per Ton of Semi-finished Product

RFP	U.S.	M.East	Asia	S.America	E.Europe
Land & Overhead	$ 4.62	$ 3.08	$ 2.40	$ 3.43	$ 4.62
Labor	$ 11.89	$ 16.90	$ 6.46	$ 3.17	$ 3.44
Input	$ 13.17	$ 6.34	$ 6.34	$ 9.16	$ 13.17
Machine OE	$ 7.61	$ 1.08	$ 1.08	$ 7.90	$ 8.45
Profit Margin	10%	10%	10%	10%	10%
TOTAL COST	$ 41.02	$ 30.14	$ 17.91	$ 26.03	$ 32.66
TOTAL COST adj.	$ 258.47	$ 197.85	$ 117.58	$ 164.02	$ 205.80
SFP	**U.S**	**M.East**	**Asia**	**S.America**	**E.Europe**
Tomato	$ 258.47	$ 197.85	$ 117.58	$ 164.02	$ 205.80
Labor	$ 5.98	$ 2.06	$ 1.24	$ 1.99	$ 1.99
Energy	$ 56.14	$ 103.10	$ 42.36	$ 79.01	$ 27.29
Packaging	$ 26.63	$ 26.63	$ 26.63	$ 26.63	$ 26.63
Maintenance/Repair	$ 4.63	$ 4.63	$ 4.63	$ 4.63	$ 4.63
TOTAL COST	$ 356.20	$ 335.43	$ 193.14	$ 277.45	$ 267.50

As a result of the ABC analysis, the decision makers obtain reliable estimates that can be used in assessing multiple location and decision alternatives. Although these values cannot be precise, they can be considered as an effective basis for evaluating the cost differences between regions and further be utilized during the implementation and execution of offshoring. The total cost, as indicated in the last row of Table 5-3, gives the total production dependent cost that will employed in the next section where a mathematical model is built to determine an optimal long term offshoring decision.

5.2 MATHEMATICAL MODEL FOR XYZ

As described in Chapter 3, the mathematical formulation of the decision model is expressed as a fixed charge plant location problem which is a mixed integer programming model. The model combines results from the ABC analysis with other financial and macro-economical data from public sources.

5.2.1 Model Formulation

In many instances, only the costs of alternatives are included in the objective of an economic decision model. However, for an offshoring decision, economic conditions of the countries can have significant impact on cost differences. Therefore, economic indicators such as inflation and exchange rates should be included by calculating the net present value of cost utilizing engineering economics principles. The objective value, representing the net present value of the cost of production/services, is adjusted by incorporating interest inflation, exchange and tax rates into the total cash flow over the offshoring decision's life cycle.

Indices:

I= { i = 1,2,….} set of possible supply points

J= { j = 1,2,….} set of demand points

T: Time horizon (annually divided: t = one year) - $t \in T$ represents a one year period

Decision Variables:

Associated with each alternative there are decision variables:

x_{ij}^{t} = total amount of production at location i transported to demand location j at period t.

z_i = binary variable associated with supply point i, equals 1 if there is production and equals 0 if there is no production.

Assumptions:

- Once the decision is made and the location is selected, the production at that location is not interrupted for the decision horizon (T).
- The present values of the costs are in USD and remain constant over the decision horizon. The values change as projected based on the interest, inflation and exchange rates.
- The taxes, duty rates and other trade policy variables remain constant over the decision horizon.
- Depreciation is calculated linearly along the decision horizon.
- The transfer price (cost of production added with reasonable rate of return) is assumed to be 10% added to the sum of variable and fixed production costs.
- Corporate taxes paid in the destination country is taken into consideration. Tax calculations in reality should be based on "arm's length" methodology and the existence of double taxation treaties between countries. Arm's length methodology suggests that a corporation should set the transfer price based on market value. The 10% rate of return is assumed to obey this convention.
- Each location qhas a maximum supply capacity determined by the climate and economical conditions of the region.
- The fixed costs (annual fixed expenses and capital) are composed of base portions and incremental portions expressed as a linear function. The fixed costs linearly increase with the incremental rate.
- The duties are calculated based on the sum of transfer price and freight costs. In calculating the duty per item, the fixed expenses are distributed based on the capacity of production.

Actual duty rate calculations are more complex involving quotes, subsidies and trade agreements between countries.

- The expenses are annualized and calculations are based on discrete cash flow analysis.
- The net present value is calculated with a discount based on the interest rates.

Parameters:

M = sufficiently big constant for the binary force constraints (the minimal sufficient constant should be used to prevent any computational inefficiency)

D_j^t = the total demand in location j at year t

v_i = present variable cost of production/service – taken from the results of the ABC analysis

s_{ij} = present transportation cost from location i to location j (inbound and outbound)

d_{ij} = duty rate for products transported from location i to location j

tx_i = marginal corporate tax rate in location i

q_i^t = the cumulative amount of inflation between times 0 and t at location i

g_i^t = forecasted exchange rate between country of location i and USD at time t

e^t = the cumulative amount of real interest rate between periods 0 and t for USD dollars

g_i^0 = present exchange rate (Foreign Currency / USD) at location i

fcc_i = base portion of the annual fixed cost at location i

k_i = incremental portion of the annual fixed cost at location i

tcd_i = base portion of the total capital invested (to be depreciated) at location i

l_i = incremental portion of the total capital invested at location i

C_i = capacity limit at location *i*

Objective Function:

- *Variable production cost at location i at time t in local currency:*

$$\upsilon_i^t = (1 + q_i^t) g_i^0 v_i \sum_{j \in J} x_{ij}^t \tag{5-3}$$

Variable cost at time *t* at location *i* in local currency is calculated by first converting the present cost in USD to local currency and then projecting the result to time t by considering the cumulative inflation rate.

- *Annual fixed cost at location i at time t in local currency:*

$$\varphi_i^t = (1 + q_i^t) g_i^0 \left(fcc_i + k_i \sum_{j \in J} x_{ij}^t \right) \tag{5-4}$$

Annual fixed cost at time *t* at location *i* in local currency is calculated by first converting the present cost in USD to local currency and then projecting the result to time t by considering the cumulative inflation rate.

- *Total investment capital (to be depreciated) in USD:*

$$\delta_i = tcd_i + l_i \sum_{t \in T} \sum_{j \in J} x_{ij}^t \tag{5-5}$$

The total capital investment consists of the base investment and the incremental capital increasing with respect to the total production at a location.

- *Transportation cost from location i to location j at time t in local currency:*

$$\zeta_{ij}^{t} = \left(1 + q_i^t\right) g_i^0 s_{ij} x_{ij}^t \quad (5\text{-}6)$$

- *Duty for items from location i to location j at time t in local currency:*

$$\chi_{ij}^{t} = \left(1 + q_i^t\right) g_i^0 d_{ij} (1.10 v_i + 1.10 k_i + \frac{1.10\, fcc_i}{C_i} + s_{ij}) x_{ij}^t \quad (5\text{-}7)$$

- *Corporate tax paid at location i at time t in local currency:*

$$\tau_i^t = (1 + q_i^t) g_i^0 tx_i \left[(0.10 v_i + 0.10 k_i) \sum_{j \in J} x_{ij}^t + 0.10\, fcc_i \right] \quad (5\text{-}8)$$

- *Corporate tax deducted at location i at time t in local currency (depreciation value is not projected over inflation):*

$$\omega_i^t = g_i^t tx_i \left[l_i \sum_{j \in J} x_{ij}^t + (m) tcd_i \right] \quad (5\text{-}9)$$

Annual cash flow calculations:

The objective is to minimize the net present value of total costs after taxes. The parameters are determined either by collecting cost data from the alternative suppliers or by estimation. These parameters (i.e., variable costs, transportation costs) are expressed in terms of USD for the initial state of time. Then they are projected to the future by taking into account the cumulative inflation and exchange rates. The cash flow at a location in local currency can be represented as shown in Figure 5-3.

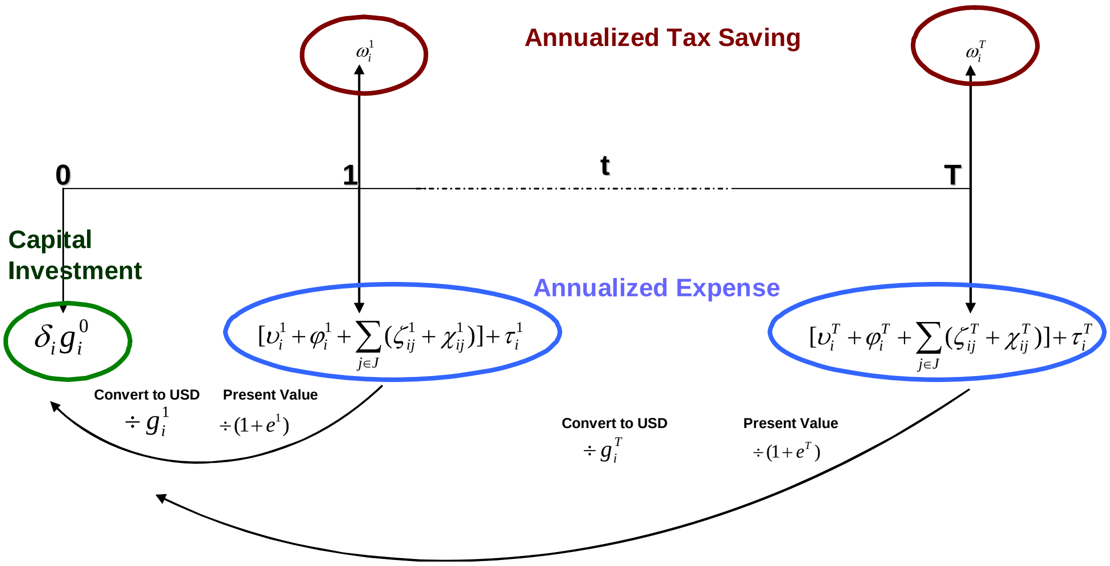

Figure 5-3. Cash Flow of Total Cost of Production at Location i (in local currency)

Expressing the **objective function** in terms of the parameters and the decision variables:

Minimize Net Present Value of Total Cost after Tax (USD):

$$\sum_{i\in I}\sum_{t\in T}\sum_{j\in J}\left\{\alpha_i^t\left[(v_i+k_i)(1+1.10d_{ij}+0.10tx_i)+s_{ij}(1+d_{ij})+d_{ij}\left(\frac{1.10fcc_i}{C_i}\right)\right]-\frac{tx_i l_i}{(1+e^t)}+l_i\right\}x_{ij}^t$$

$$+\sum_{i\in I}\left\{\sum_{t\in T}\left[\alpha_i^t\left((1+0.1tx_i)\,fcc_i\right)-\frac{(m)tx_i tcd_i}{(1+e^t)}\right]+tcd_i\right\}z_i \qquad (5\text{-}10)$$

where, $\alpha_i^t=\dfrac{(1+q_i^t)g_i^0}{g_i^t(1+e^t)}$

Constraints:

- *Demand constraints:*

Demand constraints ensure that the demand is met at each time period.

$$\sum_{i\in I}x_{ij}^t=D_j^t \qquad \forall \quad j\in J \;\text{ and }\; t\in T \qquad (5\text{-}11)$$

- *Capacity constraints:*

Capacity constraints ensure that the maximum capacity is not exceeded for each production location.

$$\sum_{j \in J} x_{ij}^{t} \leq C_i \qquad \forall \; i \in I \text{ and } t \in T \tag{5-12}$$

- *Binary force constraints:*

The binary force constraints ensure that production amounts associated for a location is zero if the location is not chosen.

$$\sum_{t \in T} \sum_{j \in J} x_{ij}^{t} \leq M z_i \qquad \forall \; i \in I \tag{5-13}$$

- *Trivial constraints:*

$$x_{ij}^{t} \geq 0 \qquad \forall \; i \in I, \; j \in J \text{ and } t \in T \tag{5-14}$$

$$z_i^{t} \in \{0,1\} \qquad \forall \; i \in I \tag{5-15}$$

5.2.2 Data Collection

In XYZ's case, the five location alternatives for offshoring are denoted by i = 1,2,3,4 and 5, representing U.S., Middle East, Asia, South America and Eastern Europe respectively. The demand regions are North America and Western Europe, denoted by j=1 and 2 respectively.

The parameters of the model are set according to the data collected from public and private sources. The data can be classified into four groups: demand data, cost data, capacity data and macro-economic indicators. Demand data include the forecasted demand of XYZ sales in the

U.S. and Western Europe. The cost data consists of fixed and variable costs of production associated with each location. Some of the cost values are estimated by the ABC analysis whereas others are assigned based on data obtained from internal and external sources. The capacity limits are determined according to the climate and social environment of the regions and will be described in the next section. The macro-economic indicators include interest rates, inflation, parities, duty rates and taxes.

A) Demand

The semi-finished product is shipped to the U.S. and Western Europe for further processing to make the end products; i.e., food condiments sold under a brand name. The total retail volumes of sauces, dressings and condiments for the decision horizon are presented for each region in the Table 5-4.

Table 5-4. Forecast Retail Volumes

Total -'000 tons	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Western Europe	3,092	3,163	3,222	3,294	3,346	3,410	3,468	3,521
North America	2,723	2,691	2,646	2,583	2,551	2,536	2,535	2,545
Condiments- Avg. 9% of all sauces and condiments								
Western Europe	278.32	284.67	289.94	296.48	301.15	306.87	312.11	316.89
North America	245.04	242.18	238.15	232.43	229.58	228.20	228.12	229.05
Condiment by XYZ- Avg. 60% share in the U.S. market and 70% in Western Europe								
Western Europe	194.82	199.27	202.96	207.54	210.80	214.81	218.47	221.82
North America	147.03	145.31	142.89	139.46	137.75	136.92	136.87	137.43

Source: Global Market Information Database by Euromonitor International

B) Costs

i) Variable Cost

Variable costs are determined by an ABC analysis that considers the relationship between cost pools, cost drivers, activities and production. The costs are evaluated in USD for 2001 and are projected to the ten year decision horizon by utilizing life cycle costing methods. Table 5-5 presents the summary of results:

Table 5-5. Estimated Variable Costs

	U.S.A	M.East	Asia	S.America	E.Europe
RFP Variable Cost	$ 41.02	$ 30.14	$ 17.91	$ 26.03	$ 32.66
Adjusted RFP Cost	$258.47	$197.85	$117.58	$ 164.02	$ 205.80
SFP Cost	$356.20	$335.43	$193.14	$ 277.45	$ 267.50

The variable costs for RFP are calculated for a ton of product and then adjusted by multiplying by the ratio of yield (1 ton of raw product yields about 0.16 ton of end product.) The exact ratio depends on the processing as well as the raw product quality. The variable costs for the SFP are calculated by adding the RFP variable costs with the processing variable costs.

ii) Total Capital Depreciated

The capital depreciated includes all of the assets whose value is considered to decrease over time because of age, wear or market conditions. The amount of capital involves both fixed costs which are necessary to implement and run a facility, and the incremental costs which are incurred as the production rate increases. For a facility processing the perishable food in this problem, the total capital depreciation is estimated to have a base cost of 10 million USD. The incremental cost is estimated by interpolating on the data the obtained from various facilities.

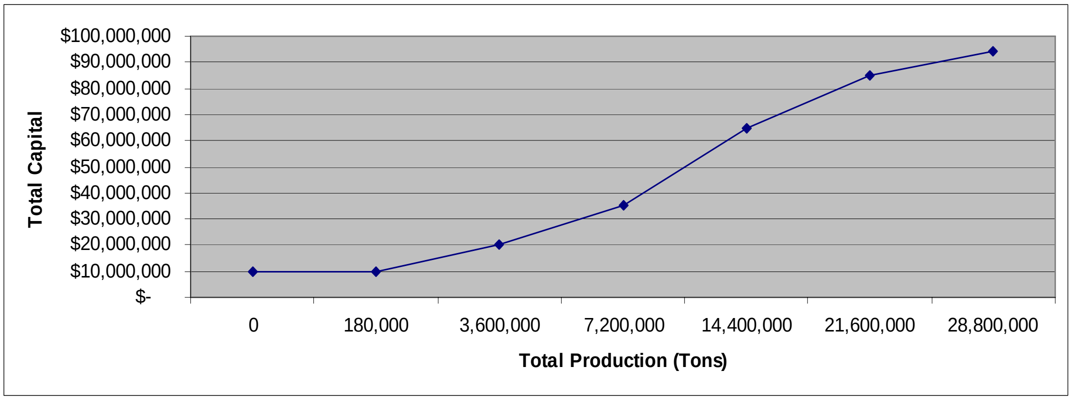

Figure 5-4. Capital Costs Interpolated

Therefore, tcd_i = 10,000,000 USD and l_i = 3.06 USD/ton for all locations.

iii) Annual Fixed Cost

Annual fixed costs include administrative expenses, indirect labor, insurance and rental. Although, they are called "fixed," it is wrong to assume they will remain fixed independent of the capacity of the facility. Therefore, fixed costs are expressed as having two parts: base cost and capacity dependent (incremental) costs. Base cost is the total cost that is incurred independent of the operation of the facility. These include base insurance costs and rental. The capacity dependent cost is the part that increases incrementally as activity increases.

The annual capital expenses are estimated to equal the amount of annual capital depreciated linearly. In addition, the insurance cost has a base of 100,000 USD per year plus 1% of capital. As a result, the annual fixed cost can be expressed as:

$fcc_i = 1.01(10{,}000{,}000 \div T) + 100{,}000$ and $k_i = 1.01(3.06) = 3.09$ for all locations.

iii) Transportation Cost

The ocean freight costs for a ton of product are used in the mathematical model. The transportation cost includes the inbound transportation (from RFP to SFP stage) and the outbound transportation (from SFP to end production). The transportation costs per ton of the semi-finished product are depicted in Table 5-6.

Table 5-6. Trasportation Costs

	N.America	W.Europe
U.S.	$ 37.11	$ 62.99
M.EAST	$ 99.20	$ 27.43
ASIA	$ 164.36	$ 89.53
S.AMERICA	$ 102.16	$ 97.46
E.EUROPE	$ 107.46	$ 85.50

C) Capacity:

Every location alternative has a maximum capacity that is determined by the economic and climate conditions of the location. The main factor affecting the capacity of the production is the size of the area that the raw product can be produced. For perishable food products, the duration of transportation should be limited in order to preserve the quality and freshness. The quality of the product deteriorates by exposure to the sun and the deterioration increases as the time between its harvesting and processing gets longer.

The food processing facility is built in the middle of the farm so that the time of transportation of the raw product from the farm to the facility is minimized while product quality is preserved. Transportation mode is one of the biggest determining factors in restricting the maximum distance the product can travel, therefore constraining the capacity of production. At some locations, transportation is done by animal carriages that can only carry a limited volume of product and transport to the facility at a slower speed. The maximum processing capacities are estimated by considering the transportation speed, efficiency and utilization of the farm field. Volume capacity for each region is shown in Table 5-7.

Table 5-7. Regional Capacities

	Unit	U.S.	M.East	Asia	S.America	E.Europe
Raw Product Capacity	*Raw Year*	6,048,000	2,368,000	852,480	672,000	2,688,000
Concentration	*Processed/ Raw*	15.87%	15.24%	15.24%	15.87%	15.87%
Processing Capacity	*Processed Ton/Year*	959,818	360,883	129,918	106,646	426,586

D) Macro-economic Data:

The offshoring decision analysis for XYZ is done with an initial time point in 2003 for an eight-year decision horizon. The historical macro-economic data and the forecasted values are obtained from research databases, mainly from Economist Intelligence Unit (EIU) and SourceOECD. EIU provides data and forecasts about political, economic, and business climates of various regions and up to 200 countries as well as related news, analysis, and risk factor assessments [107]. SourceOECD is the online library of the Organization for Economic Co-operation and Development. The database comprises book reports and financial statistics [108].

Forecasting interest rates, inflation and exchange rates is complicated and requires deep understanding of many macro-economic indicators and global monetary environment. The literature and research in this area is extensive and the field of macro-economy is profound. Therefore, in order to achieve utmost reliability in this study the forecasts for economic data are directly taken from the databases which provide professional analyses. Table 5-8 through Table 5-11 show the macro-economic parameters used in the mathematical model. The names of the countries in the regions are not disclosed for confidentiality reasons but the data associated with the countries in consideration are used in the analysis.

Table 5-8. Exchange Rates- Historical and Forecasted

Exchange Rate	**U.S.**	**M.East**	**Asia**	**S.America**	**E.Europe**
(present)2003	1.00	5.85	8.28	3.08	0.80
2004	1.00	6.10	8.28	2.93	0.80
2005	1.00	5.78	8.19	2.44	0.80
2006	1.00	5.73	7.97	2.48	0.79
2007	1.00	5.72	8.00	2.45	0.75
2008	1.00	5.73	8.00	2.39	0.74
2009	1.00	5.75	8.00	2.36	0.77
2010	1.00	5.76	8.00	2.33	0.79
2011	1.00	5.78	8.00	2.27	0.79

Table 5-9. Inflation Rates- Historical and Forecasted

Inflation	**U.S.**	**M.East**	**Asia**	**S.America**	**E.Europe**
(present)2003	2.20%	4.50%	0.90%	10.80%	0.73%
2004	2.70%	11.30%	3.40%	6.50%	3.60%
2005	3.40%	4.90%	1.80%	6.40%	2.40%
2006	3.20%	7.70%	1.40%	5.40%	2.20%
2007	2.10%	8.60%	2.50%	5.30%	3.10%
2008	2.40%	4.50%	2.60%	5.60%	2.80%
2009	2.60%	3.60%	2.80%	5.10%	2.50%
2010	2.50%	3.30%	2.60%	4.70%	2.30%
2011	2.50%	4.20%	2.50%	4.40%	2.20%

Table 5-10. Interest Rates in the U.S.- Historical and Forecasted

2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
4.10%	4.30%	6.20%	8.00%	8.10%	8.00%	8.30%	8.30%	8.30%

Table 5-11. Duty Rates

	N.America	**W.Europe**
U.S.	0.0%	14.4%
M.EAST	0.0%	14.4%
ASIA	11.6%	14.4%
S.AMERICA	0.0%	10.8%
E.EUROPE	11.6%	0.0%

5.2.3 Solution

The mathematical model when optimized to minimize the total net present value of costs, gives the optimum objective value of $ 942,712,882 USD total by selecting the U.S., Asia and Eastern Europe as the regions to implement the production process. The market demand in the U.S. is fulfilled by the U.S. production facility whereas the Western Europe market is fulfilled by the production facilities in Eastern Europe and Asia. The results are shown in the Table 5-12.

Table 5-12. Optimal Production Distribution (minimize total net present cost)

	to U.S.	to W.Europe	
	U.S. plant	E.Europe plant	Asia plant
2004	147,025	64,903	129,917
2005	145,310	69,350	129,917
2006	142,889	73,038	129,917
2007	139,456	77,620	129,917
2008	137,749	80,885	129,917
2009	136,921	84,891	129,917
2010	136,871	88,556	129,917
2011	137,427	91,907	129,917

Note that the results can easily be interpreted by looking at the cost data that were utilized in solution of the mathematical model. For Western Europe the production cost in Asia is the lowest, thus the model first assigns production to the Asia location until the capacity limit is met. The remaining demand in Western Europe is fulfilled by Eastern Europe facility because the aggregated production cost with taxes, duties and transportation in Eastern Europe is the next lowest cost alternative for Western Europe. On the other hand, for the U.S. market, production in the U.S. comes out to be the most cost advantageous because there are no added duties and transportation costs are lower.

An interesting result appears when the capacity limit of Asia increased so that it exceeds the total demand from both the U.S. and Western Europe. One may expect that if Asia's production capacity is adequate, it will be more cost efficient to transfer all of the production process to Asia. However, this is not the case. Even if Asia's production capacity is adequate, the minimization of cost is achieved by fulfilling the U.S. market demand from the U.S. location, and the Western Europe demand from Asia. The results are shown in Table 5-13.

Table 5-13. Optimal Production Distribution with Adequate Capacity in Asia

Capacity Asia increased		
	to U.S.	**to W.Europe**
	U.S. plant	**Asia plant**
2004	147,025	194,820
2005	145,310	199,267
2006	142,889	202,955
2007	139,456	207,537
2008	137,749	210,802
2009	136,921	214,808
2010	136,871	218,473
2011	137,427	221,824

5.3 ANP MODEL FOR XYZ

Although reducing the cost of production is a major objective, XYZ as a public company is concerned with many factors that may affect the company's competitiveness. Transferring operations to overseas locations necessitates difficult managerial decisions involving financial and administrative challenges. Moreover, when operations are transferred overseas, controlling them and managing the global supply network involves complications that often do not exist for in-house operations. Quality and reliability are principal values that XYZ has to keep in order to maintain its strong position in the western market. Thus, one of the biggest concerns in XYZ's offshoring decision is the possibility of negative reaction from consumers for a food product that is partly processed outside of the country.

XYZ is also looking for opportunities that can rise as a result of going into a foreign country. In addition to the organizational and financial benefits, XYZ's business in developing countries lead to long term global economic and social effects that in turn may have influence on XYZ's market outside of the western world. Although not a significant factor in the decision, it is worthwhile to include the global consequences as they will affect XYZ's business in the long term.

The ANP model is developed to synthesize the intangible factors (including concerns, benefits and possible opportunities) by evaluating how the decision alternatives contribute to the factors affecting the outcome of the offshoring process. Each decision alternative (or location in this case) has a different level of influence in the outcome. For instance a distant production location from the market creates additional logistical complications when compared to a production location that is close to the market. Starting a business in a more populated region may introduce a higher market opportunity compared to starting a business in a less populated region. As suggested before, in this research the ANP model (like the mathematical model) captures the decision of whether or not to go offshore by considering "in-house" as an alternative in the decision model to serve as a baseline of comparison.

As explained in Chapter 3.0 , the intangible factors which XYZ is considering during the offshoring decision are classified into two: opportunities and risks. Opportunities represent positive consequences such as benefits arising from emerging markets and prospective collaborations with outside vendors, whereas risks represent possible negative consequences, including longer lead times and reduced product quality. The level of opportunity and risk involved in a decision can be described numerically by quantifying all of the contributing variables. The quantification is achieved by the ANP model where the magnitude of each alternative's opportunities and risks are assessed with respect to several criteria. An ANP model can evaluate the values of opportunities and risks by blending experience, judgment and historical data using paired comparisons. The next section shows how the ANP is implemented and used to derive the weights of opportunities and risks for XYZ's offshoring decision.

First, the criteria that play a role in the decision analysis are determined. The criteria are further divided into sub-criteria that can separately be considered by the decision maker while comparing the alternatives. For instance the cluster "risk" can be divided into financial and operational risks. Financial risks can further be expressed as a combination of market fluctuations, liabilities and regional economical changes. Such a hierarchy of criteria and sub-criteria illustrates the spread of influence in the decision making process and allows the decision maker to identify the extent of influence of the alternatives. The total value of opportunities and risks associated with each alternative destination are synthesized by considering the alternative values with respected to the sub-criteria and combining them in the criteria hierarchy with a bottom to top approach.

5.3.1 Criteria Tree and the Decision Network

For each offshoring decision, the decision criteria should be set individually by considering the influential factors that will affect the offshoring process. Mainly, all of the factors that create uncertainty leading to negative consequences are classified under risks whereas all of the factors that create uncertainty leading to positive consequences are classified under opportunities.

5.3.1.1 Risks for XYZ

Companies are exposed to a variety of risks when they transfer their operations offshore. The types of risks and their impacts differ according to the market, the type of product and industry. The criteria for risks are determined based on the environment and characteristics of the offshoring process. For instance XYZ's offshore outsourcing decision does not need consideration of intellectual property risks because the business (production and processing of perishable food) does not involve any innovative edge that can be lost due to offshoring. Risks are classified as operational risks and implementation risks.

1- Operations

Sub-criteria under operational risks are presented in Figure 5-5.

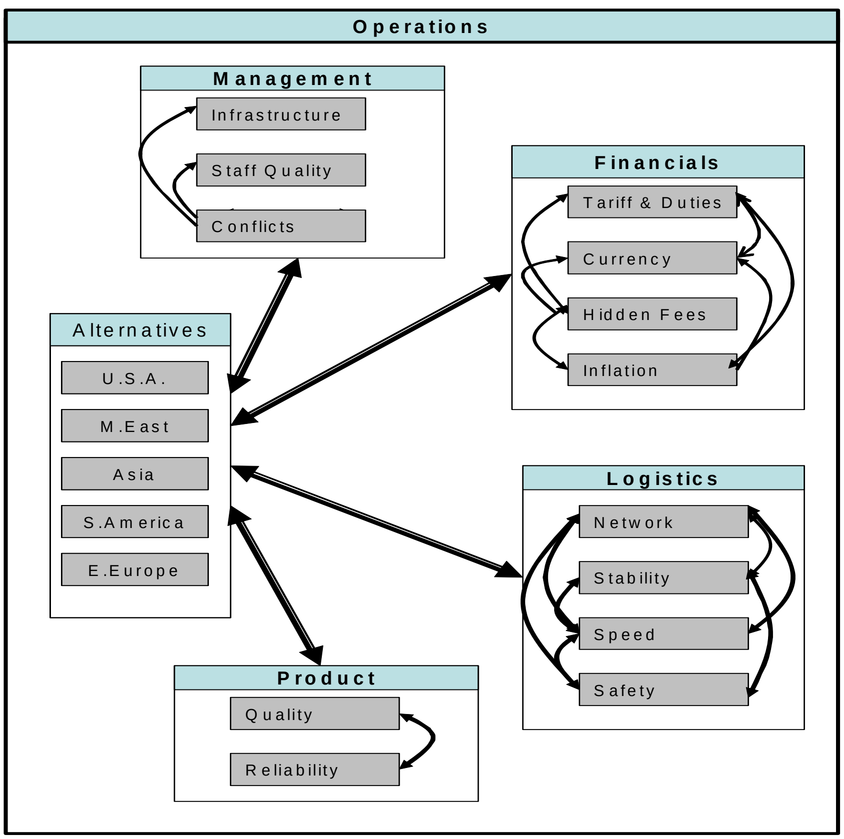

Figure 5-5. Criterion: Operational Risks

a) Financial

The financials criterion includes two types of risks: avoidable risks and unavoidable risks. Unavoidable risks emerge as a result of macroeconomic changes and economic policies of foreign countries. Some of the macro-economic criteria (such as inflation rates) are included in the mathematical model as forecasted parameter in calculating the objective function. However forecasts do not include speculative and drastic changes that may occur in an economy. The likelihood of such an event happening cannot be known but can be anticipated based on historical events and the region's economic and political stability. Therefore, they are also input into the ANP model.

i. *Tariffs and Duties:* This is the transaction fee incurred when a commodity is transported across national borders. The tariff and duty rates are not expected to change frequently but may be changed by governmental ruling as deemed necessary.

ii. *Currency:* The currency fluctuations happen as a result of many economic factors that interact with each other. The exchange rates can be estimated by assuming a steady economy. However, in some regions extreme events, such as devaluation have occurred and for these regions such risks should be taken in consideration for future.

iii. *Hidden Fees:* Hidden fees are costs that were not foreseen in the decision process but appear during implementation and execution of the decision. Hidden fees in large part depend on the type of process that is outsourced and the region the operations are located. Experiences of corporations in certain regions can be used as indicators to estimate the risk of incurring hidden fees.

iv. *Inflation:* Inflation is an important factor determining the price of raw material, labor rate and all other expenses. A region with high inflation is an economically unstable business environment subject to risks.

b) Management

Offshoring may bring managerial risks resulting from inadequate governance, organizational changes and production deficiencies.

i. *Infrastructure:* Infrastructural risks arise due to geographical distances and technological disparities that make communication and control of the processes difficult to manage.

ii. *Staff:* With offshoring major organizational changes take place and such changes often have immense effects on productivity. This can be mitigated by employing change management principles with technical and communication skills

iii. *Conflicts:* Conflicts appear as a result of misunderstanding and disagreements within an organization. As the operations dispense in different locations with different vendors, the odds for conflicts rise.

c) Product

i. *Quality:* Quality is the most important factor for consumers especially for a perishable food product. Even a small decline in the level of quality creates immense risk in the market.

ii. *Reliability:* Reliability means the consistency in product quality and on-time delivery.

d) Logistics

i. *Network*: A reliable transportation network is a vital part of a globally distributed production. The accessibility of such a network depends on the geographical condition and infrastructure.

ii. *Stability:* If transportation systems are not dependent in terms of availability and efficiency, risks involved in operating in that region are worse.

iii. *Speed*: The lead time between processes inevitably increases with offshoring due to longer distances. Moreover, in regions with slower and primal transportation systems the lead times may considerably extend.

iv. *Safety:* For a perishable food product, it is important to preserve the quality during its transportation. Especially in humid and hot climates, the product quality may deteriorate easily.

2- Implementation

The other major part of offshoring risks is the implementation risks. In the implementation phase, the operation transfers are brought to life. This includes knowledge transfer, documentation, legal contracts, training and other procedures that need time and effort. The schematic representation of implementation risk is depicted in Figure 5-6.

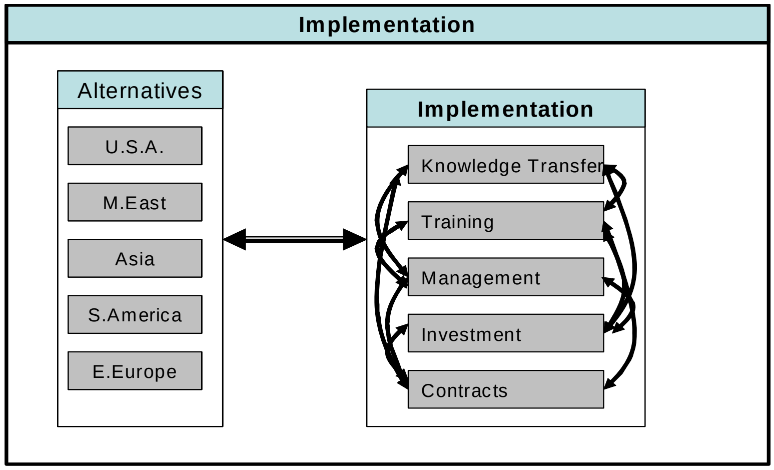

Figure 5-6. Criterion: Implementation Risks

i. *Knowledge Transfer:* During the implementation phase, a considerable amount of time is invested in documentation and communication to transfer the knowledge that exists in-house. The risks increase as the knowledge transfer gets complicated and massive because of miscommunication, lack of motivation and capacity.

ii. *Training:* Training is needed for operators and administrative workers who will be employed in the offshore location. More training is required when offshoring is done in regions that lack specialized human and technical capital.

iii. *Management:* Essential elements for successful implementation are a comprehensive contract, efficient relationship management, and a structural transition stage. Four basic management principles are applied: change management, contract management, stakeholder management, and relationship management. Any deficiency in this stage will cause failure in the implementation.

iv. *Investment:* The risk is not the amount of investment that is required; the investment amount is included while analyzing the cost of the process. Implementation risk consists of fluctuations in the expenses, the amount of unforeseeable investment that could be required once the implementation starts and non-monetary expenses, such as time and effort.

v. Contracts: XYZ when going offshore needs to have contracts with various vendors in the destination country. The contract should be comprehensive in determining the specification of the payment terms and responsibilities, revealing the perspectives of multiple parties. The business laws and bureaucracy in certain regions make the contractual agreements burdensome to plan and execute.

5.3.1.2 Opportunities for XYZ

Opportunities are divided into financial, organizational, production and global opportunities.

1- Financial

Financial opportunities are presented in Figure 5-7.

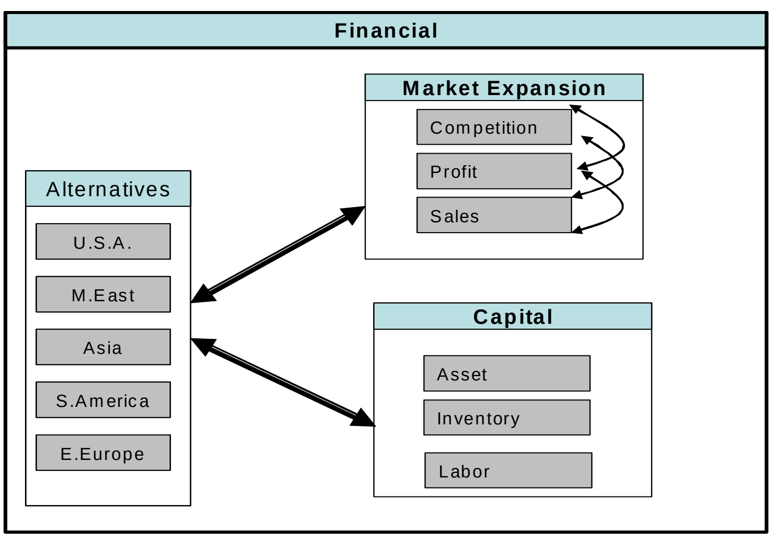

Figure 5-7. Criterion: Financial Opportunities

a) Market Expansion

i. *Competition:* The reduction in production costs are reflected to the market as reduced prices, adding power to the competitiveness of XYZ brand.

ii. *Profit:* Cost reductions are not fully reflected to the prices. The difference between the reduction in cost and prices is gained as an additional profit margin.

iii. *Sales:* With reduced prices, market share of XYZ can be expected to be higher as the sales volume and revenue increase.

b) Capital

i. *Asset:* Machine and capital investments are a part of XYZ's transfer of production to overseas. At the same time the in-house assets are considerably reduced with offshoring. Overall, the asset volume of the company may decline which can be perceived as an opportunity to elevate return to asset, increasing the shareholder value.

ii. *Inventory:* The benefit of staying in-house, or transferring operations to a closer destination is that inventory can be maintained in minimal level with short lead times. Therefore the probable opportunity value for less distant destinations is higher.

iii. *Labor:* The cost analysis includes the assessment of low labor rates in alternative countries. In addition, reduction in labor volume is also a benefit a company may gain in certain destinations.

2- Organizational

Organizational opportunities are presented in Figure 5-8.

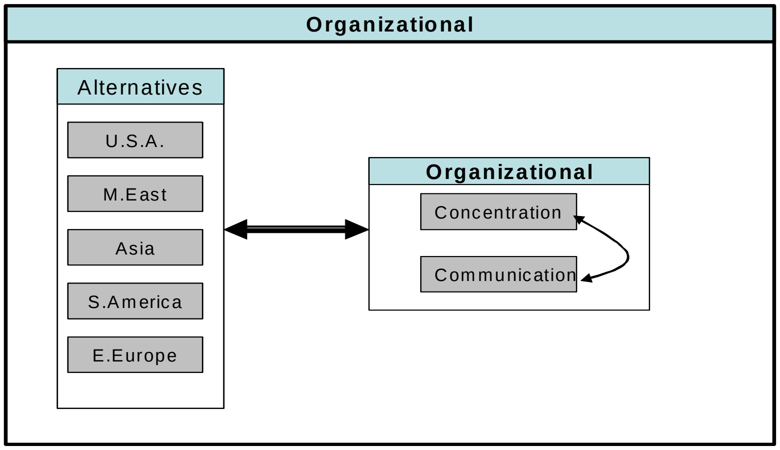

Figure 5-8. Criterion: Organizational Opportunities

i. *Concentration:* The front end production is a straightforward process that needs no further improvement. On the other hand, the end part of the process and later the sales and marketing of the brand require continuous development. One of the benefits of offshoring the front end production process is enhanced organizational focus towards the upper parts of the value chain.

ii. *Communication:* Another factor that needs to be considered is the ease of communication. The language capabilities and cultural differences play a significant role.

3- Production

Production related opportunities include flexibility and productivity as shown in Figure 5-9.

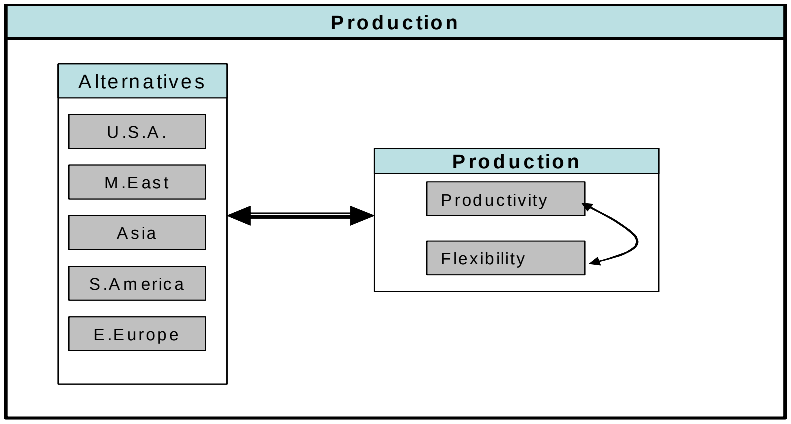

Figure 5-9. Criterion: Production Opportunities

i. *Productivity:* Productivity means the efficiency of the production process in terms of both the amount and the quality of the output. The productivity ranges from region to region based on the environmental and technical conditions.

ii. *Flexibility:* Flexibility means being able to make modifications to adjust to the changes in demand and consumer demands. For instance when the demand spikes at certain times, flexibility is necessary to increase the production capacity and reduce the transportation lead time.

4- Global

Global opportunities are classified under the sub-criteria: market, society and economy opportunities as depicted in Figure 5-10.

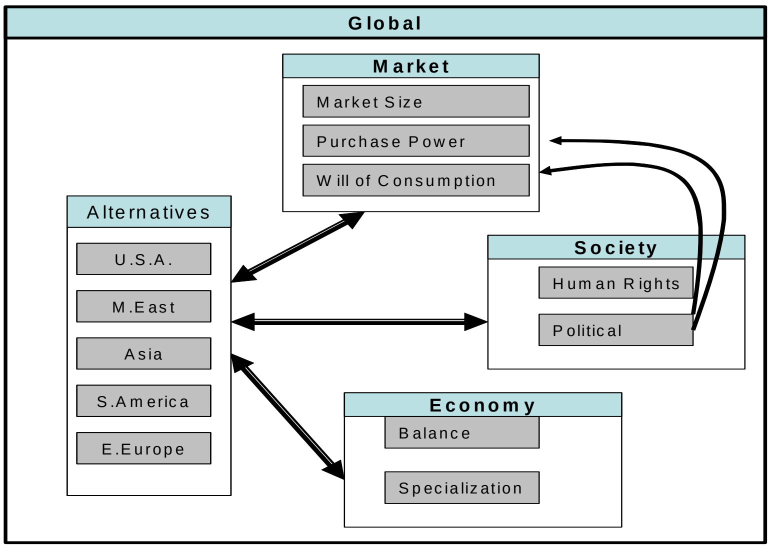

Figure 5-10. Criterion: Global Opportunities

a) Market

With more global companies entering highly populated regions, the consumption markets in these regions accelerate.

1. ***i.*** *Market size:* The market growth in the long term facilitates opportunities for expanding consumer sales in the global market.
2. ***ii.*** *Purchase Power:* The purchasing power of people in regions receiving international investment increases as more people receive employment opportunities. This in turn boosts the consumption volume.
3. ***iii.*** *Willingness to Consume:* Availability of income drives economic dynamism and elevates people's will of consumption.

b) Society

i. *Human Rights:* The expansion of global trade has social consequences which give rise to sustainable development of the regions and interdependently help a gradual movement to protect human rights.

ii. *Political:* As economies are getting more dependent on each other, an attitude towards a more democratic and peaceful environment is inevitable.

c) Economy

i. *Balance:* Industrial advances in developing countries and global trade lead to an economic balance between regions which in turn ensure a more peaceful environment for both nations and corporations.

ii. *Specialization:* In the new global economy countries are beginning to establish specialized niches leading to growth in productivity, innovation and development.

5.3.2 Data Collection and Paired Comparisons

The paired comparisons are made on a 0-9 scale based on mostly public sources, databases and literature. Some of the sources are:

- *Country macro-economic and social data* [109, 110, 111, 112, 113]

The financial and social environment of a country will reflect on the performance of offshoring processes, consequently defining the success of the business. In the case study presented here, it is important to note that the agricultural society, its culture and economic status will have direct effect on the profitability and continuity of production. For instance, in a region where land is owned by individual farmers, it is harder to maintain the product quality and reliability because common pesticide control cannot be implemented easily. Again, in automation based processes, the literacy level as well as the technological capabilities determines the ease of implementation. Databases such as CountryWatch, Europa World and publications by United Nations give statistical data on the regional economies and social structures. These statistics cannot be directly applied to paired comparisons in the ANP model but can be synthesized by the decision maker to make the paired comparisons based on actual data.

Similarly, the economic indicators of a country, such as inflation and trade balance, and the political conditions demonstrate the stability of the region's business environment and such data can be utilized to rate the risks involved in the regions. Opportunities can also be predicted by looking at the market growth statistics and infrastructural developments. The use of database statistics in paired comparisons is demonstrated in the following sections.

- *Global competitiveness indices* [114, 115]

Offshoring is an expanding business practice in many sectors. It attracts attention from both the corporations seeking a greater competitive edge and consultants that support the decision processes of corporations as they consider moving their operations offshore. For this reason, an increasing number of research is conducted to analyze the conditions of doing business in different countries. Such consulting organizations as McKinsey and AT Kearney and non-governmental organizations such as World Economic Forum publish competitiveness indices that rank countries with respect to various aspects (e.g. labor force, education level etc.).

- *Agricultural literature* [116]

The climate, processing methods, types of diseases and the landscape conditions affect the productivity and quality of the product. The literature provides a vast pool of resources on measuring agricultural productivity and sustainability in different regions of the world. These resources serve as valuable tools to compare regions according to their agricultural composition.

- *Offshoring publications* [117, 118, 119]

Many scholars and professionals carry out extensive research examining and discussing the drivers, consequences and factors in offshoring. The majority of this research provides business cases and empirical studies that elucidate the challenges and opportunities of transferring operations offshore. They also consider the regional difficulties and advantages in terms of managerial and infrastructural environment and present guidelines to the executives who are planning to go offshore.

In the ANP decision model, quantification of intangible values is achieved by comparing the influenced elements with respect to the influence (the criterion). The influence is indicated by arrows in the network and it determines the structure of paired comparisons that will be made by the decision maker(s). As discussed above, the paired comparisons, in this empirical study, rely on public and private data and the opinions of company executives.

Examples of Paired Comparisons:

1- Comparison of alternatives with respect to the "market size" under global opportunities

Although expanding the market outside of the U.S. is not the immediate plan of XYZ, it will be a future opportunity if the production is transferred to specific regions. Such an opportunity is not assigned a high weight but it will have minor effects on the decision, therefore is included in the ANP decision model. The market size opportunity depends on the population size, competitors in the market and the food culture (the cuisine) of that country. The comparison of alternatives with respect to the "market size" is illustrated in Table 5-14 through Table 5-16.

Table 5-14. Projected Populations

	2010	2020	2030
U.S.	297,989,000	317,124,000	332,619,000
M.East*	80,063,000	90,491,000	100,371,000
Asia*	1,380,972,000	1,462,735,000	1,504,096,000
S.America*	190,875,000	209,734,000	225,161,000
E.Europe*	38,691,088	38,454,552	37,377,373

**Countries in consideration. Country names are not disclosed.*
source: CountryWatch Database- www.countrywatch.com

Table 5-15. Consumption of Processed Products

	2001	2002	2003
U.S.	2,696.05	2,734.70	2,722.69
M.East	553.82	570.66	587.41
Asia	6,021.55	6,218.76	6,384.94
S.America	1,905.78	1,974.63	2,048.34
E.Europe	1,437.85	1,493.75	1,553.41

source: Global Market Information Database - www.euromonitor.com

The comparisons are done in light of the data above and the known facts about the cuisines of the regions and food habits of the people. The alternative "U.S." is not given a high level of opportunity because the present market is already in the U.S. and it is not expected to expand much regardless of the strategic action taken. Table 5-16 presents the paired comparisons for the question "With respect to 'market size' under global sub-network which alternative is better (can create more market opportunity)?"

Table 5-16. Paired comparisons w.r.t. "market size"

	U.S.	M.East	Asia	S.America	E.Europe
U.S.					
M.East	1/2				
Asia	1/6	1/5			
S.America	1/2	½	3		
E.Europe	1/2	3	4	3	

λ_{max} : 5.2123. $\mu \equiv \frac{5.2123-5}{5-1} = 0.053$ is inconsistency index. $\frac{0.053}{1.11} = 0.48$ is the inconsistency ratio.

The comparisons are done only for the lower diagonal of the comparison matrix because reciprocals of the values in the lower diagonal are automatically assigned to upper diagonal.

2- Comparison of alternatives with respect to the "infrastructure" under operational risks

The Global Competitiveness Report [114] synthesizes various factors affecting performance of global corporations based on the latest theoretical and empirical research. Combined, these factors make up the competitiveness indices of countries and serve as a basis to compare countries in the context of several international dimensions. Table 5-17 presents some factors that are critical in driving productivity and competitiveness.

Table 5-17. Rankings and Scores of Selected Regions

	Infrastructure		Institutions		Macro-economy		Health & Education	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score
U.S.	12	5.82	27	4.84	69	4.37	40	6.6
M.East*	55	3.72	48	4.12	108	3.75	50	6.51
Asia*	60	3.54	80	3.51	6	5.72	55	6.44
S.America*	71	3.29	91	3.29	114	3.42	47	6.54
E.Europe*	57	3.64	73	3.62	70	4.34	26	6.76

**Countries in consideration. Country names are not disclosed. Source: World Economic Forum*

Infrastructure evaluations are based on the availability and operational costs of energy, transportation and telecommunication systems. Institution rankings indicate the reliability of systems and agents by considering five criteria: property rights, ethics in government, independence of judiciary, efficiency in public sources and public safety. The macro-economy pillar combines the ratings of countries in terms of asset price volatility, difficulties in business implementation, inflation rate, currency debt, GDP growth and a number of other distinct variables. "Health and primary education" focuses on the availability and the quality of health care, and basic skills that enable citizens to participate in the activities of civil and professional life. With the guidance of the given indicators, paired comparisons are performed by also reflecting the requirements of the offshoring process that XYZ is considering. Table 5-18 shows the paired comparisons for the question “With respect to ‘Infrastructure’ under operational risks, which alternative is riskier?”

Table 5-18. Paired Comparisons w.r.t. "infrastructure"

	U.S.	M.East	Asia	S.America	E.Europe
U.S.					
M.East	1/4				
Asia	1/4	1/2			
S.America	1/6	1/4	1/3		
E.Europe	1/4	1	½	4	

λ_{max} : 5.2623. $\mu \equiv \frac{5.2623-5}{5-1} = 0.066$ is inconsistency index. $\frac{0.066}{1.11} = 0.60$ is the inconsistency ratio.

Table 5-19 shows the paired comparisons for the question “With respect to ‘training’ under implementation risks, which alternative is riskier?”

Table 5-19. Paired Comparisons w.r.t. "training"

	U.S.	M.East	Asia	S.America	E.Europe
U.S.					
M.East	1/4				
Asia	1/5	1			
S.America	1/3	2	2		
E.Europe	1/2	3	4	3	

The paired comparison values are not taken directly from the available data; rather they are elucidated within the framework of the conditions and the importance of factors in the decision. For instance, although the primary education and the health care rankings for the U.S. are low, the risks for U.S. are not rated high because the existing facilities are in the U.S. and there is actually no training necessary if XYZ decides to stay in-house.

5.3.3 Synthesis

Altogether, comparisons are performed in 138 paired comparison and 15 cluster comparison matrices. The synthesis is done with the same methodology as explained in previous sections. For the purpose of illustration, the calculation for risks is given in Table 5-20.

Table 5-20. Synthesis of Risk Weights

Control Criterion *Normalized*	***Operations*** *Limit CC* 0.8	0.8	***Implementation*** *Limit CC* 0.2	0.2	*Results*	*Results*
Alternatives	*Idealized*	*(CC x Ideal)*	*Idealized*	*(CC x Ideal)*	***SUM***	***Normalized***
U.S.	0.2487	0.1990	0.3178	0.0636	0.2625	0.0798
M.East	0.9458	0.7566	0.7388	0.1478	0.9044	0.2749
Asia	1.0000	0.8000	1.0000	0.2000	1.0000	0.3040
S.America	0.8793	0.7034	0.4704	0.0941	0.7975	0.2424
E.Europe	0.3520	0.2816	0.2176	0.0435	0.3251	0.0988

As a result, the corresponding risk weights are:

- U.S.: 0.2625 Normalized: 0.0798
- Middle East: 0.9044 Normalized: 0.2749
- Asia: 1.0 Normalized: 0.3040
- South America: 0.3251 Normalized: 0.2424
- Eastern Europe: 0.3251 Normalized: 0.0988

Opportunity weights are calculated in similar fashion and the corresponding weights are:

- U.S.: 04954 Normalized: 0.1900
- Middle East: 0.3926 Normalized: 0.1506

- Asia: 0.7175 Normalized: 0.2752
- South America: 0.5471 Normalized: 0.2099
- Eastern Europe: 0.4543 Normalized: 0.1743

5.4 INTEGRAGED MODEL FOR XYZ

There are three objectives in the developed integrated model: minimizing total costs, minimizing total risks and maximizing total opportunities. Minimization of total costs is achieved by solving the mathematical model which minimizes the present value of total cost over a decision horizon subject to demand and capacity constraints. As Section 5.2 indicates, the optimal solution to this problem is having production plants in Asia, Eastern Europe and the U.S.

The risks in XYZ's offshoring decision involve mainly macro-economic risks. Even though there are some implementation risks, their importance weights are much lower. Therefore, it can be assumed that risks are predominantly diversifiable. On the other hand, opportunities in large part are based on global and market opportunities, which are nondiversifiable. Thus, the total risks and opportunities for XYZ in this model are calculated by taking the average of risk and opportunity values weighted by the production amounts performed at each location. Thus, the objective of "minimizing total risk" is defined as $\boldsymbol{\pi_2(x)}$ = $\min \sum_{i \in I} \left(R_i \frac{\sum_{t \in T} \sum_{j \in J} x_{ij}^t}{\sum_{i \in I} \sum_{t \in T} \sum_{j \in J} x_{ij}^t} \right)$ and the objective of "maximizing total opportunity" is define as $\boldsymbol{\pi_3(x)}$ =

$\max \sum_{i \in I} \left(O_i \frac{\sum_{t \in T} \sum_{j \in J} x_{ij}^t}{\sum_{i \in I} \sum_{t \in T} \sum_{j \in J} x_{ij}^t} \right)$. By replacing the objective function in the mathematical model with π_2**(x)** and π_3**(x)** one at a time, the optimal solutions for maximum opportunity and risk subject to demand and capacity constraints are obtained as shown in Table 5-21.

Table 5-21. Optimal Production Distribution (minimize risk and maximize opportunity)

	Minimize Risk		**Maximize Opportunity**			
To	**U.S.**	**W.Europe**	**U.S.**		**W.Europe**	
From	**U.S.**	**U.S.**	**U.S.**	**S.America**	**S.America**	**Asia**
2004	147,025	194,820	105,282	41,743	64,903	129,917
2005	145,310	199,267	108,014	37,296	69,350	129,917
2006	142,889	202,955	109,281	33,608	73,038	129,917
2007	139,456	207,537	110,430	29,026	77,620	129,917
2008	137,749	210,802	111,988	25,761	80,885	129,917
2009	136,921	214,808	155,166	21,755	84,891	129,917
2010	136,871	218,473	118,781	18,090	88,556	129,917
2011	137,427	221,824	122,688	14,739	91,907	129,917

Therefore, minimization of risks can be achieved by having all of the production at the less risky location, in the U.S which can satisfy all of the demand required during the decision horizon. Maximization of opportunities can be achieved by distributing production, starting from Asia and allocating production to the next opportunistic locations as the capacities permit. The utopia points (the optimal values for single objective optimizations) give conflicting results as depicted in Table 5-22.

Table 5-22. Utopio Points

Objective Value	**Cost**	**Risk**	**Opportunity**
min.Cost	$ 942,712,882	0.1675	0.2181
min. Risk	$ 1,114,772,667	0.0798	0.1900
max. Opportunity	$ 1,104,697,479	0.2128	0.2278

The model suggest that U.S. plant remain open because with respect to all objectives, some amount of production is necessary in the U.S. The decision of transferring operations to an overseas country needs further deliberation and consideration of tradeoffs between the three objectives. The location decision does not have to be based on maximizing or minimizing any of the objectives. A compromise solution can be found by sacrificing an amount from one objective to gain a little from another. Such solutions can be evaluated by utilizing multi-objective optimization tools which find the Pareto optimal points.

Two methods are used to generate the Pareto front: the weighted-sum approach with upper lower bound transformation and the epsilon-constraint approach with Pareto-maximum bounds. For weighted sum approach the transformation ratio is scaled up to ensure computational efficiency. As shown in Table 5-23 and Figure 5-11, a total of 22 Pareto optimal solutions (including three utopia points) are found.

Figure 5-11 shows the Pareto points on a three dimensional graph whose axes represent each objective: cost, opportunity and risk. The Pareto points are clustered into groups based on their proximity in order to make the evaluation of the tradeoffs less complicated. The decision maker can make judgments by considering the marginal differences between the groups and later if necessary one decision point can be selected among the group.

Table 5-23. Pareto Optimal Points- XYZ

	Cost	Risk	Opp.	Selected Regions
Group A	$ 942,712,882	0.1675	0.2181	U.S., Asia, E.Europe
	$ 943,595,480	0.1628	0.2159	U.S., Asia, E.Europe
	$ 945,735,349	0.1528	0.2109	U.S., Asia, E.Europe
	$ 948,125,089	0.1428	0.206	U.S., Asia, E.Europe
	$ 950,884,445	0.1328	0.2011	U.S., Asia, E.Europe
Group B	$ 951,456,670	0.0912	0.1806	U.S., E.Europe
Group C	$ 954,100,581	0.1228	0.1962	U.S., Asia, E.Europe
	$ 957,602,397	0.1128	0.1913	U.S., Asia, E.Europe
Group D	$ 970,266,533	0.0897	0.1818	U.S.,E.Europe
Group E	$ 973,939,549	0.1652	0.22	U.S., Asia, E.Europe
	$ 987,777,342	0.1628	0.22	U.S., Asia, E.Europe
	$ 989,378,032	0.1428	0.21	U.S., Asia, E.Europe
	$ 992,469,728	0.1632	0.2217	U.S., Asia, E.Europe
Group F	$ 993,303,807	0.1228	0.2	U.S., Asia, E.Europe
	$ 998,978,607	0.1028	0.19	U.S., Asia, E.Europe
Group G	$ 1,036,179,923	0.1328	0.2102	U.S., Asia
	$ 1,051,194,558	0.1128	0.2	U.S., Asia, E.Europe
Group H	$ 1,055,405,747	0.0928	0.19	U.S., Asia, E.Europe
Group I	$ 1,077,363,882	0.2028	0.2265	U.S., Asia, S.America
	$ 1,099,146,067	0.2109	0.2275	U.S., Asia, S.America
	$ 1,104,697,479	0.2128	0.2278	U.S., Asia, S.America
Group J	$ 1,114,772,667	0.0798	0.19	U.S.

Ascending Cost Order

The tradeoffs are assessed by the decision makers to attain a convergence based on their preferences. Both the relative importance of objectives and the amount of difference in the value of objectives play a role in making the final decision. First, the decision maker should observe the maximum and minimum value for each objective. For instance in this problem, the value of total opportunity changes at most 26% between the least and most opportunistic decision choices because the opportunity weights associated with alternative locations are similar in value. On the other hand total risk and total cost vary dramatically with the choice of location.

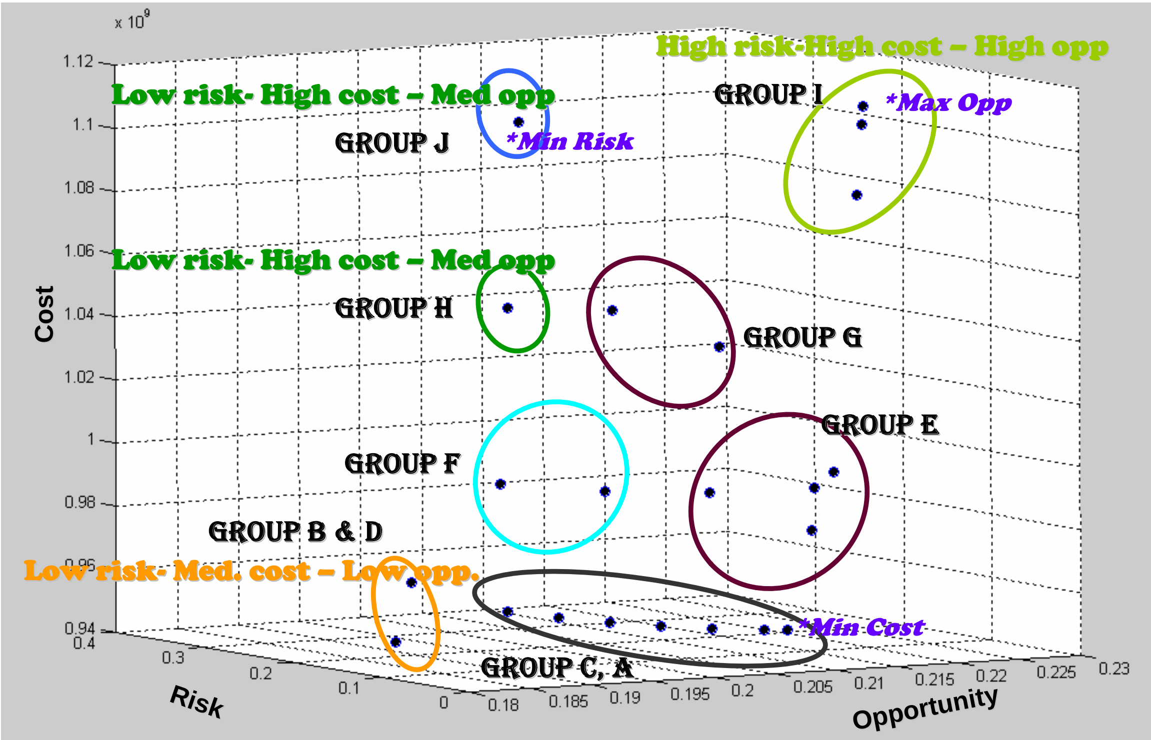

Figure 5-11. Pareto Points for XYZ

Although the decision maker's preferences determine the exact decision, as a preliminary analysis the following reasoning is practical to eliminate some of the decision points that are not credible.

1- Middle East does not exist as an alternative in the Pareto set. Thus, it should be eliminated from the decision space because it is not a credible location to transfer production in terms of all of the objectives.

2- Some of the points can be eliminated by evaluating the tradeoffs between groups. Following are the suggested eliminations.

- When compared with Group A, Group B reduces risks significantly (around 45%) by sacrificing insignificant amount (around 1%) from costs. Since the expanding market of Asia is excluded in Group B, opportunity reduces. However if opportunity is not an important criterion for the corporation, Group A can be eliminated since it escalates the risks considerably while providing very little cost advantage.

- When compared with Group E, Group I does not provide a significant gain in opportunity (at most 8%) but it causes both risks and costs to increase significantly. Unless opportunity is the most important criterion, Group I can be eliminated.
- Adding South America to the selected regions increases opportunity values while increasing both the risk and cost values. The incremental increase in the opportunity values by the addition of South America is very small compared to the loss in risks and costs. Therefore, South America can be eliminated from the decision space.
- If Group E and Group F are compared, one can see that Group E sacrifices significant amount of risk in return for little gain in opportunity and cost. Therefore, Group E is not credible.
- Group H, D and B provide similar levels of risks and opportunities while Group H presents a total cost significantly more than Group D and B. Therefore Group H can be eliminated.
- Group J (the least risky point) provides the minimum risk by increasing costs significantly. Group D and Group B sacrifice some from risks to reduce costs and may be considered instead of Group J. This means, instead of keeping all of the production in the U.S., XYZ should consider distributing some production to Eastern Europe which may be more advantageous.

3- Therefore the decision can be reduced to four alternatives: 1- Production only in the U.S. (high cost, low opportunity, very low risk), 2- Production in the U.S. and Eastern Europe (medium cost, low opportunity, low risk), 3- Production in the U.S. and Asia (high cost, medium risk and high opportunity) , 4- Production in the U.S., Asia and Eastern Europe (medium cost, medium risk, high opportunity or high cost, low risk, low opportunity)

4- For the final decision the production schedule should also be reviewed. For instance, the second point in Group F (cost = $998,978,607, risk = 0.1028, opportunity = 0.19) seems as a credible alternative. However in this case, production in Asia takes place only for two years. Therefore, it is not a realistic option.

As a result, the problem is significantly reduced by eliminating the alternatives: Middle East and South America. Moreover, the analysis clearly suggests that keeping at least a part of the operations in the U.S. is essential for the optimal decision. The final decision is based on the company's objectives and priorities which are determined by exploiting the utilities of costs, opportunities and risks for XYZ's stakeholders. In practice, the stakeholders may discuss their preferences and evaluate the advantages and disadvantages of the alternatives with respect to the company's strategic position and vision and find the optimal decision accordingly.

If a more theoretical and scientific approach is needed, utility elicitation methods can be utilized. The utilities for the alternatives are calculated by adding the utility for the corresponding objective values and the final decision is made by choosing the alternative which gives the maximum total utility.

The result is interesting in revealing that two of the alternatives (Middle East and South America) need not be considered for transferring operations offshore. Moreover, keeping at least a part of production in the U.S. is essential no matter which objective is prioritized the most. Without applying the integrated method developed in this study, such a controversial result would not be expected which would cause a deceptive strategic decision for the company.

5.5 INSIGHTS

Figure 5-12 describes the decision process as multiple methods are employed and uncertainty of the decision reduces while number and type of variables incorporated escalates. The uncertainty in the beginning involves the uncontrollable uncertainties inherent in the decision problem as well as the uncertainties due to the intangible variables and cost estimations. The uncontrollable uncertainties such as the unforeseeable changes in the global economy cannot be eliminated, but uncertainty can overall be reduced by implementing models that can incorporate intangible values and provide reliable cost estimation tools.

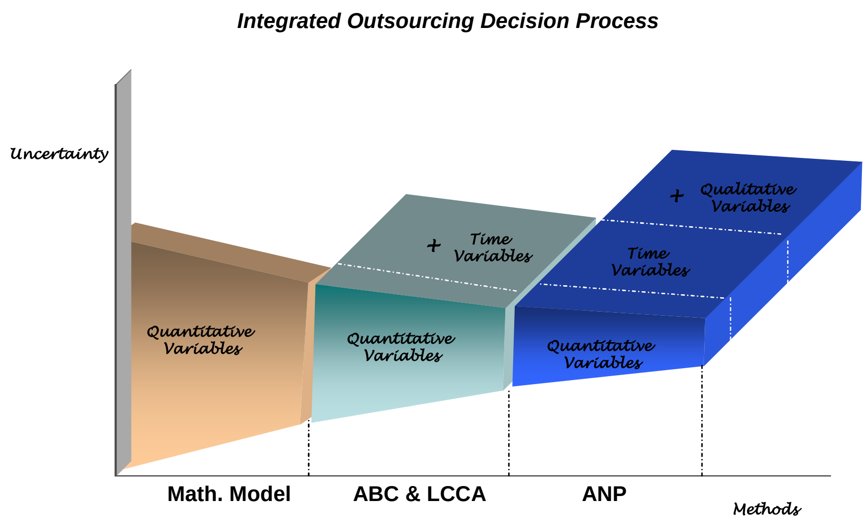

Figure 5-12. Decision Process for XYZ

In this case study, when the integrated decision model is applied two of the five alternatives are eliminated from the decision space because of their inferior objective values. If a traditional cost analysis is to be performed, one would consider the least costly alternatives, mainly Asia, Middle East and Eastern Europe. However when all of the facets of the decision are included by applying the developed integrated method, a contradictory result emerges. Middle

East does not appear in any of the non-dominated solutions. All of the non-dominated solutions include the U.S. alternative even though its production cost (without the addition of transportation,duties, etc.) is the highest. This means at least a part of the production operations need to stay in-house.

In conclusion, this empirical study shows the following:

- If offshoring is a long term decision that involves substantial investment, the price quotes should not be used as a basis of judgment. Instead, the cost of production should be assessed by utilizing estimation tools (such as ABC) which makes use of economic data that can reliably be obtained from public databases.
- Although, low production costs in some locations are attractive, adding hidden costs (such as transportation and duties) reveals that transferring operations to the least costly regions is not the best strategic decision. Additionally, the decision analysis needs to rely on life cycle costing of the product in order to incorporate economic indicators in an international environment.
- In addition to the monetary objectives, the offshoring decision involves many intangible variables especially for global public companies that operate in multiple locations and hold considerable shares in multiple markets. The decision should be evaluated from the perspective of both making the most profit and reducing the risks while opening up opportunities for future. Employing an integrated method is a necessity for a complex decision like offshoring.
- With several alternative destinations for offshoring and numerous combinations for distribution of production, the decision problem gets complicated. An extensive analysis can help simplify the decision problem by eliminating the inferior alternatives.

In summary, this empirical study highlights the necessity for utilizing multiple methods to incorporate both tangible and intangible variables. It also emphasizes the importance of applying engineering economic tools in long term offshoring decisions to secure reliability and accuracy. Most importantly, this empirical study serves as an evidence of the applicability and usefulness of the developed integrated decision making methodology in offshoring decisions.

6.0 SUMMARY AND CONCLUSIONS

Offshoring is a growing trend in today's global economy. It is a complicated process that leads to the strategic transformation of a company and affects its organizational structure, the supply chain system, financial values and many other aspects of the business. Deciding to go offshore and selecting the best regions and suppliers for operations are challenging tasks that are often evaluated from financial standpoint without considering other factors which can have far reaching consequences on the competitiveness of a company.

In this research, an integrated decision approach is developed to incorporate multiple dimensions of offshoring while taking the life cycle of the decision in consideration. This integrated decision approach is illustrated through two "real life" cases that have different characteristics in a similar decision context. In the next section, these two case studies are compared and the conclusions are drawn from their results. Later, the developed integrated approach is criticized by evaluating its effectiveness and applicability. The advantages as well as the disadvantages are presented along with improvement suggestions. In the last sections, related future research areas are discussed and the contributions of this dissertation to the body of knowledge are summarized.

6.1 COMPARING EMPIRICAL STUDIES

The developed integrated model is applied to two different organizational settings where offshoring is carried out with different formats considering different product types. The fundamentals of the decision approach are executed in similar manners. Both problems are evaluated by incorporating tangible and intangible factors to find the best location (or supplier) alternatives and the most cost effective distribution of production among these locations. Yet, there are a number of dissimilarities that require utilization of different methodologies and modifications in the application of the integrated model. These dissimilarities illustrate how the developed integrated decision approach can be used in a variety of settings so that a diverse set of offshoring problems that are commonly faced by today's corporations can be addressed.

XYZ is a large global public company which is making a location selection for transformational offshoring involving significant amount of investment over a long time horizon; whereas SIMA is a mid-size private company that is looking for a specific supplier who can manufacture products within their innovative design specifications in a very short period of time. Therefore, in XYZ's decision model there is an additional monetary uncertainty and complexity that should be taken into account while analyzing location alternatives. Engineering economic tools such as Activity Based Costing and Life Cycle Costing are utilized in order to reduce the cost uncertainties in XYZ's decision process. On the other hand for SIMA's decision, offshore outsourcing is a contractual agreement, so the supplier price quotes can be taken directly as a basis of calculation.

XYZ's product is perishable food that requires quality control rather than innovative design and as a public company, XYZ has to put stakeholder values and global implications into the criteria set that will determine the risks and opportunities of the regions. Many of these criteria can be assessed by making use of the data and the statistics that are mostly publicly available. SIMA on the other hand makes fast moving consumer products that require innovation and need design protection. Thus, the criteria set consists of product and supplier specific considerations. Therefore, the criteria can be assessed accurately only by company executives and engineers who acquire extensive knowledge about the product and have experience with suppliers in overseas.

The approaches followed in the tradeoff analyses differ due to the characteristics of the problems. In XYZ's case demand is stable over time and can be forecasted (approximately). The decision encompasses several years of high volume production that requires initial capital and investment. Because of its extensive strategic consequences, a change in the total risk value gets a higher priority than the total cost and the total opportunity. Moreover, within the greater scope of this decision and also when the size of the company is taken in consideration, slight changes in the cost are insignificant even though the monetary value of the change may be a very large amount.

In contrast, SIMA's total production volume is expected to be lower but it is volatile depending very much on the product life cycle and the competition in the market. Therefore, it is desired to have a robust decision whose optimality is maintained with demand changes. During the product's life cycle phases, priorities of risks, opportunities and costs change as well. As the product enters into its mature phase, even slight differences in the cost value become important because at this stage there is immense price competition. For this reason, small cost differences play a significant role in decision making. The level of risk averseness is also dependent on the company's size and product line and will have affect on how the final decision is made.

As a result of the empirical studies, the applicability of the developed integrated decision approach in diverse settings is illustrated. In both cases, the inferior alternatives are eliminated from the decision space and the best solutions are identified by incorporating tangible and intangible values. One of the implications is that although the approach is modified by adding different methodologies, the basic structure of the decision making process can be employed in a variety of organizations including private, public, global, local, large and small sized companies. It can also be applied to long term transformational offshoring as well as short term contractual offshore outsourcing decisions.

6.2 IMPLEMENTATION AND VALIDATION

The developed integrated decision model provides a tool for decision makers that should be an improvement over current methods by:

- Presenting multiple "good" solutions whose tradeoffs can be assessed by the decision maker to attain the best strategic decision.
- Eliminating the bias of intuition by systematically analyzing and incorporating the intangible variables in a well-established methodology.
- Adding certain important, but often overlooked factors (hidden costs, time variables and estimations) quantitatively to reduce the inconsistencies that can appear in evaluating offshore alternatives.

Yet, in order for organizations to implement this integrated model for real world situations they need to further appraise its strengths and weaknesses. By applying the developed decision approach in two cases, this study demonstrated the model's applicability and usefulness. This section will discuss the validation initiatives that were taken during the implementation of the model on the SIMA and XYZ cases. Later, different approaches will be proposed to escalate its validation to a higher level.

There is no doubt that validating a model with a significant intangible component is difficult. Unlike quantitative analysis, qualitative analysis is not a black and white approach. There are many gray areas that inject subjectivity based on experience and feelings. There is no "perfect" answer to a decision, such as offshoring, that includes many intangible variables along with tangible variables which can mostly yield contradictory solutions (e.g.. the least costly alternative is often the most risky). This research cannot and does not intend to claim that the solutions resulting from the developed integrated method are the "only" and the "perfect" solutions. The model itself is an abstraction of the actual setting. Therefore the model needs to be validated in terms of it being a good abstraction and producing good solutions. Being a good abstraction means reflecting the decision process accurately whereas good solutions represent good decisions that direct a corporation to the right offshoring strategy. The validity of the model also determines the validity of the solution. In summary, in the scope of this research, validation is defined as "being able to capture the important dimensions of an offshoring decision in a structured methodology which yields sensible results that can be trusted and respected for corporations to use in their strategic supply chain and network decisions

In XYZ's case, the results of the quantitative analysis were utilized by management to make a decision on where to locate the front-end production process and how much volume to distribute among these regions. The methodology followed in the analysis was discussed with the managers and the validity of the methodology and the results were approved. In the end of this analysis the decision makers noted that the final decision would not be based solely on the quantitative results because qualitative factors needed to be considered. Due to the sensitivity and confidentiality of the case, the actual decision process implemented by XYZ could not be pursued further.

For SIMA offshoring decisions involve selecting a supplier who can manufacture the products in such a manner to meet that product's short life cycle. Such decisions are strategic but not long term. Still the consequences of these decisions can be as severe as exiting from the product market if the supplier fails to provide the required specifications. Such a consequence has financial implications which can have major effects on this mid-size company. Over the years, SIMA's management team developed and refined a management process for selecting and managing suppliers. Normally (without applying the developed integrated decision approach) the supplier selection occurs in parallel tracks that are comprised of location, capability and experience criteria. Ideally a vendor which has a local office is preferred for communication and documentation convenience but due to the cost considerations, the company often chooses vendors that quote lower product prices even if they do not have U.S. offices. Then the capability level of a supplier is assessed by their customer portfolio. Further evaluation is performed on the selected number of suppliers by assessing their sample products, along with the technical observations of their manufacturing facilities. Small imperfections in manufacturing capabilities may be overcome by training and consultancy if the supplier is well-suited and trusted for the particular product.

During this research, SIMA managers explained that they classify the qualitative measures under the criterion "experience" since experience is their only indicator that reflects such measures. Thus, after eliminating the suppliers that do not meet the cost and technical capability standards, SIMA selects the supplier who has been involved in prior business relationships with SIMA.

Although the experience criterion is a good indicator, SIMA is not always able to find an experienced supplier for all of the products. Additionally in order to maintain price competitiveness SIMA may not always be able to choose the most experienced supplier because there may be other suppliers who offer the same product to SIMA and to the competitors of SIMA at a much lower price. On the other hand, there is a big risk in working with a new supplier because of all the unknowns. Thus, supplier selection is a big challenge involving tradeoffs and uncertainties. Although their existing supplier selection approach gained through experience has worked well for some products, there is always the chance of missing a good supplier and losing a competitive edge.

The developed integrated decision approach was attractive to SIMA because they needed a structured offshore supplier selection process which could present reliable answers by classifying and evaluating all the factors that are necessary for a successful business relationship. In this decision model, their existing criteria, such as technical capability and location could be included in the evaluation of the risks and opportunities associated with the suppliers. Moreover, the priorities of these criteria, such as insignificance of small imperfections, are incorporated by assigning weights to them. As a result, the existing intuitive evaluation of suppliers could be maintained while other factors that normally would be overlooked were captured.

When the managers and employees were introduced to the developed method, they confirmed that the two-phase approach is a systematic and rigorous approach for analyzing both the quantitative and qualitative variables. During the implementation of the ANP phase, they confirmed that most of the results of ANP comply with their intuition while providing a clearer view of the magnitude of the associated intangible factors. There were some counterintuitive results, too. For instance the risk level of the supplier "Function" was higher than what they had expected. Normally a U.S. based company would be expected to have lower levels of risks. However when the criteria under risks were articulated, the results were felt to be realistic.

The results of the case application were confirmed by SIMA. SIMA chose the Taiwanese supplier (Amberson) for manufacturing of HDMI switchers and in the first phase of the product life cycle, they encountered success in developing and launching the products in the market. However, as the market became more competitive, the cost objective gained utmost priority forcing SIMA to shift production to the lower cost supplier. According to the results, the model suggests that SIMA negotiate with Amberson to lower the price. SIMA indicated that this suggestion would be feasible if the demand volumes remain high in the maturity phase. However the market for HDMI switchers was immediately taken by larger manufacturers and that caused SIMA's market share to shrink considerably. In such a price competitive environment, negotiation with Amberson would not be feasible due to the low projected sale volumes.

The conclusions drawn from the case study were also in line with SIMA's other experiences. Interviews with the president indicated that for similar electronic products, the demand gets higher and it is better to shift production to low cost suppliers as the product goes into its mature phase. The model revealed that this was not only because of the escalating price competition but also because with the increasing demand the monetary gains of low cost suppliers start to even out the higher risks involved with those suppliers. This also became apparent after several bad experiences which caused major crisis in the company. If such a model were implemented before, conclusions would be drawn earlier saving the company these experiences. Another point of validation was the elimination of Hong Kong and the U.S.

suppliers. For a majority of product lines, SIMA has been shifting production from Hong Kong and the U.S to Taiwan and China. The results of the case study justify this shift.

A more extensive validation of the developed integrated decision model can be performed by applying the methodology in several different settings and later conducting debriefing sessions where experts can review the model's competency. The model can further be enhanced by experimenting on prototypical situations and comparing the approach with other feasible decision processes that experts use in organizations today. Furthermore, longitudinal validation lends itself to the offshoring decision to ensure that benefits realized in the short term are sustained in the long term. Face validation provides a noteworthy reference, but most important of all the eventual validation of such a developed decision making approach can be achieved as it is implemented and organizations observe the outcomes of these decisions.

6.3 CRITIQUE

Offshoring is a complicated strategic decision process involving multiple variables, multiple objectives and multiple stakeholders. The integrated decision approach developed in this research captures the multi-dimensionality by utilizing different methodologies and blends them in a decision approach to come up with the best solution alternatives. Yet, one unique solution is not given to the decision makers as "the" optimal solution. This is the strength of the approach, rather than a flaw. For such complicated decisions, one cannot expect to obtain a unique solution that is superior in terms of all of the objectives and variables incorporated in the decision. In fact, giving one unique solution may be inaccurate and be misleading in a number of ways. Instead, multiple optimal solutions should be evaluated within a sensitivity analysis framework to structure a decision that is satisfactory from every aspect. In this way, the decision maker can also see the behavior of the optimal solution with respect to the changes in the parameters and make his/her decision accordingly.

As illustrated in the empirical studies, one of the several benefits of the integrated decision approach developed in this study is its ability to eliminate unfavorable offshoring alternatives from the decision problem. For instance, in XYZ's case the Middle East is eliminated from the decision space because Middle East does not appear in none of the "good" solutions. Again for SIMA, Function and NTC are eliminated from the decision space regardless of the demand. Elimination of unfavorable alternatives simplifies the decision process by reducing the number of measures and principles the decision maker needs to consider. It also provides an opportunity to carry out more accurate decisions by collecting more precise parameters to input into the model. In XYZ's case, once the decision problem is reduced further analysis can be performed by removing some of the assumptions and including other dimensions (such as the cost of asset reduction in the U.S.) into the problem. In SIMA's case, once the decision is reduced to two alternatives, Belton and Amberson, the contractual agreement with the suppliers may be further negotiated to reach a fair compromise.

A successful start does not always mean that anticipated benefits will continue all the way through. Loss of direct interactions, distributed supply networks, and cultural differences challenge achievement of the objective. The complexity of the environment necessitates continuous monitoring of performance specifications. Any economic, sociologic, or political alteration in the world can affect the business. Hidden costs behind the operations, such as logistics and communication costs, are likely to be elevated by a global distortion. Reevaluation of the offshoring decision should be performed periodically based on industry changes. There is always a possibility that cost-saving expectations may turn into losses due to cost increases or performance reductions [120]. The developed integrated approach not only provides the tools to make a strategic offshoring decision but also can be utilized to monitor the performance of that decision after it is implemented. As actual cost values become apparent and the company gains experience with the business environment, parameters can be updated to see if the decision maintains its optimality. If the offshoring process in practice is found to be inferior, the operations can either be moved to a better location or continued at the same location by employing improvement initiatives. Since offshoring usually requires long term commitment, making improvements at the same location may be a more credible option rather than moving the operations to a different location with the risk of facing new challenges.

The decision approach is primarily developed for application in offshoring decisions to obtain the optimal location/supplier selections and product/service distributions that will enhance the competitiveness of a corporation. In addition, this decision approach can be utilized as:

- A tool to give insights on the impacts of different variables in an offshoring decision and assist management to conceptualize the process before implementing it
- A process for internal management to explain the reasons and implications of offshoring to the employees by taking account of not only the cost variables but also the intangible factors
- A basis for negotiations with suppliers and other third party vendors
- A system to control internal and external performance of the offshoring process
- A justification mechanism for upper management

The benefits of the integrated decision approach come with a price. In order to apply this decision approach, a number of techniques from various disciplines need to be understood.

Mathematical programming, multi-objective optimization and Analytic Network Process modeling are the three essential components of the decision approach. Additional tools such as ABC and LCC are also employed as needed. Moreover, data collection, model implementation and solution analysis require time and effort, making the decision process burdensome for corporations that do not have the resources or the skill sets.

A remedy that may help reduce the method's complexity is employing simpler methodologies. For instance replacing Analytic Network Process model with a simpler multi-criteria decision making method such as Simple Multi-Attribute Rating Technique (SMART) is a way to simplify the approach. In the SMART technique, a value tree which is similar to ANP's criteria network is formed by decomposing the attributes with respect to which the alternatives are assessed. The attributes need to be independent of each other and free of redundancy. Alternatives are rated for each attribute beginning from the worst (score of 0) to the best (score of 100). The attributes are weighted by a technique called "swing weights" and the total value for each alternative is determined by aggregating the rate of each alternative with the weights of attributes. The results can be normalized to obtain the normalized weights associated with each alternative.

A disadvantage of this model is its inability to capture interdependencies among attributes. The rating method can also be perceived as a disadvantage. Yet, SMART is a much simpler method that may be preferred in corporate decision making because it requires less computational time and cognitive effort. For instance in SIMA case, the major complaint was the large number of paired comparisons required for the ANP model. Moreover, in order to synthesize the results for ANP, the decision maker has to either calculate the matrix eigenvalues and aggregate them or use the software Superdecisions. In contrast, SMART analysis can easily be performed on a spreadsheet with straightforward algebraic calculations.

In this research ANP is selected as the multi-attribute decision modeling technique to quantify intangible values because the paired comparisons method is a realistic approach that can easily be comprehended by corporate decision makers. Moreover, it can capture interdependencies and is applicable to complex decisions that include multiple levels of criteria. On the other hand, different multi-attribute decision modeling techniques may be preferred depending on the requirements of the decision problem and the decision makers. If the problem does not involve interdependencies between criteria, simpler multi-attribute decision models can be utilized. If there is a limited number of criteria and the decision makers are knowledgeable about probability theory, multi-attribute utility theory may be applied. The choice of the quantification method also depends on the decision makers' preferences. In ANP, paired comparisons are employed as a basis of quantification whereas in other techniques rating, score assignment and linguistic variables are used to express the values of the intangible variables.

It is important to employ a method for which the decision makers can comfortably express their ideas. The time and resource restrictions are also important. For instance, in ANP the paired comparisons take significant time and effort, which may make the method difficult to apply in cases with time limitations (depending on whether the company is willing to commit the effort). Some decision models such as utility based methods may not be feasible to apply because of their theoretical complexity that requires extra knowledge. The accuracy of the decision model is as well critical and should be investigated.

The integrated decision approach developed in this research provides several benefits to the corporations that are in the process of deciding whether or not to go offshore, where to transfer operation and in what proportions to distribute production and services among these locations. The decision model utilizes multiple analytical tools and can be applied to real life cases as illustrated in the empirical studies. However, its applicability and usefulness may not be persuasive enough for corporate managers to adapt the approach as a decision support tool instead of continuing with the traditional cost analysis. Additional effort is needed to introduce its effectiveness over time.

6.4 FUTURE RESEARCH DIRECTIONS

Uncertainty is inevitable in real life. By the same token, both quantitative and qualitative variables in offshoring decisions embrace uncertainty. Intuition, expert evaluation, political factors and other extraneous influences are also intrinsically probabilistic. Thus, uncertainty is unavoidable for offshoring decisions where the present values are based on an estimate of the future economic structure and the utilities are determined subjectively. As an extension of this research, methods may be developed to handle the uncertainty by including elements of uncertainty and solving the algorithms in a non-deterministic environment.

In a multi-criteria decision problem there are two elements of uncertainty:

1- *Inherent uncertainty in both quantitative and qualitative decision variables.*

For instance, the present value of an investment depends on economic factors.

2- *Subjectivity of the decision maker.*

This element is especially important for the qualitative variables where the quantification is done by the expert evaluation. Experts cannot always be objective while determining the ratio scales of comparison parameters. The probabilistic nature arising from such subjectivity should be considered in the decision making model.

Inherent uncertainty in quantitative variables can be included in the decision approach in the mathematical modeling part whereas uncertainty in the qualitative variables can be represented in the multi-criteria decision modeling part. One way to handle the uncertainty in quantitative variables is to apply the fuzzy set theory while estimating costs via activity based costing [121]. Utilizing the fuzzy ABC method enables the decision maker to see the best and worst case results by calculating cost estimates based on smallest possible, most promising and largest possible parameters. By solving the decision model with such estimates, the sensitivity of the decision to different scenarios can be analyzed.

Additionally, the uncertainty in the quantitative variables may be incorporated by implementing a stochastic mathematical model instead of a deterministic one. In general, stochastic programs are generalization of deterministic mathematical programs in which some uncontrollable data are not known with certainty [122]. In stochastic models variables involving uncertainty are expressed with probability distributions rather than distinct numbers. A stochastic programming model is formulated in terms of decision stages. First, decisions are taken without full information, in the latter stages corrective action is taken with full information which is called recourse. The inherent uncertainty in the qualitative variables can also be handled by employing probability information into the multi-criteria method.

In offshoring decisions, the decision maker's attitude directly affects the quantification of qualitative variables, and therefore determines the numerical values of the intangible criteria (which are risks and opportunities) associated with the alternatives. One way to handle the subjectivity of the decision maker is to multiply the decision maker's judgments (the paired comparisons) with weights that represent the attitude of the decision maker. Yager [123, 124, 125, 126] investigated the uncertainty elements and proposed methods that allow the deliberation of the uncertainty factors in decision making problems. In these methods, the decision maker's attitude is included in the models based on the use of the ordered weighted averaging (OWA) operator. By Yager's definition; an OWA operator of dimension *n* is a mapping $F : \Re^n \rightarrow \Re$ which has an associated weighting vector:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ w_n \end{bmatrix} \text{ where } w_j \in [0,1] \text{ and } \sum_{j=1}^{n} w_j = 1 \qquad (6\text{-}1)$$

$$F(a_1, a_2, ..., a_n) = \sum_{j=1}^{n} w_j b_j \text{ with } b_j \text{ being the } j^{th} \text{ largest of the } a_i. \qquad (6\text{-}2)$$

The weights define the optimism level of the decision maker. By integrating event probabilities with the OWA operator, a decision can be made based on both the probabilistic nature of the problem and the decision maker's preferences. Liu and Da [127] also extends Yager's work by deriving OWA operators from decision maker's optimism degree.

The modeling of offshoring decisions can be expanded in various ways. In this research the integrated decision making approach is applied to offshoring decisions involving mainly manufacturing activities. On the other hand, with developing communication technologies, more companies are inclined towards offshoring services in the form of business process and information technology outsourcing. The span of outsourced services varies immensely from tasks as simple as call centers to as complex as software development and product design. The cost structure and the criteria for making offshoring decisions in the service sector differ from the ones in the manufacturing sector. For instance, service operations may encompass additional implementation and management cost elements that have significant impact on the total cost. Furthermore, the cost analysis cannot be performed on product basis, rather it should be based on activities and processes. The criteria, limitations and priorities also differ and should be incorporated in the multi-criteria analysis. The offshoring decisions for the service sector can be evaluated on the foundations of the developed integrated model, however a future research initiative is necessary to analyze the differences between manufacturing and service offshoring and adapt the developed integrated model.

Offshore outsourcing is an extensive area that includes many issues that are subject to further research. Among the plausible operations, determining the right application to offshore outsourcing is also essential. The products or functions that have already reached maturity are less risky choices. These applications do not need big changes and can be managed without the need for direct control. Complexity is also important. More effort is needed to outsource complex functions. The possibility of failure escalates as the complexity of the job intensifies. Operations will need close monitoring, which in turn will add to the transaction and communication costs. Companies may face unsatisfactory negative results if the decision of which operations to offshoring is not made properly.

Offshoring may also be done in different formats. Linder divides offshore outsourcing into two categories, conventional and transformational [128]. Conventional outsourcing is transferring non-core, simple interfaces to another entity whereas transformational outsourcing is outsourcing to achieve a rapid, sustainable, step-change improvement in enterprise-level performance. Conventional outsourcing has little flexibility and involves well-understood processes whereas transformational outsourcing involves outsourcing ongoing services that are critical to the performance of the business. Transformational outsourcing is operationalized by partnering or investments (do it yourself, merge/acquire or joint venture). In order find the most appropriate form of offshore outsourcing, a company needs to consider several factors such as the company's core competences, industry environment, available options and future goals.

Although these issues (determining the right process and format for offshoring) are broadly discussed in literature, the number of comprehensive analytical decision models that can systematical support corporate offshoring decisions is scarce. As globalization accelerates, there will be more offshoring practices, both successful and unsuccessful, and the necessity of applying analytical tools for decision making will become more apparent.

6.5 SUMMARY

Traditional methodologies for offshoring decisions are focused on benefit-cost analyses, often incorporating mathematical programming to determine optimal location selection and operational distribution. However a strategic decision does not lead to success if made only from a financial standpoint, excluding potential implications for both the corporation and the communities.

In this research the traditional decision making approach is expanded by introducing:

- Multi-attribute assessment techniques to incorporate intangible variables that are important for the welfare of all of the stakeholders.
- Engineering economic tools to realize accurate cost estimations and comprehensive analysis of the decision over a long time horizon.

- Tradeoff analysis to evaluate both tangible and intangible variables for decisions that are favorable with respect to every aspect of the decision

This research contributes to the literature by developing a novel integrated analytical decision approach by embracing the strengths of multiple tools to incorporate intangible and tangible factors with continuous and discrete variables. This decision approach is also customized to offshoring decisions by exploring the dimensions of offshoring and including the necessary elements for successful global practices. The application of this integrated decision approach should not only provide sustainable and better offshoring decisions for the well being of corporations but also serve as a platform to promote understanding of the key components that make a prosperous global business structure.

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