The Analytic Network Process Applied in Supply Chain Decisions, in Ethics, and in World Peace

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The Analytic Hierarchy/Network Process which was developed by Dr. Thomas Saaty "has revolutionized how we resolve complex decision problems" (INFORMS, 2008). The Analytic Network Process (ANP) is applied herein in the context of supply chain decision making; then as a tool to bridge the separation thesis between business and ethics and show that ethical decision and business decisions are interrelated and can and should be jointly considered; and finally to guide the G-2 powers in their efforts to improve relations.

In the first supply chain model a Metrics Arrow of relevant performance metrics that follow the temporal flow of the product is presented and used to select a third party logistics provider. The ANP model also provides managerial insight into the interdependencies of the performance metrics. The second model deals with selecting which green supply chain initiative a company should implement. A generalized framework is developed and then customized and applied in a specific case study of a TV audio video producer's supply chain.

Two ethics cases are analyzed in the first chapter on ethics to demonstrate the benefits of using a rigorous prioritization process, the ANP, to make ethical decisions. This chapter is intended to act as introduction of the ANP to the ethics community and focuses on the benefits of using the ANP. Next, a complex model that uses a stakeholder theory approach is used to address the ethical issues of hydraulic fracturing. The benefits to the natural gas industry to participate in an integrative stakeholder approach are demonstrated.

As another demonstration of the ANP a complex decision with a direct influence on peace and stability in the world is the relationship between the two superpowers the People's Republic of China and the United States is analyzed. As improvements have been made in the relationship between the two countries there are critical decisions that must be faced in the near future. This model suggests which of five initiatives if addressed will be most beneficial to both countries. In the final chapter the main findings are summarized and future research is suggested.

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1.0 INTRODUCTION

The desire to develop a method to prioritize and rank alternatives with a valid mathematical basis led Dr. Thomas Saaty to develop the Analytic Hierarchy Process (AHP) (Saaty, 1980; 1996a; Saaty, 2005; Vargas, 2011). The AHP is designed to take advantage of humans' ability to decompose problems into meaningful parts, prioritize the individual parts, and then synthesize the priorities to make a decision (Vargas, 2011). Not only would such a method be able to combine data but, more importantly, deal with intangibles. Intangibles, according to Saaty (Saaty, 2012),

> "can be non-physical influences that are passing and very transient. No conceivable instrument can be devised to measure them, other than the mind itself that must also interpret their meaning, Intangibles leave an impact on our minds, which are biologically endowed to respond to influences."

One of the first applications of the AHP was the Sudan Transport Study (Saaty, 1977b) which won an award from the Institute of Management Sciences, College on the Practice of Management Science. The AHP has subsequently been applied in academic and industry setting (Sipahi & Timor, 2010). Due to computational limitations the general form of the AHP, the Analytic Network Process (ANP), while developed in the late 1970's and early 1980's, was not available to everyday decision makers until the 1990's. An AHP model is a specific subset of an ANP model (Vargas, 2011). The advantage of an ANP model is the ability to handle dependence and feedback among the criteria and alternatives. Furthermore multiple networks like benefits, opportunities, costs, and risks can be synthesized together. This flexible yet rigorous decision making method has been applied across a diverse array of fields including; conflict resolution, planning, resource allocation, engineering, government, manufacturing, and personal decision (Vaidya & Kumar, 2006). According to the 2008 INFORMS Impact Prize award letter, the AHP/ANP "has revolutionized how we resolve complex decision problems" (INFORMS, 2008). In the field of multi-criteria decision making the AHP/ANP is now the most published multi-criteria decision method (Wallenius et al., 2008).

Another field of research in Operations Management that has experienced a great deal of growth and attention is supply chain management (SCM). While the issues addressed in supply chain management have been addressed for centuries, the term began to receive its identity in the 1980's (Gripsrud et al., 2006). . SCM refers to movement of goods from their origin as raw materials until their final consumption (Harland, 1996). SCM research has been developed extensively over the past 30 years; and with an increased interest in gaining value from products after final consumption SCM has been extended to include reverse logistics (Carter & Ellram, 1998). SCM has become an even more complex and integrated system with the advent of global supply chains. With advances in research and technology the metrics and data used to make decisions are also more complex. Ultimately the decision making responsibilities are left to management within organizations within varying levels of the supply chain. Many decision making tools have been developed to help managers make better decision and give companies a competitive edge.

The subsequent two chapters focus specifically on the application of the AHP/ANP within the context of SCM: first, in the context of using the interaction of performance metrics by following the temporal flow of a product through the supply chain to select a third party logistics provider; next, the challenge of incorporating sustainability and greening initiatives into the context of SCM is addressed, ethical cases are analyzed to advocate incorporating ethical decision making into business decisions, furthermore the ANP is applied in the context of the PRC an US relations, and finally the main findings are summarized and future work is proposed.

1.1 THIRD PARTY LOGISTICS PROVIDER SELECTION

This research was motivated by the logistics needs of a multinational pharmaceutical company, which has 99,000 employees worldwide. The headquarters of its consumer healthcare division is located in Pittsburgh, Pennsylvania. The firm is the world's second largest over-the-counter health products provider and is ranked second globally in sales of oral care products. The supply chain of the firm consists of suppliers, manufacturers, warehouses and retail distribution centers. These manufacturers make several dozen brands and over a thousand stock-keeping units (SKUs), totaling four billion packs each year.

The healthcare distribution network of the firm has existed for many years. However, some leases on Regional Distribution Centers were due for renewal. This presents the company an opportunity for contracting out to third-party logistics providers (3PL).

This chapter focuses on 3PL performance measures that can be organized in a sequential format, or logical flow, beginning after the production stage and continuing through delivery. Every organization and management system requires measures and standards to drive performance and achieve continuous improvement. Performance metrics (PMs) are the measures of an organization's activities that support the needs of customers, employees and stakeholders. They are used to assess the health of a project, a venture or a business unit and often comprise important criteria such as length of time, cost, flexibility, scope and quality. The evaluation of the supply chain flow in terms of information, products and funds is organized into the Metrics Arrow.

The Metrics Arrow is used to organize and illustrate the PMs according to the temporal flow of the product and take advantage of the Analytic Network Process (ANP) to capture the interrelated influences among the PMs and derive weightings to select a 3PL. The ANP not only provides the weights for the importance of each PM but also provides managerial insight into the relative impact of each metric as well as warning signals or trigger points within the network of PMs. The very act of identifying metrics and then measuring them through pairwise comparisons provide managers with information about relationships and causes of problems that may occur throughout the 3PL process. Using the ANP allows the decision makers to capture important interdependencies to avoid biasing a 3PL to perform well on specific criteria at the cost of other criteria influenced by the trade-offs. The complexity of the ANP model allows managers to capture the influence and interactions of each performance metric (PM) on an organization's overall performance. As input is sought from across the organization, the influence and interactions among PMs are identified and weighted. Those weights allow management to select the 3PL that will provide the competitive edge sought after by considering outsourcing logistics.

1.2 GREEN SUPPLY CHAIN MANAGEMENT

The consideration of environmental issues has a tremendous impact on the development and operations of a supply chain. However, green supply chain management (GSCM) is an emerging research area, thus there are limited conceptual models on this important subject. In particular there are a limited number of models that consider the effect of environmental directives (ED) on greening a supply chain. In consideration of the significance of ED on the performance of a supply chain, this work develops a conceptual model for the successful greening of a supply chain that also takes into consideration environmental directives such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of the use of certain Hazardous Substances (RoHS). Various similar terminologies have emerged to describe GSCM. Some authors (Handfield et al., 2005) state that environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials. More widely they define GSCM as the formal system that integrates strategic, functional and operational procedures and processes for employee training and for monitoring, and summarizing and reporting environmental supply chain management information to stakeholders of the firm.

The present work proposes a multi-criteria based approach for supporting environmental sustainability analysis of the entire supply chain. The approach is based on the integration of

Environmental Performance Evaluation (EPE) with a multi-criteria tool based on the well known Analytic Network Process (ANP) methodology and a BOCR Analysis (Benefits, Opportunities, Costs and Risks). The aim of this work is to develop the ANP/BOCR model through the definition of EPE to identify significant factors on environmental aspects; in this way, the ANP/BOCR model supplies valuable information about critical factors/areas throughout the whole supply chain in order to reduce its environmental impact. This study focuses on the supply chain of a typical cathode ray tube of computers and televisions.

The chapter is organized as follows: in section 2, a brief review about the policies and legislation on Waste Electrical and Electronic Equipment is described; section 3, the theory and conceptual model is explained. Then, in section 4, the proposed approach is applied in a specific case study. Finally in section 5, conclusions and results are analyzed. Based on the results of this model in the specific case study of the TV & audio and video supply chain the manufacturer should install solar panels. The general model and criteria can be adapted and applied to other supply chains and to include different alternatives. The model is an integrated approach to evaluate the environmental sustainability of a supply chain.

1.3 THE ANP AND ETHICAL DECISION MAKING

One might ask, “what does ethical decision making have to do with SCM?” The first reason stems back to the training and sensitivity toward ethical concerns possessed by the early founders of operations research. The second reason is related to the Separation Thesis: that business decision making has nothing to do with ethics and ethical decision making has nothing to do with business (Freeman, 1994; Harris, 2008). The subsequent chapters do not directly deal with issues in supply chain management but lay a foundation for future research that puts the AHP/ANP into the research arena of ethical decision making. Currently there are two papers in the ethics literature that address the use of the AHP in ethical decision making. One response to this discrepancy is that operations research strayed from its foundation and in doing so made itself less relevant to ethical decision making; Ackoff argues this passionately in his paper entitled “The Future of OR is Past” (Ackoff, 1979). Another possibility is that many perceive ethical decision making as philosophical and operations research as technical, leaving little room for common ground. It may also be the case that most ethical decision making practitioners lack training in analytic methods, and from outside appearances, do not see how the two disciplines would connect.

Chapters 4 and 5 are targeted to the business ethics community to make a case for the incorporation of the AHP/ANP into ethical decision making. This approach addresses one side of the separation thesis that business has nothing to do with ethical decision making. As a subsequent project which is addressed in more detail in the final chapter regarding future work I propose addressing the other side of the Separation Thesis and demonstrate the advantages of using the ANP to incorporate ethical decision making into SCM. Chapter 4 lays the groundwork for incorporating the AHP into ethical decision making and demonstrates the potential benefits via two case studies.

In the first example, Badaracco (1997, p. 51) mentions the need to go beyond listing ethical considerations to somehow prioritize and weight those considerations. The example is of a new employee, Steve Lewis, who is faced with an ethical dilemma where he is asked to serve on a team to present to a particular company. This decision might seem simple enough, but Steve learns he is asked to attend the presentation only because his is an African-American and the executive client they are presenting to is also an African-American. Steve’s parents had been active in the civil rights movement and he is concerned about serving only as an “African-American potted plant.” Steve also feels obligated to fulfill his obligations to his company, his mentor, his career, his church teachings, and his race. An AHP model is built around the issues Badaracco describes that Steve must address. The sample weightings and results are presented. This example concludes with a discussion of the benefits that the AHP provides when addressing this type of ethical decision.

In the second example, the AHP is applied to the Kardell case (Brooks, 2010, pp. 224-226), where a plant manager must decide whether or not to replace current processing equipment with a new closed cycle process to prevent potential contaminants from getting into the river that the plant is built on.

The information from the Kardell case will be used to illustrate how a stakeholder hierarchy can be built and how to use the hierarchy to establish priorities among stakeholders and among decision alternatives. This example is a natural extension of the prioritization process used in example 1, but with two important additions. First, this example is a vehicle for showing how to build a stakeholder hierarchy, which allows the decision maker to define more specific stakeholder groups without adding significantly to the computational burden. The advantage of hierarchies in general is that they allow a system to be analyzed in smaller chunks while using the hierarchy to preserve the structure of the whole system.

The second feature in this example that is different from the previous example is that this is a group decision in contrast with the personal decision faced by Steve Lewis. In the Steve Lewis example, the priorities were unique to Steve. The challenges for Steve were to recognize and establish his priorities. In the Kardell case, the decision making process includes a variety of different interest groups which means that different individuals and groups may have incredibly different priorities that are held very strongly. In situations with strong and conflicting priorities, a decision process called Scenario Planning can be very helpful (De Geus, 1997; Schwartz, 1991; Senge, 1990).

With two examples to make the initial argument that an ethical decision maker can benefit from using the AHP, a literature review is presented to demonstrate how the ANP naturally incorporates ethical issues. Multiple tables are provided as a reference for decision makers interested in incorporating ethical issues into their decision models.

1.4 FRACKING

Hydraulic fracturing, “fracking” is a current topic in the energy industry that is laden with ethical issues; there are many nontrivial benefits that fracking provides which are surrounded by a great deal of uncertainty and potential risk. Energy consumption in the United States of America is not only increasing but is also tagged with additional stipulations about how the energy is produced and the potential long term effects on the environment. As environmental and ethical concerns enter the decision the need for methods to compare and combine these concerns arises. In the context of the previous two cases it can be argued that the ANP is an effective tool to address complex decisions. In particular the ANP can be used to capture the dependencies and interdependencies of the multiple stakeholders. The ANP model captures and measures the economic, environmental and ethical concerns with respect to their impact on the stakeholders.

The fracking case is similar in many ways to the Kardell case. The fundamental ethical issue is the same: the conflict between providing a useful product involving synthetic chemicals into the marketplace while taking responsibility for unanticipated externalities that may cause health harm to innocent victims. Because of this similarity, stakeholder analysis would be a good starting point of analysis. Despite the similarities, there are also significant differences between the Kardell and the fracking examples. The stakes are much higher in the fracking case. Fracking is an industry-wide practice with a very large customer base, huge economic impact, large numbers of citizens with risks from direct exposure, and even more citizens that could suffer from indirect exposure that could occur hundreds of miles away.

The degree of uncertainty is also much higher in the fracking case than in the Kardell case, where much was known. First of all, there is uncertainty about how much fracking chemicals are making their way into local aquifers, if at all. The second source of uncertainty is about the nature of the chemicals used in fracking. The lists and mixtures of synthetic chemicals are protected by trade secret laws. Another source of uncertainty is in the severity of the harm, if fracking chemicals are getting into aquifers. Assessing the severity of health harm is problematic since the exact nature of many of the synthetic chemicals used in fracking is unknown. It is essential to emphasize that all this speculation and circumstantial evidence does not prove that fracking is harmful; it merely points to a need for prudence in dealing with an issue where little is known about the probabilities of harm and the severity of harm.

The issues of likelihood and severity must both be dealt with in decisions made in the presence of uncertainty. Homogeneous clustering is employed to build risk profiles to measure the expected risks and the expected opportunities. The results of the model suggest that the while the integration approach is the most expensive, it is also the least risky and provides the most benefits and opportunities for each stakeholder.

1.5 WORLD PEACE: PRC AND US RELATIONS

One of Dr. Saaty's greatest desires is to see that world peace, or at least peace between different countries, be brought about through nonviolent means. During the last fifty years the economic, social and political relationships between the People's Republic of China (PRC) and the United States of America (US) have progressed along a hilly journey of ups and downs. In the last few years the PRC's economy has continued to grow dramatically despite an overall global downturn. This recent double digit growth along with the steady growth experienced over the last few decades has led the PRC to become the second largest economy in the world. The PRC has also continued to develop its military (Art, 2010; Evans, 2011; He & Feng, 2008); according to Art (2010) the PRC is also determined to climb the technological ladder. Because of this growth and investment, the US and the PRC have been referred to as a G-2 of superpower (Pardo, 2009). Over the last few decades the US had been able to unilaterally decide monetary, trade, and military policies (Breslin, 2009; Evans, 2011). However, with continued budget deficits (Nederveen Pieterse, 2008), a wounded military (Art, 2010), and the efforts of other nations to collaborate together (Friedberg, 2002; He & Feng, 2008), the US hegemony is weakening.

Over the last 100 years, when emerging economies have wished to flex their muscles and the dominant economy has been unwilling to concede its place at the top, the primary mode of resolution has been conflict, armed conflict in particular (Copeland, 2000). While conflict between the two is inevitable, it is important to clarify what type of conflict is inevitable. According to Follet (Graham, 1995), conflict is nothing more than differences; and "as conflict – difference – is here in the world, as we cannot avoid it, we should I think use it" (Graham, 1995, p.67). By no means should the term conflict within this paper be interpreted as any form of armed conflict. To the contrary, the act of addressing the differences and improving relations between the PRC and US can serve as a stabilizing force against armed conflict, particularly with surrounding nations.

While a great deal of progress has been made, the G-2 relationship is still considered by many to be very fragile (Ross, 1997; Shambaugh, 2000; Wu, 2009). With significant economic, political, and security issues at stake it is crucial that the efforts to continue to strengthen relations are prioritized and implemented. The resources that are available to improve relations are scarce and should be allotted wisely.

A rigorous prioritization process is essential to deal with these issues that are more “diffuse and illusive” than ever before (Shambaugh, 2000, p. 113), and to reduce what Evans describes as a “potential for mistakes and miscalculations” (Evans, 2011, p. 113) which could wreak havoc on many fronts. While Friedberg laments that scholars and analysts lack “powerful predictive tools” (Friedberg, 2005, p. 8) to predict a state of relations in five years, both the Analytic Network Process (ANP) and a specific subset of the ANP called the Analytic Hierarchy Process (AHP) have successfully been used to address complex economic and political decisions (Saaty & Zoffer 2011; Saaty & Vargas, 2001; Tarbell & Saaty, 1980). The ANP is used here as the decision framework to prioritize the efforts and initiatives in the G-2 relationship. After reviewing the relevant literature, the model is presented with an explanation of the criteria and alternatives. The results with a detailed sensitivity analysis present additional insight into the suggested solutions and then the overall findings are summarized in the conclusion.

1.6 CONCLUSION AND FUTURE WORK

The key findings and results from each chapter are summarized to emphasize the advantages of using the ANP to select a third party logistics provider, to select which green supply chain alternative to implement, to measure and combine the relative importance of ethical issues in ethical decision making, to incorporate ethical decision making and stakeholder theory in decision making, and to improve PRC and US relations. Three extensions to the current work include extending the Steve Lewis case in chapter 4 as a complex ANP model that include economic, social, political and religious clusters, using stakeholder theory in supply chain decision making, and using the results from the US PRC relations model to build a subsequent model to determine how to implement the preferred alternative.

2.0 SELECTION OF A 3RD PARTY LOGISTICS PROVIDER: CAPTURING THE INTERACTION AND INFLUENCE OF PERFORMANCE METRICS WITH THE ANP

This research was motivated by the logistics needs of a multinational pharmaceutical company, which has 99,000 employees worldwide. The headquarters of its consumer healthcare division is located in Pittsburgh, Pennsylvania. It is one of the world's leading research-based pharmaceutical companies, with the goal of reaching out and improving the quality of human life. The firm is the world's second largest over-the-counter health products provider and is ranked second globally in sales of oral care products. The supply chain of the firm consists of suppliers, manufacturers, warehouses, and retail distribution centers. Currently, products are produced by four US manufacturing plants and several contractors around the world. These manufacturers make several dozen brands and over a thousand SKUs, totaling four billion packs each year. Together with two co-packing facilities, they form the supplier network of the firm’s consumer healthcare products. The supply chain has four regional distribution centers to ship its products to more than 400 retail accounts, each of which has multiple customer distribution centers. In all, it covers 30,000 retail stores. Annually, more than 80,000 customer orders are handled and millions of cases of products are shipped.

The healthcare distribution network of the firm has existed for many years. However, some leases on Regional Distribution Centers were due for renewal. This presents the company an opportunity for contracting out to third-party logistics providers. Due to ever-increasing fuel costs, the firm’s distribution function is under constant pressure to become more efficient but still remain responsive to customer needs. The firm has seriously considered the 3PL option, because in the last decade the headline events for supply chains were how to manage the excessive fuel cost. High fuel prices raised the firm’s logistics costs to a record-high of $40 million. Executives believe using 3PL could help cut back the costs. In addition, contracting out noncore business such as the logistics function would also improve core business focus. The 3PLs are usually more logistics-competent and efficient; outsourcing the logistics function to a 3PL allows a firm to access to a wider variety of distribution facilities in terms of location and size choice. Therefore, an overhaul of the supply chain performance metrics is expected by the management team in order to more effectively determine which performance metrics should be used to select a 3PL.

The performance of any organization can be improved through a streamlined focus on its core competencies while outsourcing the supplementary areas of the business. Logistics is a business function within a supply chain that can often be outsourced to a third party logistics provider (3PL) who has a core competency of logistics. Once an organization has decided that it can improve its performance through outsourcing logistics, the organization must then select a 3PL that shares common goals and is capable of achieving desired service levels so as to provide the greatest improvements in the organization's productivity and effectiveness. This paper focuses on 3PL performance measures that can be organized in a sequential format, or logical flow, beginning after the production stage and continuing through delivery. The evaluation of the supply chain flow in terms of information, products and funds is organized into the Metrics Arrow, which will be discussed in greater detail below.

Every organization and management system requires measures and standards in order to drive performance and achieve continuous improvement. Measurement alone is insufficient to facilitate improvement; a certain standard level of performance must be demanded, and resources must be prioritized to return the most value and indeed improve performance. Performance metrics (PMs) are the measures of an organization's activities that support the needs of customers, employees, and stakeholders. They are used to assess the health of a project, a venture, or a business unit; and often comprise important criteria such as length of time, cost, flexibility, scope, and quality. In this paper we present the Metrics Arrow to illustrate and organize the PMs according to the temporal flow of the product and take advantage of the Analytic Network Process (ANP) to capture the interrelated influences among the PMs and derive weightings to select a 3PL. ANP not only provides the weights for the importance of each PM, but also provides managerial insight into the relative impact of each metric as well as warning signals or trigger points within the network of PMs. Due to the need for confidentiality, in this paper we will present a fictitious but representative scenario to illustrate the procedure of choosing the best 3PL that is capable of achieving the greatest improvements within an organization's PMs.

The organization of this chapter is as follows. In section 2, we review the performance metrics related to the supply chain management performance evaluation, the use of 3rd party logistic providers within the supply chain, and the Analytic Network Process. The development of the Metrics Arrow (flow network) and ANP model is presented in Section 3. Section 4 focuses on the sensitivity analysis of the network. Final remarks and conclusions are given in Section 5.

2.1 LITERATURE REVIEW

Performance Metrics can be employed within every division of an organization. Our use of PMs has specifically focused on supply chain management (SCM). The logistics involved in the production of a product can be measured throughout the product lifecycle process, from obtaining raw materials to final delivery (Agarwal et al., 2006). Researchers such as Beamon (1999), Gunasekaran et al. (2001,2004), Hervani et al. (2005), Kleijnen and Smits (2003), Lai et al. (2002), and Melnyk et al. (2004), have studied the use of performance metrics within the supply chain. Most of their models support the use of both quantitative and qualitative measures as well as financial and non-financial measures.

2.1.1 Performance metrics and evaluation

Brewer and Speh (2000) pointed out that some of the challenges that are unique to the supply chain include the trade-off between product standardization or customization, and product cycle time. While Hervani et al. (2005) maintain the multiple levels or tiers in a supply chain are the main obstacles of establishing a universal PM, Kleijnen and Smits (2003) and Shepherd and Gunter (2006) believe that the difficulties lie in the competition between external and internal motivators. According to Brewer and Speh (2000) and Gunasekaran et al. (2004), organizational managers have expressed that they are not concerned with the generalizability of a particular model but with what works within a given company, and that the model must be balanced with a controllable number of metrics. To focus on the managerial concerns, Gunasekaran et al. (2001) have divided the organization into different hierarchical levels including strategic, tactical, and operational focuses. Other common methods of addressing managerial concerns include: SMART, which was first used in the 1980s and incorporated non-financial measures (Cross & Lynch, 1998) and the Balanced Scorecard (BSC). The BSC is a strategic planning and management system that is widely applied in profit and nonprofit organizations to align business activities to the vision and strategy, so as to improve internal and external communications and monitor organization performance against strategic goals (Kaplan & Norton, 1992). The BSC makes use of multiple approaches to balance competing objectives. Brewer and Speh (2000) show that the BSC encourages coordination and focused efforts that can provide real benefits when both long-term and short-term motives are rewarded.

2.1.2 Determining the performance metrics

Organizations are increasingly driven to focus on core competencies (Brewer & Speh, 2000). It can be challenging to identify and prioritize core competencies when the development of PMs does not allow for the unique weighting of specific performance metrics. A drawback of extant performance measurement systems is that many PMs are strictly driven by predetermined requirements for International Organization for Standardization (ISO) ratings (Hervani et al., 2005). A PM model should be flexible, balanced, able to incorporate additional “interactions” among the PMs, and able to specifically “weight” PMs (Beamon, 1998; Bhagwat & Sharma, 2007; Gunasekaran et al., 2001; Jharkharia & Shankar, 2007; Marasco, 2008).

Bhagwat and Sharma (2007) began with the traditional BSC approach; however in order to deal with the issues of balance, interactions, and weighting, they settled with the Analytic Hierarchy Process (AHP) to weigh and to prioritize the different performance metrics. AHP uses a system of pairwise comparisons to measure the importance of the components of the structure, and to prioritize the alternatives in the decision. AHP has been used to weight PMs in other models, as seen in (Agarwal et al., 2006; Sarkis, 2003; Yurdakul, 2003). More recently, Hervani et al. (2005) and Vachon and Klassen (2006) took interest in Green Supply Chain Management, and suggest a multi-criteria hierarchical PMs could be applied to build an evaluation model for their systems.

2.1.3 Third party logistics

Organizations may choose to outsource their distribution function in order to focus on their core competencies, take advantage of cost reductions, outsource international logistics providers, increase the availability of capital, and/or develop the potential for long-term relationships (Fantasia, 1993; Hertz & Alfredsson, 2003; Marasco, 2008; Rao et al., 1993). Third Party Logistics (3PL) is a multi-billion dollar business that has become increasingly competitive on the margins (Hertz & Alfredsson, 2003). Vaidyanathan (2005) found that the use of a 3PL provider can improve customer service. Teaming with a 3PL can pose various challenges including information sharing (Jung et al., 2008), trust and reciprocity (Knemeyer & Murphy, 2005), and opportunism (Marasco, 2008). Several approaches have been used to evaluate 3PL selection. They include DEA (Zhou et al., 2008), ANP (Jharkharia & Shankar, 2007), a marketing perspective (Knemeyer & Murphy, 2004), and an IT-based framework (Vaidyanathan, 2005). In section 3 we discuss how ANP can be used to organize the 3PL selection decision according to the temporal flow of the product.

2.1.4 The Analytic Network Process

The Analytic Network Process (ANP) is a more general form of the AHP used in multi-criteria decision analysis to analyze complex decisions (Saaty, 2005). The ANP structures a decision problem into a network with decision criteria organized into relevant clusters which are weighted and compared against alternatives to decide which alternatives should be selected. The ANP is a flexible but rigorous method designed to model and prioritize decisions. The added value of using a network over a hierarchy comes from the ability to allow for and incorporate the interactions and dependencies among the criteria throughout all levels of the model which are assumed to be independent in a hierarchical model. Saaty (2005) refers to the interactions between the criteria of the network as influences. The influences among criteria are identified and then compared using the 1 to 9 scale (Saaty, 2005).

An ANP model also facilitates the incorporation of quantitative performance metrics and cost data along with qualitative information by using the 1 to 9 scale. A common example that has been used to support the use of the 1-9 scale over exact measurement is in comparing the sizes of objects (Saaty, 2005). The inconsistency index also adds to the flexibility of ANP by accounting for how decision makers make decisions and allowing for some inconsistency within the pairwise comparisons. The ANP lends itself to decisions made both by a single individual and in a group. Further discussion regarding combining group judgments including the geometric mean has been addressed by Saaty and Vargas (2007). After a network has been synthesized, the decision makers can perform sensitivity analysis to determine the robustness of a proposed decision. Potential trade-offs can be addressed through the sensitivity analysis.

2.2 MODEL

To gain the support of various departments, a five-member team consisting of a representative from forecasting, sales, inventory control, and transportation, and a supply chain manager, (who took on the role of a critical assessor), was organized to study each possible criterion. The committee was introduced to the nominal group technique (NGT) to help them present different views. The NGT involves four steps (Delbecq & Van de Ven, 1971). They are (1) *Idea generation*. Each participant silently writes down ideas/judgments for 5–10 min. (2) *Idea recording*. Collect ideas by allowing members share in round-robin fashion (one response per person each time). (3) *Ideas discussion*. (4) *Voting on ideas*. Each participant privately rates each item from no importance "0" to top priority "10." The leader then calculates the rating and records the cumulative rating for each item. The procedure limits the urge to oppose and gives the advocate a chance to make his case and not to be dismissed due to misunderstanding.

Team members' inputs are mainly from the organization's current PMs model, the literature on supply chain coordination, 3rd party logistics, and the Grocery Manufacturers Association (GMA) logistics survey. The GMA report is valued since it provides relevant and important information regarding the world's leading consumer products and the food and beverage industry. The committee decided that the evaluation criteria for 3PL would be deliberated from the perspective of the entire supply chain, including the flow of information, materials, cash, and services from suppliers through factories and warehouses to the end customer. Based on such an expectation, the committee adopted the NGT to identify a broad array of factors (28 in all) that have an effect on the achievement of the goal of the supply chain. Evaluating the performance of different 3PL at various stages of the supply chain is nontrivial. Many factors are subjective and not receptive to quantitative analysis. The dynamics among decision-makers and stakeholders add complexity and may trigger anxiety in the decision making process. Emphasis was given to the availability of data from the organization's current technology to track the PMs and to organize the data into a logical framework.

2.2.1 Framework

The framework for the design and analysis of the model was originally synthesized as a pyramid of performance measures ranked by priority levels. However, in practice a supply chain does not operate as a hierarchy, cleanly moving from one step to another. In fact, many of the metrics in the supplier/distribution system interact with each other, i.e. a focus on transportation costs may directly impact another metric such as the on-time percentages. Hence these interactions should be recognized and considered. Limited knowledge about the interactions may affect the goal one sets out to achieve. Decision makers have a tendency to focus on a small number of factors which are believed to be important. Yet, often they fail to recognize the extent of the interconnections within the system they endeavor to improve. Using the proposed ANP model, the interactions among the stages of a process can be linked, compared, and prioritized within a network of flows. The multiple stages of the product flow are used as the categories of groupings and compared to each other to capture different levels of importance or influence on the entire process.

The following categories were identified as the different stages in the flow of the 3PL process: Incoming Order Management, Transportation to Regional Distribution Center (RDC), Inventory Management, Transportation from the RDC to a Customer Distribution Center (CDC), and Delivery Management. The specific Key Performance Indicators (KPI) under each category must be applicable within the specific industry and preferably a best practice measure which involves internal and external and financial and operational metrics that are both historical and forward-looking measures. Each category is represented by a column in the Metrics Arrow (see Figure 2.1).

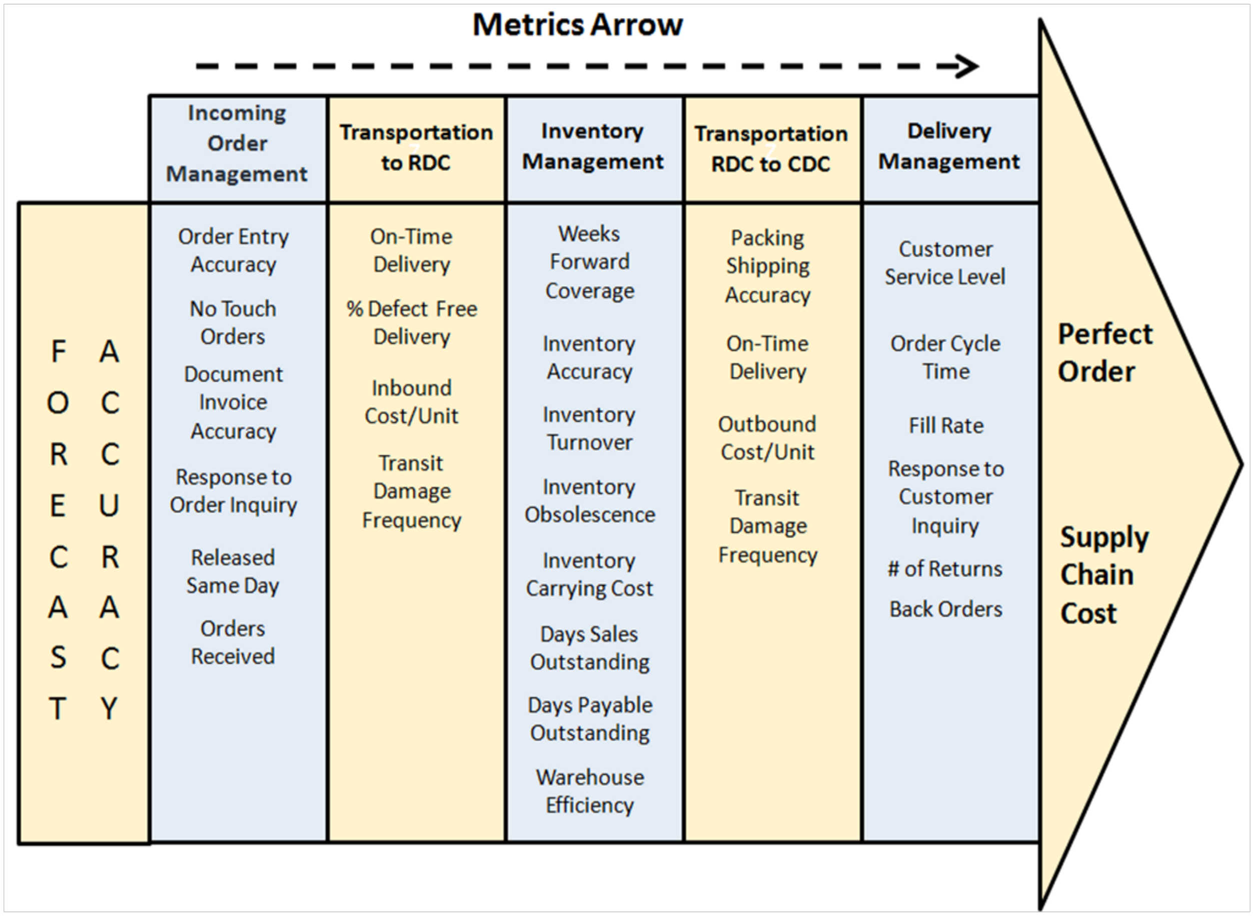

Figure 2.1 Metrics Arrow

The Metrics Arrow begins with Forecast Accuracy to emphasize the need for accurate forecasts and the downstream impact that inaccurate forecasts can cause. The specific PMs for each category are listed in the column. On the right side of the arrow are the two competing goals of a supply chain: Fulfilling a Perfect Order and reducing the Supply Chain Cost. The subsequent section defines the KPI under each category within the Metrics Arrow in chronological order.

2.2.2 Key performance indicators

2.2.2.1 Incoming order management

While a product has been monitored in the supply chain throughout production, the 3PL involvement for the studied company begins when orders are taken. The initial stages of the process are crucial to the ability of the 3PL to meet and satisfy the subsequent performance metrics.

- *Order entry accuracy*. The percent of orders that are entered accurately. This not only entails entering the right products and quantities but also ensures that the current SKUs are correctly updated within the system (Waller et al., 2006).
- *No-touch orders.* Electronic inventory systems allow for orders to be placed without the interaction of sales or customer service employees. The potential to reduce human capital costs underscores the reasons to track and improve performance under this metric, which was measured in the line count form as a percentage of the total number of lines that were on time.
- *Document invoice accuracy.* Invoice accuracy is similar to Order entry accuracy. The difference occurs in what the customer receives and pays for (Stank et al., 1997). If the invoice is not accurate the significance of the Order entry accuracy and Packing & shipping accuracy PMs is reduced. That influence is reflected in the relationships defined in the network. The preceding three PMs are compared to each other with respect to other PMs. Increased invoice accuracy has been shown to accelerate payments from customers (Stewart, 1995).
- *Response to order inquiry.* After an order has been placed, if the customer updates or changes the order, the response is framed as an order correction in the mind of the customer. In order to encourage customer satisfaction and the perception that orders are correct, it is important to rapidly respond to order inquiries.
- *Released same day.* The ability to cut down lead times and keep shipping costs low can provide a crucial competitive advantage. As long as an order is placed by a certain time each day, it can be released the same day, thus providing the consumer with increased flexibility. Measurement is as a percentage of total orders.
- *Orders received.* There is a value to track the numbers of orders received, to track ordering behavior, and look for predictive patterns or opportunities to combine orders and reduce costs. An organization may also be concerned about the 3PL's ability to handle its high demand.

2.2.2.2 Transportation to RDC

Regional Distribution Centers (RDC) are strategically located to achieve the goal of the supply chain. The RDC may host products from a single or from multiple suppliers or serve only as a location to transfer goods between transportation units. There are four metrics tracked at this stage.

- *On-time delivery.* On-time delivery is the percentage of deliveries that arrive as scheduled. The metric is simple to calculate and interpret, but useful in identifying potential problems within the delivery process. In the model, On-time delivery is compared against criteria not only within the Transport to RDC category, but also spanning multiple criteria where competing objectives such as Fill rate and number of Back orders compete against each other. This network of comparisons helps ensure that performance metrics in one stage are not sacrificed for those in another stage.

- *% defect free delivery.* Similar to the last PM, Percentage Defect Free Delivery is measured in a simple straightforward manner and compared throughout the network.
- *Inbound cost/unit.* In many instances, the transportation cost is the most expensive part of the process. Addressing the costs against other criteria poses difficult trade-offs. The trade-offs between a delivery being one day late and achieving a huge cost/unit reduction must be considered and properly addressed to balance costs and customer satisfaction.
- *Transit damage frequency.* Measuring the frequency at which products are damaged during transit encourages the 3PL to avoid cutting corners that would provide higher ratings on On-Time Deliveries and reduced transportation costs, but render the product useless upon delivery.

2.2.2.3 Inventory management

Regardless of whether inventory management is performed in house or by a 3PL, the same costs and issues apply and will ultimately contribute to or erode a company's bottom line. In this category more so than in other categories, every one of the PMs overlap and influence one another. The number of interdependent comparisons is highest within the inventory management category.

- *Weeks forward coverage.* Inventory levels must be balanced between keeping enough on hand to meet demand and accounting for uncertainty while keeping the inventory costs down. Because the model incorporates other aspects of inventory management, this metric can be balanced with the other metrics that could drive the Weeks forward coverage up or down.
- *Inventory accuracy.* In most instances it is better to list an item as out-of-stock than to commit to deliver something that is not in stock. Inventory accuracy is also crucial to controlling costs, improving turnover rates, and avoiding obsolescence.
- *Inventory turnover.* This refers to the rate at which inventory is delivered and replaced; measured in number of days. Higher turnover rates will compete with maintaining sufficient Weeks forward coverage and low Transportation Costs but also improve cash cycles.
- *Inventory obsolescence.* Obsolete inventory translates into lost sales, unnecessary carrying costs, and confounding information within the database systems.
- *Inventory carrying cost.* In many instances, the carrying cost may not be calculated directly but simply counted as a percentage of inventory costs. This cost will compete directly with transportation costs and On-Time Deliveries.
- *Days sales outstanding.* Generally, the number of days before payment is due is set within a contract; however, the time can be reduced by speeding up the delivery process, translating into a shorter cash cycle.
- *Days payable outstanding.* The length of time a 3PL is willing to wait to receive payment improves cash flow and allows the supplier to invest more in production.
- *Warehouse efficiency.* A criterion that may be difficult to compare across companies with a uniform definition, Warehouse efficiency leads to quicker delivery times and reduced handling costs.

2.2.2.4 Transportation RDC to CDC

The performance metrics in this section are almost identical to those categorized as Transportation to RDC. The primary difference is that here the 3PL is responsible for packing orders. Transportation costs must be effectively balanced with respect to location through the network comparisons.

- *Packing & shipping accuracy.* A higher percentage of orders that are packed correctly leads to reduced waste, less time spent correcting orders, and increased customer satisfaction.
- *Outbound transportation costs.* Similar to Inbound transportation costs, Outbound transportation costs are differentiated by their reference to CDC. Comparing inbound and outbound costs against each other will help reduce the bias that can occur due to the proximity of one location to another.

2.2.2.5 Delivery management

The retailers and final customers may have little information or concern regarding the prior stages of the production and logistics processes. Their ultimate concern is to get what they want and feel that they are being served well. If the 3PL does not satisfy the final customer, the remainder of the process becomes marginalized.

- *Customer service level.* While this metric may be considered as a "catch all" for the subsequent criteria, it is important to capture an overall impression of the perceived service level.
- *Order cycle time.* This begins with the placement of an order and ends with the delivery. The length of time may be affected by decisions about when to fill current back orders or sacrificing the On-time delivery rate.
- *Fill rate.* This is the percentage of orders that can be satisfied with the current inventory.
- *Response to customer inquiry.* With changes in demand, corrections to order quantities, and other requests from the customer, it is important to measure what percentage of order inquiries were able to be addressed and corrected.
- *# of returns.* The reasons for the return of an item can be difficult to accurately record, thus the weighting of this criteria is not as critical as other aspects of customer service. However, by measuring the number of returns, one can identify areas where a 3PL may be compensating for other performance metrics.
- *Back orders.* This metric may seem more appropriate with inventory management; however, there is little incentive for a 3PL to back order an item solely to reduce costs unless the marginal cost of delivery exceeds the cost to put an item on an upcoming under-filled shipment. The main impact of a back order is on the end customer and hence categorized under Delivery Management.

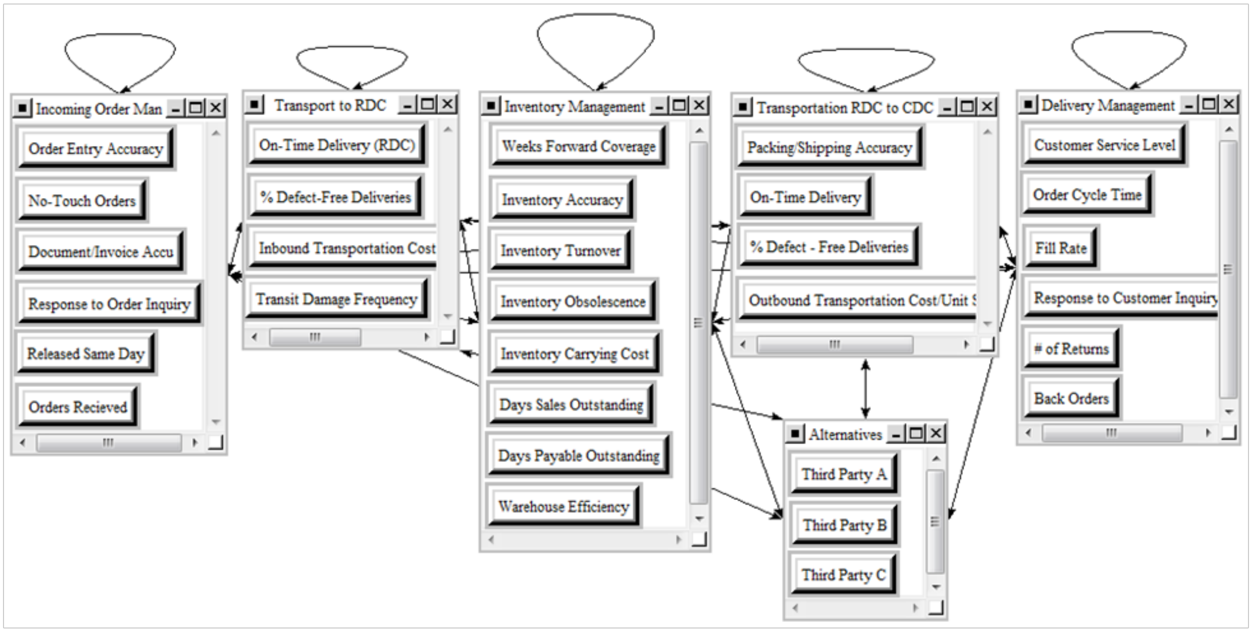

Figure 2.2 The Metrics Arrow captured as an Analytic Network Process model

2.2.3 Network connections

The capturing of relationships among the PMs in the Metrics Arrow is naturally represented as a network (see Figure 2.2). The specific PMs are related not only within each category but also across categories. While a network involves more comparisons than a hierarchy, the complexity provides four primary benefits: Redundancy, the ability to represent and capture influences, managerial insight into warning signals and trigger points, and the relative impact of each metric. Redundancy equates to the need to complete more comparisons. A criticism of AHP/ANP is the number of comparisons that must be made. An example from the Metrics Arrow will demonstrate the value of doing the comparisons with respect to different influences. Within the Delivery Management cluster, the entire set of criteria is first compared with respect to their influence on Customer service level. Next, the entire set of criteria are compared with respect to their influence on # of returns; their influence on the Fill rate, etc. Sample weights are presented in Table 2.1. While customer service remains significant overall, it is less significant when considering the influence on Fill rate (0.199 vs. 0.271). Order cycle time has a greater influence on Fill rate than the number of returns. The effects of the different weights are captured in the supermatrix; and as the supermatrix is raised to powers the influences interact with each other until the matrix converges providing the weight each criterion has on the overall network.

Table 2.1 Priority vectors from redundant comparisons

	Customer Service Level	# of Returns	Fill Rate
# of Returns	0.118	0.272	0.196
Back Orders	0.066	0.113	0.101
Customer Service Level	0.271	0.233	0.199
Fill Rate	0.148	0.117	0.227
Order Cycle Time	0.136	0.108	0.169
Response to Customer Inquiry	0.261	0.154	0.109

Management has the opportunity to seek additional insight into the interrelations among the PMs and express the need to link PMs together within the network. The ability to capture the influences across the network cannot be realized with a hierarchy. As the influences are connected and the comparisons are made, management is left in this intermediate step with insight into warning signals and trigger points among the individual steps within the process. Eliciting, identifying, and then literally seeing (Figure 3) these relationships provides diagnostic direction when management needs to fix or improve a particular PMs. The value of the diagnostic direction is underscored by seeking group input in both identifying the relationships and the weights. As the comparisons are made, not only are the relationships established, but management can identify the relative impact of each PM.

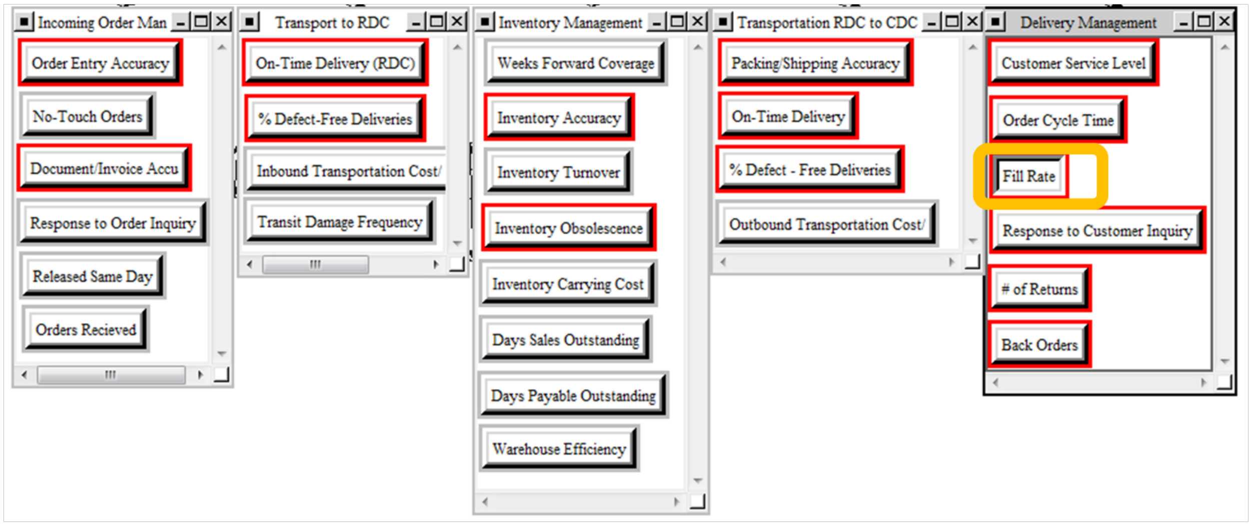

Figure 2.2 Diagnostic relationships among key performance indicators that impact 'Fill rate'

2.2.4 Ratings

The full network compares every 3PL for how well they satisfy each of the PMs in the metrics arrow. The weightings for the criteria and individual nodes are completed by members of the committee who have relevant experience and knowledge. In most cases, the entries for comparing the alternatives against each other with respect to each criterion can be calculated directly from information provided by the 3PL. For example, if one 3PL has a 97% on time delivery rate and another has an 85% on time delivery rate 12% more of the first 3PL deliveries are on time. The criteria could also be rated as "moderately better, significantly better, etc." Warehouse efficiency may be more difficult to quantify and rank solely based on information provided by the 3PL. In that case, expert opinions can be used with the 1-9 ratings. The last two examples demonstrate an advantage of the ANP decision process which is the ability to capture measurements and interactions. To further strengthen the confidence one has in the ratings of the criteria, sensitivity analysis can be performed to verify the robustness of the comparisons or suggest revisiting comparisons which may be sensitive to small changes in ratings and have an impact on the overall decision. The sensitivity analysis will be discussed in section 2.3.

The eigenvectors from each set of relationships compared were entered into the supermatrix. The entries in the supermatrix are weighted according to their respective cluster weights. In the weighted supermatrix in

Table 2.2 and Table 2.3, each column is normalized so that the entries sum to 1 to ensure the matrix is column stochastic. The weighted supermatrix is then raised to powers as shown in Table 2.3 and

Table 2.5. This step is also known as model synthesization and it is used to capture the interactions among the ratings as the weighted supermatrix converges into the limit matrix, which contains the final priority weights.

Table 2.2 Weighted supermatrix

	Alternatives			Delivery Management								Incoming Order Man			
	Third Party A	Third Party B	Third Party C	# of Returns	Back Orders	Customer Service Level	Fill Rate	Order Cycle Time	Response to Customer Inquiry	Document /Invoice Accuracy	No-Touch Orders	Order Entry Accuracy	Orders Received	Released Same Day	Response to Order Inquiry
Third Party A	0.0000	0.0000	0.0000	0.3333	0.3079	0.0989	0.2040	0.0618	0.1902	0.0244	0.1299	0.0715	0.0965	0.0852	0.1248
Third Party B	0.0000	0.0000	0.0000	0.1323	0.1694	0.0989	0.1020	0.0389	0.1902	0.1118	0.3094	0.0715	0.0531	0.1548	0.1248
Third Party C	0.0000	0.0000	0.0000	0.1050	0.0932	0.0989	0.1020	0.1472	0.1902	0.0426	0.0818	0.0358	0.0292	0.2812	0.1248
# of Returns	0.0393	0.0453	0.0199	0.0888	0.0000	0.0000	0.0888	0.0000	0.0000	0.0564	0.0000	0.0889	0.0000	0.0000	0.0000
Back Orders	0.0279	0.0275	0.0232	0.0516	0.4294	0.0000	0.0464	0.0000	0.0000	0.0169	0.0000	0.0000	0.0385	0.0000	0.0000
Customer Service Level	0.0248	0.0223	0.0325	0.0687	0.0000	0.2233	0.0240	0.0000	0.0000	0.0199	0.0000	0.0000	0.0000	0.0000	0.1878
Fill Rate	0.0242	0.0223	0.0240	0.1115	0.0000	0.0000	0.0653	0.0000	0.0000	0.0227	0.0000	0.0280	0.0769	0.0000	0.0000
Order Cycle Time	0.0365	0.0262	0.0168	0.0798	0.0000	0.0000	0.0552	0.1866	0.0000	0.0188	0.0000	0.0176	0.0192	0.0000	0.0000
Response to Customer Inquiry	0.0112	0.0203	0.0474	0.0289	0.0000	0.0000	0.0273	0.0000	0.4294	0.0000	0.0000	0.0000	0.0000	0.0000	0.0939
Document/Invoice Accuracy	0.0360	0.0456	0.0445	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0415	0.0000	0.0507	0.0000	0.0000	0.0000
No-Touch Orders	0.0153	0.0142	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0218	0.4789	0.0161	0.0000	0.0000	0.0000
Order Entry Accuracy	0.0426	0.0411	0.0471	0.0000	0.0000	0.1818	0.0000	0.0000	0.0000	0.0443	0.0000	0.0507	0.0000	0.0000	0.0000
Orders Received	0.0654	0.0621	0.0708	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0215	0.0000	0.0161	0.1643	0.0000	0.0000
Released Same Day	0.0157	0.0143	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0171	0.0000	0.0154	0.0000	0.4789	0.0000
Response to Order Inquiry	0.0252	0.0229	0.0167	0.0000	0.0000	0.0909	0.0000	0.0000	0.0000	0.0182	0.0000	0.0154	0.0000	0.0000	0.3440
Days Payable Outstanding	0.0213	0.0157	0.0187	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Days Sales Outstanding	0.0288	0.0207	0.0303	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Inventory Accuracy	0.0825	0.0979	0.0771	0.0000	0.0000	0.0000	0.0000	0.3922	0.0000	0.2122	0.0000	0.2829	0.0000	0.0000	0.0000
Inventory Carrying Cost	0.0474	0.0318	0.0779	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2829	0.0000	0.0000
Inventory Obsolescence	0.0166	0.0123	0.0284	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Inventory Turnover	0.0436	0.0401	0.0269	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0707	0.0000	0.0000	0.0000	0.0000	0.0000
Warehouse Efficiency	0.0389	0.0498	0.0353	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Weeks Forward Coverage	0.0655	0.0763	0.0499	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
% Defect-Free Deliveries	0.0319	0.0275	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Inbound Transportation Cost/ Unit	0.0673	0.0551	0.0891	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
On-Time Delivery (RDC)	0.0256	0.0333	0.0246	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1144	0.0000	0.1144	0.1144	0.0000	0.0000
Transit Damage Frequency	0.0146	0.0234	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
% Defect - Free Deliveries	0.0298	0.0274	0.0661	0.0000	0.0000	0.0000	0.0712	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
On-Time Delivery	0.0164	0.0171	0.0147	0.0000	0.0000	0.0691	0.0272	0.0433	0.0000	0.0000	0.0000	0.0000	0.0312	0.0000	0.0000
Outbound Transportation Cost/Unit	0.0731	0.0900	0.0277	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Packing/Shipping Accuracy	0.0328	0.0176	0.0436	0.0000	0.0000	0.1382	0.1866	0.1299	0.0000	0.1249	0.0000	0.1249	0.0937	0.0000	0.0000

Table 2.3 Weighted supermatrix continued

	Inventory Management								Transport to RDC				Transport CDC to RDC			
	Days Payable Outstanding	Days Sales Outstanding	Inventory Accuracy	Inventory Carrying Cost	Inventory Obsolescence	Inventory Turnover	Warehouse Efficiency	Weeks Forward Coverage	% Defect-Free Deliveries	Inbound Transportation Cost/ Unit Shipped	On-Time Delivery (RDC)	Transit Damage Frequency	% Defect - Free Deliveries	On-Time Delivery	Outbound Transportation Cost/Unit Shipped	Packing/ Shipping Accuracy
Third Party A	0.0968	0.0655	0.2090	0.2130	0.2511	0.1549	0.1911	0.0758	0.0642	0.0950	0.0596	0.0529	0.1594	0.0544	0.1958	0.0740
Third Party B	0.1937	0.1717	0.1150	0.0813	0.0889	0.1549	0.1204	0.1204	0.0214	0.2851	0.0596	0.1746	0.0608	0.1131	0.3108	0.1175
Third Party C	0.0968	0.1501	0.0633	0.0931	0.0473	0.0775	0.0758	0.1911	0.1284	0.0475	0.0596	0.0961	0.0348	0.0392	0.4934	0.0466
# of Returns	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2435	0.0000	0.0000	0.0000	0.0000
Back Orders	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Customer Service Level	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1346	0.0000	0.0000	0.0000	0.0000	0.0000
Fill Rate	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1611	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Order Cycle Time	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Response to Customer Inquiry	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Document/Invoice Accuracy	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0511	0.0000	0.0000	0.0949	0.0000	0.1094
No-Touch Orders	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0322	0.0000	0.0000	0.0000	0.0000	0.0000
Order Entry Accuracy	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0811	0.0000	0.0000	0.0949	0.0000	0.1094
Orders Received	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Released Same Day	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Response to Order Inquiry	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Days Payable Outstanding	0.6127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0723	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Days Sales Outstanding	0.0000	0.6127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0430	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Inventory Accuracy	0.0000	0.0000	0.0000	0.1903	0.0000	0.2913	0.0000	0.1079	0.0000	0.0000	0.0000	0.0000	0.4035	0.1941	0.0000	0.3767
Inventory Carrying Cost	0.0000	0.0000	0.0000	0.2692	0.0000	0.1682	0.0000	0.1522	0.0000	0.0000	0.1414	0.0000	0.0000	0.0815	0.0000	0.0000
Inventory Obsolescence	0.0000	0.0000	0.0000	0.0634	0.6127	0.0971	0.0000	0.0452	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Inventory Turnover	0.0000	0.0000	0.0000	0.0897	0.0000	0.0561	0.0000	0.0650	0.0000	0.0000	0.0000	0.0000	0.0000	0.0513	0.0000	0.0000
Warehouse Efficiency	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6127	0.0526	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Weeks Forward Coverage	0.0000	0.0000	0.6127	0.0000	0.0000	0.0000	0.0000	0.0745	0.3385	0.0000	0.1414	0.0000	0.0000	0.0000	0.0000	0.0000
% Defect-Free Deliveries	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1369	0.0000	0.0189	0.0000	0.1632	0.0000	0.0000	0.0000
Inbound Transportation Cost/ Unit Sh	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2736	0.0542	0.0000	0.0000	0.0000	0.0000	0.0000
On-Time Delivery (RDC)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0295	0.0517	0.0000	0.1322	0.0000	0.0000
Transit Damage Frequency	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0117	0.1552	0.0000	0.0000	0.0000	0.0000
% Defect - Free Deliveries	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1121	0.0000	0.0000	0.2260	0.0678	0.0564	0.0000	0.0000
On-Time Delivery	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0374	0.0000	0.1249	0.0000	0.0173	0.0182	0.0000	0.0000
Outbound Transportation Cost/Unit S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2987	0.0000	0.0000	0.0526	0.0326	0.0000	0.0000
Packing/Shipping Accuracy	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0406	0.0371	0.0000	0.1663

Table 2.4 Limit matrix

	Alternatives			Delivery Management							Incoming Order Man				
	Third Party A	Third Party B	Third Party C	# of Returns	Back Orders	Customer Service Level	Fill Rate	Order Cycle Time	Response to Customer Inquiry	Document /Invoice Accuracy	No-Touch Orders	Order Entry Accuracy	Orders Received	Released Same Day	Response to Order Inquiry
Third Party A	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048
Third Party B	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942
Third Party C	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794
# of Returns	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173
Back Orders	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177
Customer Service Level	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179
Fill Rate	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
Order Cycle Time	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135
Response to Customer Inquiry	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157
Document/Invoice Accuracy	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185
No-Touch Orders	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098
Order Entry Accuracy	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
Orders Received	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
Released Same Day	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086
Response to Order Inquiry	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129
Days Payable Outstanding	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289
Days Sales Outstanding	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282
Inventory Accuracy	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855
Inventory Carrying Cost	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555
Inventory Obsolescence	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381
Inventory Turnover	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241
Warehouse Efficiency	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411
Weeks Forward Coverage	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829
% Defect-Free Deliveries	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114
Inbound Transportation Cost/ Unit	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279
On-Time Delivery (RDC)	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173
Transit Damage Frequency	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
% Defect - Free Deliveries	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163
On-Time Delivery	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Outbound Transportation Cost/Unit	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279
Packing/Shipping Accuracy	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285

	Inventory Management								Transport to RDC			Transport CDC to RDC				
	Days Payable Outstanding	Days Sales Outstanding	Inventory Accuracy	Inventory Carrying Cost	Inventory Obsolescence	Inventory Turnover	Warehouse Efficiency	Weeks Forward Coverage	% Defect-Free Deliveries	Inbound Transportation Cost/ Unit Shipped	On-Time Delivery (RDC)	Transit Damage Frequency	% Defect - Free Deliveries	On-Time Delivery	Outbound Transportation Cost/Unit Shipped	Packing/ Shipping Accuracy
Third Party A	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048	0.1048
Third Party B	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942
Third Party C	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794
# of Returns	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173
Back Orders	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177	0.0177
Customer Service Level	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179
Fill Rate	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
Order Cycle Time	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135	0.0135
Response to Customer Inquiry	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157	0.0157
Document/Invoice Accuracy	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185	0.0185
No-Touch Orders	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098	0.0098
Order Entry Accuracy	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
Orders Received	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
Released Same Day	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086	0.0086
Response to Order Inquiry	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129
Days Payable Outstanding	0.0291	0.0288	0.0289	0.0289	0.0288	0.0289	0.0288	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289
Days Sales Outstanding	0.0282	0.0284	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282	0.0282
Inventory Accuracy	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855	0.0855
Inventory Carrying Cost	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555	0.0555
Inventory Obsolescence	0.0380	0.0380	0.0381	0.0381	0.0382	0.0381	0.0380	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381	0.0381
Inventory Turnover	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241
Warehouse Efficiency	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0413	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411
Weeks Forward Coverage	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829
% Defect-Free Deliveries	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114	0.0114
Inbound Transportation Cost/ Unit Sh	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279
On-Time Delivery (RDC)	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173	0.0173
Transit Damage Frequency	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
% Defect - Free Deliveries	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163
On-Time Delivery	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Outbound Transportation Cost/Unit S	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279	0.0279
Packing/Shipping Accuracy	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285

Table 2.5 Limit matrix continued

The weighting of the categories (clusters) and the final weighting of each of the criteria within their respective clusters and within the overall model are presented in Table 2.6. The weights are taken directly from the limit matrix. First, the influence of a PM within its respective cluster is calculated by dividing an entry by the sum of the entries within the cluster or category to which it belongs. The overall influence is then calculated by multiplying the within-cluster influence of an entry by the weight the cluster carries in the overall model. The following paragraph highlights the most important PM in each cluster.

Table 2.6 Priority vectors at both the cluster and overall levels

Cluster comparisons	
Delivery management	16.4%
Incoming order management	20.0%
Inventory management	34.5%
Transport to RDC	13.9%
Transportation RDC to CDC	15.2%

Delivery management cluster	**Cluster (%)**	**Overall (%)**
No. of returns	18.0	2.9
Back orders	18.4	3.0
Customer service level	18.7	3.1
Fill rate	14.6	2.4
Order cycle time	14.0	2.3
Response to customer inquiry	16.3	2.7

Incoming order management cluster	**Cluster (%)**	**Overall (%)**
Document/invoice accuracy	19.4	3.9
No-touch orders	10.3	2.1
Order entry accuracy	23.9	4.8
Orders received	23.9	4.8
Released same day	9.0	1.8
Response to order inquiry	13.5	2.7

Transport to RDC cluster	**Cluster (%)**	**Overall (%)**
% defect-free deliveries	18.2	2.5
Inbound transport cost/unit	44.5	6.2
On-time delivery (RDC)	27.7	3.9
Transit damage frequency	9.6	1.3

Transportation RDC to CDC cluster	**Cluster (%)**	**Overall (%)**
% defect-free deliveries	19.6	3.0
On-time delivery	12.6	1.9
Outbound transport cost/unit	33.5	5.1
Packing/shipping accuracy	34.3	5.2

Inventory management cluster	**Cluster (%)**	**Overall (%)**
Days payable outstanding	7.5	2.6
Days sales outstanding	7.3	2.5
Inventory accuracy	22.3	7.7
Inventory carrying cost	14.4	5.0
Inventory obsolescence	9.9	3.4
Inventory turnover	6.3	2.2
Warehouse efficiency	10.7	3.7
Weeks forward coverage	21.6	7.4

Within the Incoming Order Management cluster, the weights within the cluster of the PMs range from (0.09 to 0.239). The most important PMs to rate the 3PL are Orders Received and Order entry accuracy (.239), corresponding to global weight of 4.8%. For the Transportation to RDC cluster, Transportation Costs trump all other considerations (0.445) which corresponds to a global weight of

6.2%. Inventory accuracy and Weeks forward coverage are the most important PMs in Inventory Management. After the product leaves the RDC, in the Transportation to the CDC cluster, Packing/Shipping Accuracy (0.343) is slightly more important than the Transportation Cost (0.335). The shift from Transportation Costs is due to consideration of lost sales and the costs associated with providing the correct products as a subsequent delivery. Customer service level (0.187) is vital to Delivery Management; but the # of returns and Back orders are closely related to the Customer service level which is reflected in their weighting.

Table 2.7 Synthesized results

Alternatives	Normalized	Raw	Ideals
Third party A	0.3765	0.10481	1
Third party B	0.3383	0.09417	0.898
Third party C	0.2853	0.07942	0.758

With the specific ratings used in this example, Third Party A is the preferred 3PL as can be seen in Table 2.7. The individual contributions of some of the PMs appear to be minimal in this model; however, that does not diminish their importance in other industries or settings. The marginal contribution of some of the PMs in the context of the project could also help explain why the final model implemented by the organization contained fewer PMs. In other settings, the individual weighting of each of the criteria could change and merit its inclusion. Other criteria may merit additional attention and sensitivity analysis to explore the impact of different weightings. The difference in weightings could be due to subjective priorities or the difference in the PMs of the 3PL that differ from the data used here. In summary the model shows how the Metrics within the Metrics Arrow can be applied to select a 3PL and should not be considered as a general result.

2.3 SENSITIVITY ANALYSIS

Now that Third Party A has been identified as the best company to hire, one may wish to know under what circumstances Third Party B or C may have been the favored outcome. In this section we perform sensitivity analysis on the weights of individual PMs and on the categories or stages of the Metrics Arrow. We assume that each 3PL company’s performance remains the same and do not address a change in the comparison of how well each company satisfies each PM; only that the importance of criteria vary. Figure 2.3 demonstrates the robustness and interdependency of the model where the weight of a single PM compared to another is changed and the overall outcome does not change based on that single comparison. In the studied case, Third Party B outperforms Third Party A in Document and Invoice Accuracy while Third Party A outperforms Third Party B in Back orders. Third Party A is the preferred choice regardless of the weighting of invoice accuracy. This does not eliminate the possibility that changes in the weights of multiple criteria could result in a change in the ranking. For example, if all the PMs where Third Party B dominated Third Party A were the criteria with the heaviest weights then of course the rankings would change. It is the case throughout the entire model that simultaneously changing the weights of two criteria do not change the outcome. The conclusion one can draw from this type of sensitivity analysis is that the model is robust; in this case as Invoice Accuracy becomes more important the decision to select Third Party A remains the same.

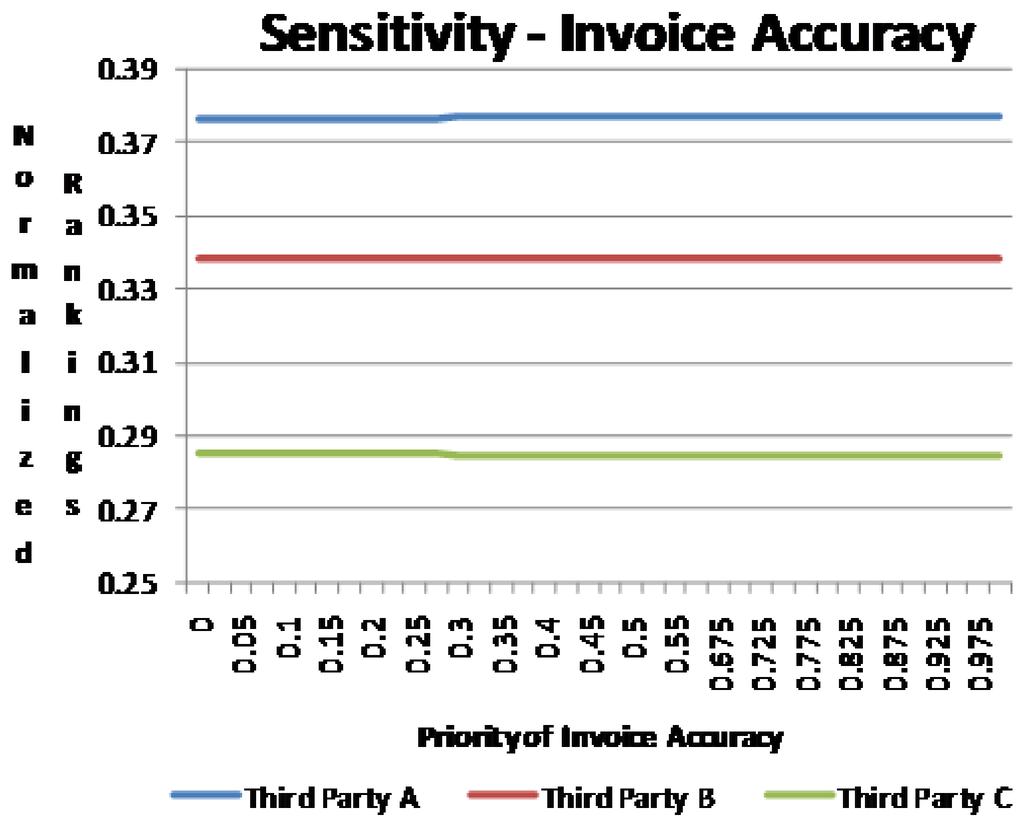

Figure 2.3 Sensitivity analysis changing by changing weights of Invoice Accuracy and Back orders

Next, we alter the weights of the categories or stages within the Metrics Arrow. How would the outcome change if Delivery Management, and hence the six specific PMs within Delivery Management, are more or less important than originally thought? In this case as the cluster weights will change (refer back to Table 2.6) the overall weights of the PMs within an entire cluster will change with respect to the other PMs within other clusters. Similar to the work of Tjader et al. (2010) we use an orthogonal vector to vary the weights of the clusters +/- 50%. The supermatrix is updated, raised to powers until it converges to the outcome with the new weights. The Metrics Arrow has 5 categories, each of which we considered at three different weightings (low, current, and high), resulting in 243 (3^5) unique combinations of weightings that can occur. Figure 2.4 provides a visual guide to the rankings over the 243 simulated weightings. A few observations are worth noting: First, while Third Party C outperforms its competitors under some of the individual PMs, it is never an overall contender and therefore merits no additional consideration. Second, 96% of the time Third Party A is the preferred provider which allows the decision makers to select Third Party A with a high level of confidence. Third, to increase the level of confidence in the decision one might ask, in what cases was Third Party B the preferred provider? After identifying the 9 cases that Third Party B outperforms Third Party A and looking at the weightings in each of case a clear pattern evolves.

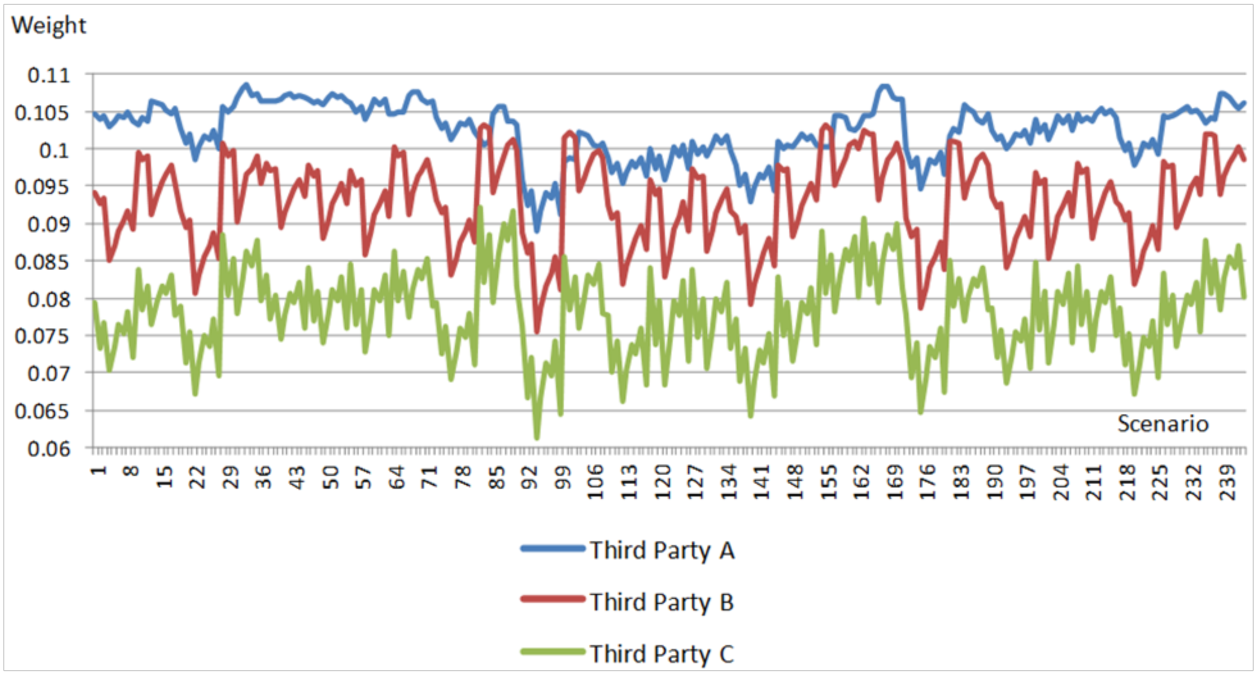

Figure 2.4 Multi-criteria sensitivity analysis

Recognizing this pattern allows the decision makers to review their judgments and in this case continue with the decision in favor of Third Party A. The nine exceptions occur when Transportation to RDC is always weighted High (+50%), Inventory and Delivery Management are both always weighted Low (-50%), and then for every combination of weightings for the final two criteria, Transportation from RDC to CDC and Incoming Order Management, hence the 9 (3^2) exceptions. Given the overall importance of Inventory and Delivery Management it is unreasonable to expect those categories to always be rated low either individually or collectively, which reinforces the original decision to select Third Party A. The sensitivity analysis demonstrated that the network of interactions was interdependent and robust, and provided the decision makers with an increased level of confidence in their decision.

2.4 CONCLUSION

Measuring and evaluating the performance metrics in terms of the flow of the 3PL process is a logical process that facilitates addressing the multiple criteria that must be satisfied in order to be a competitive player in the market. The Metrics Arrow reflects the temporal flow of the product and organizes the flow into categories and metrics that allows decision makers to identify relationships between the metrics. Using ANP allows the decision makers to capture important interdependencies to avoid biasing a 3PL to perform well on specific criteria at the cost of other criteria influenced by the trade-off. The complexity of the ANP model allows managers to capture the influence and interactions of each performance metric on an organization's overall performance. The very act of identifying metrics and then measuring them through pairwise comparisons provide managers with information about relationships and causes of problems that may occur throughout the 3PL process. Another advantage of the network is the redundancy among the pairwise comparisons, which help more accurately reflect the complex interactions that exist. As input is sought from across the organization, the influence and interactions among PMs are identified and weighted. Those weights allow management to select the 3PL that will provide the competitive edge sought after by considering outsourcing logistics. Once the comparisons are made and a 3PL is identified the decision makers can perform sensitivity analysis to test the robustness of their decision. The generalized model can be tailored to the specific needs of an organization by focusing on and comparing the specific key performance indicators that are relevant in a given setting.

3.0 GREEN SUPPLY CHAIN DESIGN BY INTEGRATING LCA AND BOCR ANALYSIS

The consideration of environmental issues has a tremendous impact on the development and operations of a supply chain. However, green supply chain management (GSCM) is an emerging research area, thus there are limited conceptual models on this important subject (Koh et al., 2011). In particular the number of models that consider the effect of environmental directives (ED) on greening a supply chain is very limited. In consideration of the significance of ED on the performance of a supply chain, this work develops a conceptual model for the successful greening of a supply chain that also takes into consideration environmental directives such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of the use of certain Hazardous Substances (RoHS). Various similar terminologies have emerged to describe GSCM. Some authors (Handfield et al., 2005) state that environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials. In a wider sense they define GSCM as the formal system that integrates strategic, functional and operational procedures and processes for employee training and for monitoring, and summarizing and reporting environmental supply chain management information to stakeholders of the firm.

The present work proposes a multi-criteria based approach for supporting environmental sustainability analysis of the entire supply chain. The approach is based on the integration of Environmental Performance Evaluation (EPE) with the well known Analytic Network Process (ANP) methodology and a BOCR analysis (Benefits, Opportunities, Costs and Risks). The aim of this work is to develop the ANP/BOCR model through the definition of EPE to identify significant factors on environmental aspects; in this way, the ANP/BOCR model could supply valuable information about critical factors/areas throughout the whole supply chain in order to reduce the environmental impact. This study focuses on the supply chain of a typical cathode ray tube for computers (and televisions).

In section 1, a brief literature review addresses specific areas of supply chain management that are particularly relevant to achieving sustainability measures; regulatory policies and legislation on Waste Electrical and Electronic Equipment are presented. In section 2, the theory and conceptual model is explained; then in section 3, the proposed approach is applied to the specific case study. Finally in section 4, results are analyzed and conclusions are drawn.

3.1 LITERATURE REVIEW

3.1.1 Reverse supply chain management

A crucial aspect of a GSCM is the integration of the operational procedures and processes of Reverse Supply Chain Management (RSCM). The main goal of RSCM is to accommodate two-way material flows across the supply chain in order to provide products with opportunities for reuse and recycling (Kocabasoglu et al., 2007). According to the US Council of Logistics Management (Sarkis, 2001), RSCM should encompass two flows. The first is a divergent flow, known as an open-loop system, using traditional SCM skills. The other is a convergent flow, or a closed-loop system; which is a backward linkage that processes all end-of-life products throughout the entire supply chain from end-customers to the original suppliers. The basic driving forces behind RSCM are the increasing pressure from the public for eco-friendly products, the potential financial returns from reuse, recycling, and recovering materials, and the requirements from environmental regulations such as the Waste Electrical and Electronic Equipment (WEEE) (Eckerth, 2004; Lysons & Gillingham, 2003). While reverse logistics in and of itself is becoming increasingly important in the context of analyzing the waste accumulation on the downstream supply chain (Hua et al., 2011; Prahinski & Kocabasoglu, 2006; Sundarakani et al., 2010), RCSM is really a sub-set of GSCM. Although GSCM enables the maximization of the value of residual assets, attention should be drawn to the challenges which arise from managing the reverse supply chain activities, the inter-firm relationships, and/or the cross-functional supply chain activities.

3.1.2 Directive 2002/95/EC and Directive 2002/96/EC: ROHS & WEEE

The useful life of consumer electronic products is relatively short, and continues decreasing as a result of rapid changes in equipment features and capabilities (Kang & Schoenung, 2004). The growing importance of Information and Communications Technology (ICT) to the world economy has brought about a surge in demand for electronic equipment (Macauley et al., 2003). Waste from electrical and electronic equipment, EEE (WEEE) is one of the highest priority streams in waste management because of its major challenges. The challenges faced by WEEE management are not only consequences of growing quantities of waste but also the complexity of WEEE; it is one of the most complex waste streams because of the wide variety of products that move through this stream. The products range from mechanical devices to highly integrated systems as a result of the accelerating technological innovations (Yla-Mella et al., 2004). As a result of the sheer variety of product models, sizes, compatibility issues, etc., the recovery of WEEE is very challenging (Kumar et al., 2005). WEEE has also become an issue of concern to solid waste management professionals (Musson et al., 2000).

In the last two decades, there has been an increase in the number of environmental policies and legislation focusing on the product development process with an effort to reduce the harmful impacts on the environment of the products throughout their entire lifecycle: from the product design stage to manufacturing to consumption and then the eventual end-of-life (EoL) management. These policies and legislation are almost all based on the principles of extending not only the producer’s but the entire supply chain’s responsibility. This concept has become an established principle of environmental policy in many countries. This approach integrates principles of sustainable development into the international trade arena based on an international environmental law principle known as the "Polluter Pays Principle" (Kilbert, 2004).

The European Union (EU) is primarily responsible for setting the green product regulations. One of the most profound examples is the establishment in 2002 of two environmental directives: directive 2002/95/EC on the restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment (Parliament, 2003a); and directive 2002/96/EC on waste electrical and electronic equipment (WEEE) (Parliament, 2003b). Directive RoHS is a legal requirement that bans the use of Lead, Mercury, Cadmium, Hexavalent Chromium (Chromium VI), Polybrominated Biphenyl (PBB), and Polybrominated Diphenyl Ether (PBDE). Directive WEEE introduces the producers' responsibilities, such as increasing the recycling and recovery rate of waste from electric and electronic equipment.

The aims of these two directives are not at merely limiting the use of harmful substances, but they also permeate into the recovery of these harmful substances by requiring recovery rates of at least 70–80% of electrical and electronic equipment in the EU market at the end of their useful life. This includes products such as PCs, laptops, printers, scanners and other related products.

Sustaining a green supply chain requires the joint collaboration between suppliers including ODM (Original Design Manufacturers)/OEM (Original Equipment Manufacturers) and brand companies. In addition, the organization of manufacturing networks must take product recovery into consideration (Francas & Minner, 2009). Reverse logistics also needs to be carefully designed and embedded in the supply chain network (Srivastava, 2008) in order to be successful.

3.2 CONCEPTUAL MODEL AND THEORY

While our understanding of a green supply chain has been expanded there is still a great deal of latitude in how it is defined. Currently, there is an imbalanced scenario within the research, which when considered together provides synergies and contradictions at the same time. The green supply chain could be viewed as a system, with interlocking elements or sub-systems (suppliers and customers), that aims to minimize wastes in the supply chain. Practices and changes within the sub-system(s) will have direct and indirect effects on the subsequent sub-system(s).

It is very difficult for a company to guarantee that a component is completely compliant with environmental directives as it flows through the manufacturing process due to the limited capabilities and influence a single company has within the entire supply chain. The alternative strategy is to combine the operational strategy of the whole product supply chain to ensure the overall capabilities match the environmental requests, some examples include: new green products design and development, environmental performance assessment, green purchasing, eco-friendly materials, green SCM, environmental information management system, and recycling of end-of-life products.

The aim of this work is to incorporate these considerations into a strategic decision framework for GSCM. This approach highlights the components and elements for GSCM and how they serve as a foundation for the decision framework. In the next section, we analyze the theoretical background of the Analytic Network Process and its application in the conceptual model.

3.2.1 The Analytic Network Process – ANP: theoretical background

The Analytic Network Process (ANP) is the successor of the popular Analytic Hierarchy Process (AHP) model developed by Saaty (1980). The AHP is a Multi-Criteria Decision Making (MCDM) tool at the core of which lies a method for converting subjective assessments of relative importance to a set of overall scores or weights. The AHP is a top-down decision model and, therefore, the criteria and alternatives are assumed independent. However, bias could occur when the criteria and subcriteria are correlated with each other. Fifteen years after the publication of the pioneering work in the field of AHP, technology was able to perform the necessary calculations in the ANP model, which could handle this situation of inner dependence among elements in a network (Saaty, 1980, 1996a).

Details on the Analytic Network Process (ANP) model can be found in Saaty (1999); the fundamentals are summarized here for completeness. An ANP model consists of the control hierarchies, clusters, elements, interrelationships between elements, and interrelationships between clusters. The modeling process is better understood by dividing it into several steps which are described as follows:

Step 1: Pairwise comparison and relative weight estimation. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion based on the principle of AHP. Saaty (1980) suggested a scale of 1-9 when comparing two components (see Table 3.1).

Table 3.1 Saaty's scale for pairwise comparisons

Intensity of importance a_{ij}	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it

The result of the comparison is the so-called dominance coefficient a_{ij} that represents the relative importance of the component on row (i) over the component on column (j), i.e. $a_{ij} = w_i / w_j$ $a_{ij} = w_i / w_j$. The pairwise comparisons can be represented in the form of a matrix (Saaty & Peniwati, 2007). The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j.

After all the pairwise comparisons are completed the priority weight vector (w) is computed as the unique solution of $Aw = \lambda_{max}w$, where λ_{max} is the largest eigenvalue of matrix A. Matrix A is defined as:

$$A=\begin{bmatrix} W1/W1 & \cdots & W1/Wn \\ \vdots & \ddots & \vdots \\ Wn/W1 & \cdots & Wn/Wn \end{bmatrix} = \begin{bmatrix} 1 & \cdots & a1n \\ \vdots & \ddots & \vdots \\ 1/a1n & \cdots & 1 \end{bmatrix}$$

Step 2: Consistency index estimation. To more accurately represent judgments, the comparisons need not be entirely consistent. However, if a set of comparisons are too inconsistent one could just as well have used random entries and the information from the comparisons would not be useful. In order to provide a balance the consistency index (CI) of the derived weights could then be calculated by: $CI = (\lambda_{max}-n)/n-1$. In general, if CI is less than 0.10, one may be satisfied with the judgments that were derived (Saaty & Ozdemir, 2005).

Step 3: Formation of the initial supermatrix. Elements in the ANP represent the entities in the system that interact with each other. The determination of relative weights mentioned above is based on pairwise comparisons just as in the standard AHP. The weights are then put into the supermatrix (see Figure 3.1) that represents the interrelationships of elements in the system. The general form of the supermatrix is described here below where CN denotes the N^{th} cluster, e_{Nn} denotes the nth element in the N^{th} cluster, and W_{ij} is a block matrix consisting of priority weight vectors (w) of the influence of the elements in the i^{th} cluster with respect to the j^{th} cluster.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">C_1</td><td colspan="4">C_2</td><td rowspan="2">…</td><td colspan="4">C_N</td></tr>
<tr><td>e_{11}</td><td>e_{12}</td><td>…</td><td>e_{1n}</td><td>e_{21}</td><td>e_{22}</td><td>…</td><td>e_{2n}</td><td>e_{N1}</td><td>e_{N2}</td><td>…</td><td>e_{Nn}</td></tr>
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<tr><td>e_{N2}</td></tr>
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<tr><td>e_{Nn}</td></tr>
</table>

Figure 3.1 Supermatrix

Step 4: Formation of weighted supermatrix. The initial or "unweighted" supermatrix consists of several eigenvectors each of which sums to one. The clusters in the initial supermatrix must be weighted and transformed to a matrix in which each of its columns sums to unity.

Step 5: Calculation of global priority vectors and weights. In the final step, the weighted supermatrix is raised to limiting power to get the global priority vectors as in Equation (1):

$$\lim_{n \to \infty} (W)^n \qquad (1)$$

3.2.2 Conceptual model

Approaches for analyzing the environmental sustainability of a supply chain could be classified into two main types: *top-down models* based on global level analysis and *bottom-up models* based on performance of individual companies in a supply chain. The first type is essentially based on a Life Cycle Analysis (LCA) approach which allows one to measure sustainability from a system perspective. LCA is increasingly used as a decision support system that enables the modelling, the evaluation and the comparison of different alternatives of products, processes or supply chains with regards to their environmental and sustainable impacts (Boufateh et al., 2011). On the other hand, bottom-up models such as climate change, related fossil energy use, or ISO 14000 guidelines are focused on measuring the environmental performances of a single company (Gerbens-Leenes et al., 2003).

From this point of view the aim of our model is to integrate different techniques. The decision framework (Figure 3.2) is represented by the Analytic Network Process, which varies from a standard decision structure as defined by the standard Analytic Hierarchy Process. Figure 3.2 shows a description of the decision process, which does not detail the components within each cluster. The objective or goal of the organization, which appears on the right hand side of Figure 3.2, is to develop improved green supply chains. This objective will be influenced by the various clusters that will be described in this paper. The model is characterized by these steps:

1. Collection of data in order to analyze a green supply chain system from the point of view of economic, environmental and social prospective;
2. Development of a general multi criteria sustainability model based on ANP and LCA in order to improve supply chain from environmental point of view; the model developed reflects the priorities of the influences on the supply chain environmental sustainability level. The primary focus is to assess strategic and/or operational alternatives which could improve the environmental sustainability level of a supply chain. The result is a prioritized set of potential alternatives.
3. Implementation of the model.

The decision making process followed in the study was divided into three phases: problem analysis and data collection, synthesis of the ANP model, and implementation. The study was developed jointly with a research team of electrical equipment manufacturers. The initial project was based on the criteria of economic profitability, and technical and environmental feasibility. The conceptual model is presented in Figure 3.2.

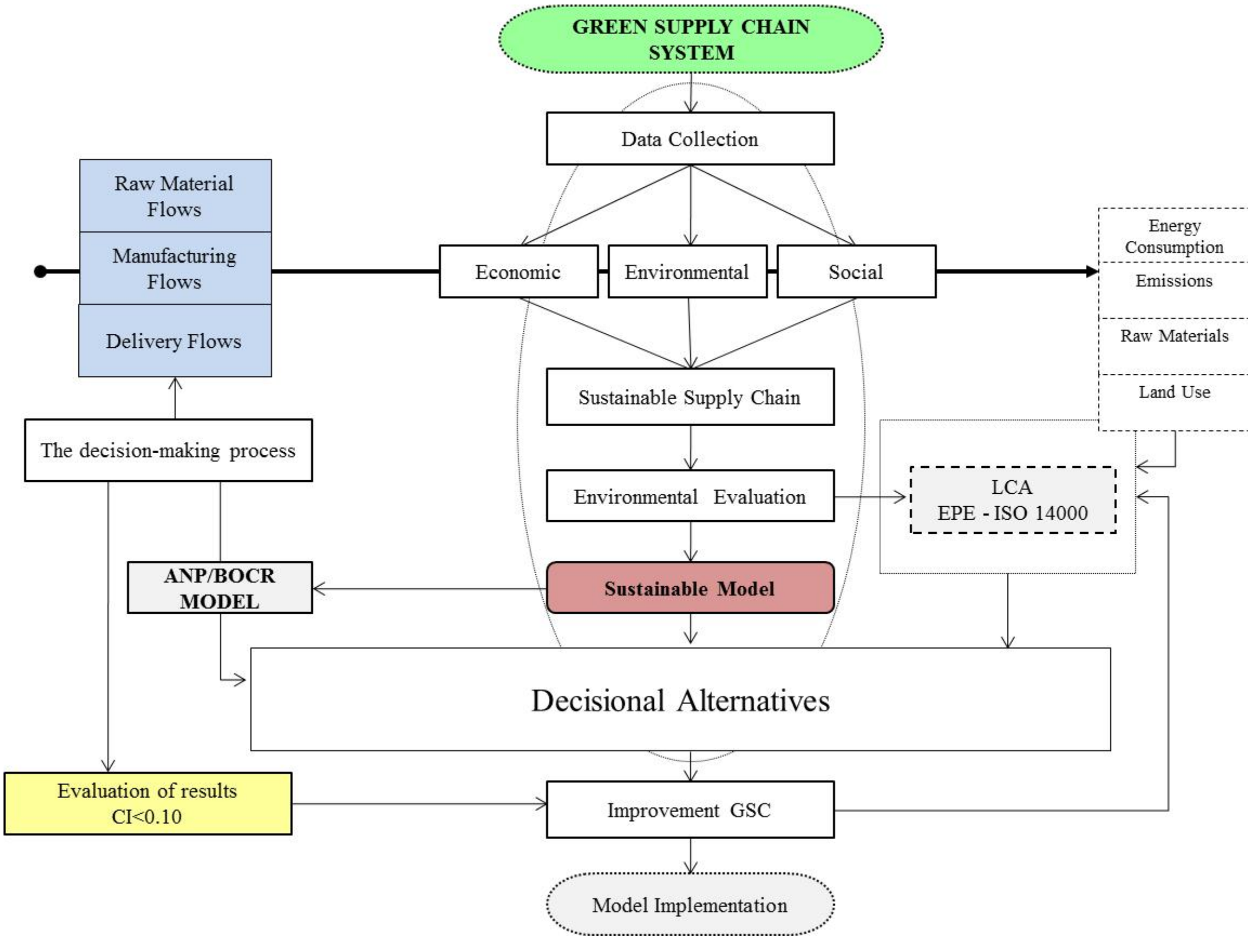

Figure 3.2 Conceptual framework for green supply chain evaluation

The design of an effective measuring method is carried out with the aim to integrate information derived from operational fields with global level effects. As reported in the literature review, the effectiveness of a reporting system is heavily influenced by the specific structure of a supply chain. This preliminary activity represents a focal analysis as it supplies information about processes and procedures at each level of the SC.

According to ISO 14031 (ISO, 1999), three main subcategories under the Operational and Management Performance Indicators are proposed in order to evaluate sustainability of supply chain: OPI - Operational Performance Indicators, MPI - Management Performance Indicators, and ECI - Environmental Condition Indicators. The first category refers to aspects regarding facilities and equipment such as energy flows, waste and emissions, etc. The second is focused on the management's efforts to influence process oriented environmental performances and the last provides information about the condition of the environment which may be useful for the implementation of environmental performance evaluation within an organization. These indicators are fundamental to the development of the BOCR multi-criteria decision support system as they point out critical intervention areas for SC environmental sustainability assessment.

3.3 THE CASE STUDY: TV & AUDIO VIDEO SUPPLY CHAIN

The proposed model is applied in a full scale case study regarding a TV & audio video production supply chain (Figure 3.3). Usually, this sector is a resource intensive sector; thus, TV & audio and video manufacturers and processors are under ongoing pressure to maximise efficiency in all areas of production. Supply chain management in this context is complicated due to the particular nature of the product: bulky, fragile, and difficult to deliver intact while meeting stringent requirements for high quality and safety. The supply chain structure is quite linear; it consists of a company which produces TV & audio video products, with a low number of first-tier suppliers and several intermediate customers (i.e. the final product is an intermediate material for different applications). A schema is proposed in Figure 3.3 which highlights the main parameters that influence its environmental sustainability level.

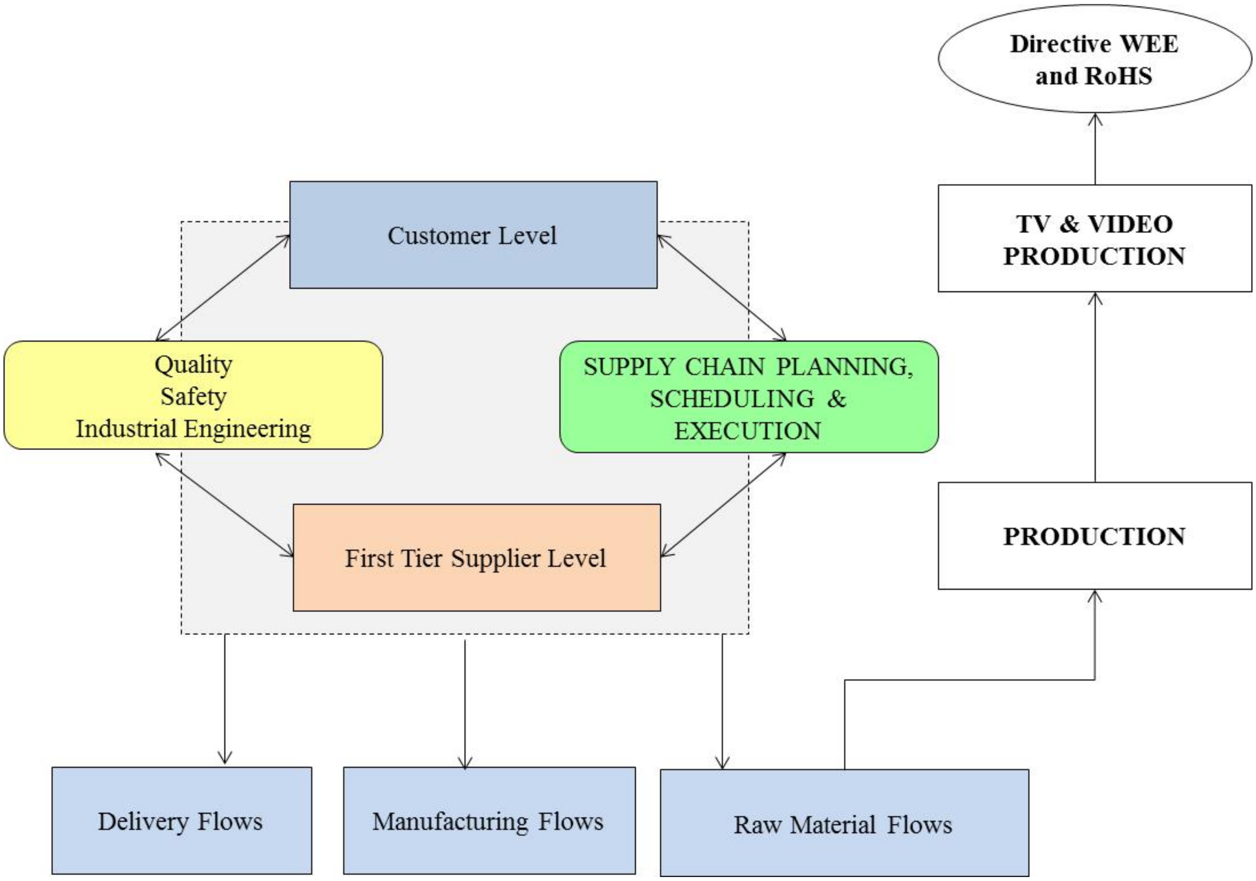

Figure 3.3 TV and audio video supply chain schema

The proposed model has been applied to evaluate the SC environmental sustainability level and areas where intervention must have priority. Whenever possible the SC structure has been analyzed by applying the metrics system from the EPE process.

3.3.1 Collection and aggregation of information

Information with regards to current performance was retrieved from a database made available by the company and with information from managers in the areas of interest (see Table 3.2, Table 3.3, Table 3.4, and Table 3.5). This data is used to provide weightings in the model under these criteria which is explained in greater detail below.

Table 3.2 Consumption data

Description	Unit/total
Production	66,273.31 Ton
Electric Energy	53.499,67 MWh
Cogeneration Electric Energy	71.395,00 MWh
Thermic Electric Energy	80.319,38 MWh
Natural Gas Consumption	10.896.127,84 Nm^3
Water Consumption	1,892,000.0 m3
CO_2 emissions Consumption per unit	1.3 Ton per ton produced
Auxiliary materials (sodium hydroxide for the production of demineralized water)	855.700 kg
Raw materials	80.000 kg

Table 3.3 Waste data

Description	Unit/total
Hazardous Waste	8,800 kg
Other wastes	665,135 kg
Waste	5,469,336 kg

Table 3.4 Packaging data

Description	Unit/total
Paper and carton packaging	3,674,816 kg
Plastic packaging	57,644.5 kg
Wood packaging	1,282,278 kg
Iron packaging	8,900 kg

Table 3.5 LCA data

Description	Unit/total
Acidification	6.55 g SO_2/kg product
GWP 100	0.855 kg CO_2 eq/kg product
Ecotoxicity	14.2 cgPb eq/kg product

3.3.2 ANP/BOCR model

In this section we analyze an ANP/BOCR model and its elements. The process of developing an ANP/BOCR model follows these practical steps:

1. Structure the problem with respect to its goal;
2. Create the benefits, opportunities, costs and risks networks;
3. Establish control criteria to evaluate the benefits, opportunities, costs, and risks;
4. Define the decision subnets for each control criteria;
5. Complete the pairwise comparisons on cluster elements;
6. Evaluate the rating model to combine the benefits, opportunities, costs, and risks;
7. Synthesize/Combine the model with respect to the strategic criteria;
8. Perform sensitivity analysis to test the stability of the results.

The ANP model has been developed and implemented in the Super Decisions Software for Decision Making®.

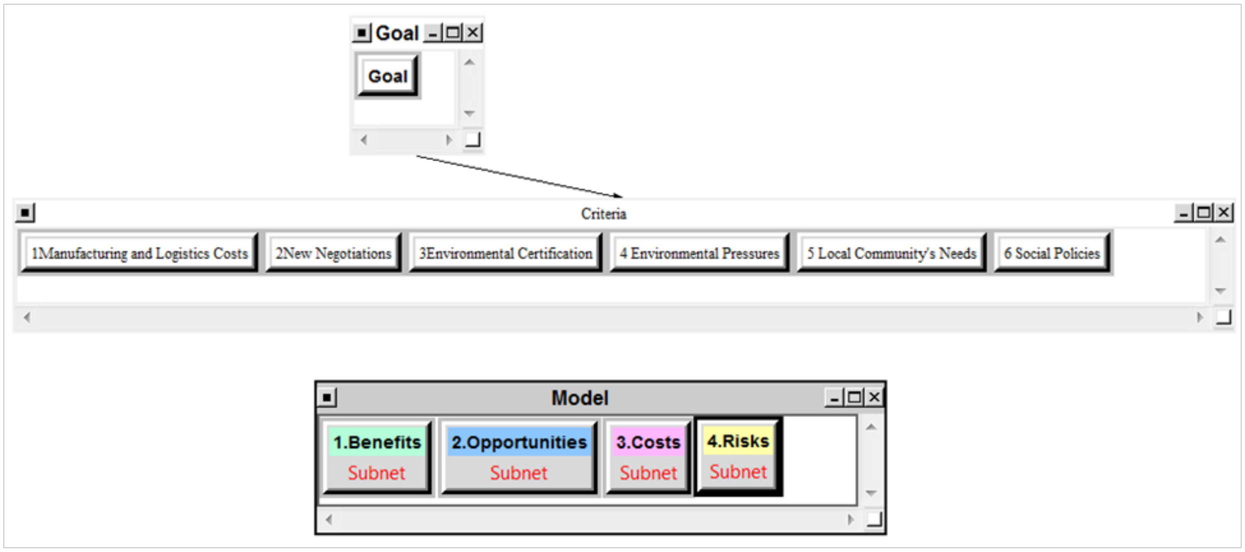

Figure 3.4 ANP BOCR model

3.3.2.1 Alternatives

Alternatives may include changes to the technological, process, or organizational characteristics. A few potential projects (alternatives) which are available to the organization for improving the environmental performance of its supply chains have been identified. The **alternatives** cluster is represented by the following specific alternatives: (A1) Installation of emission abatement equipment, (A2) Installation of evaporative towers to recycle water, (A3) Installation of solar panels, (A4) Reuse packaging, and (A5) Reuse of second hand materials.

These five examples are only a few of the emerging technologies, models, and processes that can be evaluated using the proposed decision framework. Each alternative was evaluated with respect to its relevant criteria so as to obtain the desired final priority order of the projects under study.

3.3.2.2 Strategic criteria

The criteria described below are used as control criteria to weight and combine the priority vectors from the benefits, opportunities, costs and risks (BOCR) networks (Saaty, 2005). With an overall goal to prioritize the various alternatives these criteria allow the decision maker to evaluate and prioritize the alternatives with respect to all of the benefits, all of the costs, opportunities, and risks that each alternative provides (see Figure 3.4). The set of criteria must accomplish the following requirements: to be related to sustainability indicators, to be structured in clusters, to be non-redundant and to be easy to understand for the different stakeholders. The weighting of the BOCR is achieved through a ratings comparison matrix (Saaty, 1996a). A ratings model allows the decision makers to create scales that are relevant to each of the respective criteria. The alternative with the highest relative weight in each of the BOCR networks is used in the comparisons to determine how well that alternative satisfies the control criteria. The individual weights for the benefits, opportunities, costs, and risks, respectively (b,o,c,r), are then used in the additive synthesis formula bB+oO-cC-rR to combine the alternatives eigenvectors from each network. The final vector for the alternatives can then be used to determine which alternatives will provide positive returns and the most benefits and opportunities. The specific control criteria used in this model are described in greater detail below:

- *Manufacturing and logistics costs*. These encompass the costs throughout the entire supply chain. They are some of the single most important factors to consider (Cooper & Kaplan, 1987, 1988; Thomas & Griffin, 1996). While one may argue it all boils down to the costs there are additional components that are worth considering (Ho et al., 2010).
- *New negotiations.* The changes that come about because of negotiations from other members of the supply chain, e.g. a company demanding a 25% reduction in packaging. Supply chain coordination is difficult to implement and measure. A particular challenge arises when changes are made in one part of the supply chain because it can impact both upstream and downstream suppliers (Brewer & Speh, 2000).
- *Environmental certification*. The need to satisfy the requirements for ISO certification and of legislation, e.g. the installation of catalytic converters. Organizations can be motivated to obtain environmental certification for various reasons including marketing and to satisfy the requirements of entities downstream in the supply chain (Miles et al., 1997; Nakamura et al., 2001).
- *Environmental pressures.* Similar to Environmental certification but for issues that have not been mandated, e.g. hydraulic fracking chemicals. In the case of hydraulic fracturing residents around drilling sites have become increasingly concerned about the potential harm that can result fracking or other operations (Merkel et al., Forthcoming). Environmental groups and environmentally concerned customers are able to influence decisions regarding the use and reuse of products. According to McIntyre et al. (1998) a “feel good” factor is important to many customers.
- *Local community needs.* Requests from the community that are not mandated by law, e.g. noise pollution. Citizens from the communities located around production facilities have increased the pressure on organizations to protect or enhance the communities where they produce. In order to increase their bargaining power residents have formed alliances to negotiate contracts and leases with the organizations wishing to do business within the community (Liss, 2011). Investing within the community has also been justified as ultimately being in the corporation’s self-interest (Friedman, 1962).
- ***S**ocial pressures*. When a group or organization push for change within the supply chain. This is especially important for market share considerations, e.g. coffee and deforestation initiatives (Taylor, 2005). Groups have successfully lobbied against child labor in industries like soccer balls and clothing manufacturing (Lund-Thomsen & Nadvi, 2010). While this criteria is similar to environmental pressures the main difference is the level of acceptance determined by society as a whole.

3.3.2.3 BOCR networks

Each of the BOCR networks contain subnetworks to capture the economic, social and environmental impacts of the alternatives. Within each subnetwork the specific criteria used in this model were organized into clusters. While this step is not formally needed for the model to converge, it reduces the number of comparisons required and provides cognitive benefits to the decision makers (Saaty 1996a; Saaty & Ozdemir, 2005). With regard to the four merits BOCR, we can make a comprehensive and systematic assessment, since they consider short-term and long-term, obvious and potential, positive and negative, and tangible and intangible attributes of outcomes. In general, both benefits and costs depict the obvious and short-term results, but the benefits describe the positive results, while costs the negative ones. Uncertain or potential criteria are assigned to either opportunities or risks, depending on whether they contribute positively or negatively to the goal. The following clusters were used within the respective BOCR networks to organize the elements used in the analysis of this case study. Each cluster is defined to identify which elements can be assigned to it. Both a general list of elements that can be included in the clusters and a list of the elements which were included in the model are presented in Table 3.6, Table 3.7, Table 3.8, and Table 3.9.

Benefits

- Economic
    - *Advantages.* Activities can build value through sustainable methods. Specific value building methods are the elements clustered here.
    - *Sustainable Targets*. The elements in this cluster measure the alternatives ability to optimizing resource utilization and reduce waste.
- Environmental
    - *EPE (MPI-ECI-OPI).* The alternatives are assessed with regard to how well they satisfy environmental performance measures. The measures are clusters with respect to management performance, environmental conditions, and operational indicators.
- Social
    - *Society*. This cluster contains elements which reflect the social benefits achieved from the development of sustainability level or standard.
    - *Individual.* These elements allow the decision maker to evaluate the alternatives with respect to their potential to improve health care and reduce environmental damage.

Opportunities

- Economic
  - *Process.* Processes associated with planning, scheduling, and coordinating supply chain activities. The effectiveness of an organization in managing assets to support demand satisfaction depends on its processes. The elements in this cluster reflect improvements in the process that can be achieve through the implementation of the alternatives.
- Environmental
  - *Law.* Identification and quantification of energy and resource use and environmental releases to air, water, and land according to European or national decrees. The elements reflect the potential to develop, meet, and surpass regulatory measures.
- Social
  - *Resources.* Processes and skills associated with the development of territory and human resources e.g. lifelong learning. These elements have the potential to add untapped value into the organization.

Costs

- Economic
  - *Infrastructure.* Most activities that are focused on improving or ensuring a green supply chain will require economic investment to implement. The elements in this cluster reflect the economic costs associated with green supply initiatives.
- Social
  - *Human resources.* Activities that require economic investment to ensure safeguard of employees, citizen, etc. This cluster captures the human capital investments of the decision. Training employees to become aware of and vested in sustainability initiatives is a crucial step towards developing human capital.
- Environmental
  - *Joint venture.* Agreements with suppliers that define the levels of “sustainability” or resource upside available within state. In this case study the ability to make changes throughout the supply chain that will improve the environment it necessitates investment in joint ventures that will facilitate coordination throughout the supply chain.

Risks

- Economic
  - *Profitability.* Each of the alternatives poses the risk that the costs will exceed the benefits. As markets react, the new improvements can become a norm within the business and lead to a reduced market share. The impact on the profit margin can marginalize the success of the company. These economic risks are real and must be addressed and included in the model to prioritize the alternatives.
- Social
  - *Social risk.* Loss of competitiveness or a change in brand image. Other risks involve creating a form of paternalism that could impede competition in a free market. By

moving in the direction of sustainability, society will come to accept the gains and set new industry standards that pose a risk for incurring legal penalties.

- Environmental
    - *Environmental risks.* Actual or potential threat of adverse effects arising out of the organization's activities. If data collection methods are not clearly defined and tested there is the potential for errors and biases that will cloud the impact of the initiatives. There is also the potential for implementation to backfire or introduce adverse effects.
    - *LCA – analysis of inventory.* Qualitative and quantitative characterization and assessment of the consequences on the environment. Through this analysis there is the potential to identify additional harms or threats to the environment caused by the products.

Within the clusters it is necessary to identify tangible and intangible attributes to measure, weight, and provide meaning to the clusters. The elements in the model were developed by looking at ISO 14001 standards, from staff at the company in the case study, and group consensus. Below, in Table 3.6, Table 3.7, Table 3.8, Table 3.9, and Table 3.10 a Decision Network and BOCR analysis control criteria, clusters, elements and alternatives for a **general model** are described**.** In the general model a team of experts considered all factors that generally contribute to improving the environmental sustainability. However, all these elements are not always essential and important; therefore, in the last column the team of experts pointed out elements for our **specific model** i.e. for the specific company in the case study.

Table 3.6 Benefits network

BENEFITS				
Model	**Control Criteria**	**Clusters**	**General Elements**	**Specific Elements**
Benefits	Economic	Advantages	Increase in company's value Cost savings Green profitability Relational benefits	/
		Sustainable Targets	Optimize use of resources Optimize use of raw materials Reduce waste Reduce use of auxiliary materials Reduce packaging Optimize release of emissions	/
	Social	Society	Damage prevention Improvement in relationship with local community	/
		Individual	Health care Damage reduction Improvement in relationship with employees	/
	Environmental	EPE - MPI	Implementation of policies and programs Conformity Financial performance Employee performance Management and planning Purchases and investments Health and safety Community relations	MPI - N° of green initiatives MPI – N° of green investments
		EPE - ECI	Air Water Land Flora Fauna Humans Natural heritage and culture	ECI – C02 ECI –Natural Gas ECI – Waste ECI – Water ECI – Electricity ECI – Emissions
		EPE - OPI	Materials Energy Services to support the organizational operations Products to support the organizational operations Design Installation Operation Maintenance Land use Transportation Products supplied by the organization Services provided by the organization Waste Emissions	OPI –Auxiliary materials OPI – Total energy OPI – Raw materials OPI – Packaging OPI - Cogeneration

Table 3.7 Opportunities network

OPPORTUNITIES				
Model	**Control Criteria**	**Clusters**	**General Elements**	**Specific Elements**
Opportunities	Economic	Process	Improvement of production process Customers' satisfaction Improvement stakeholders' relationship Improvement bank's relationship Adaptability – Be Creative Development of an environmental, economic, and social culture	/
	Social	Resources	Promotion of territorial identity Develop new professional skills Stimulate the establishment of quality products	/
	Environmental	Law	New sustainable regional planning European/National Policies enforcement Sustainable production methods	/

Table 3.8 Costs network

COSTS				
Model	**Control Criteria**	**Clusters**	**Elements**	**Specific Elements**
Costs	Economic	Infrastructure	Increase in infrastructure costs Increase counseling costs	/
	Social	Human Resources	Training costs Health care survey costs	/
	Environmental	Joint Venture	Partner skills	/

Table 3.9 Risks network

RISKS				
Model	**Control Criteria**	**Clusters**	**Elements**	**Specific Elements**
Risks	Economic	Profitability	Net profit Margin Standardization	/
	Social	Social Risks	Legal Penalties Paternalism Stigma	/
	Environmental	Environmental Risks	Data Collection Implementation of failure Introduction of indirect Problems	/
		LCA – Analysis of inventory	Global warming potential - GWP Ozone Consumption of non-renewable resources Acidification Eutrophication Photochemical smog Ecotoxicity	Acidification Global warning protection Ecotoxitcity

Table 3.10 Alternatives

ALTERNATIVES	ALL NETWORKS	1. A1 2. A2 3. A3 4. …. 5. An	1. Installation of emission abatement equipment 2. Installation of evaporative towers to allow recycling of water 3. Installation of solar panels 4. Reuse packaging 5. Reuse of second hand materials

These criteria were ranked according to the BOCR. The control criteria are used to generate the weights of the BOCR with a ratings model (Table 3.11). The following figures (Figure 3.5, Figure 3.6, Figure 3.7) depict the local priority and overall synthesis according to the additive and multiplicative formulas.

Table 3.11 Control criteria ratings model

Super Decisions Ratings							
	Priorities	1Manufacturing an 0.114031	2New Negotiation 0.051063	3Environmental C(0.247578	4 Environmental P 0.350924	5 Local Communit 0.075539	6 Social Policies 0.160864
1.Benefits	0.223210	MEDIUM	LOW	Level 2	MEDIUM-HI	MEDIUM-LOW	MEDIUM-LOW
2.Opportunities	0.260958	MEDIUM	LOW	Level 2	MEDIUM-HI	MEDIUM-HI	MEDIUM
3.Costs	0.310530	MEDIUM-HI	MEDIUM-LOW	Level 2	HI	MEDIUM	MEDIUM
4.Risks	0.205301	LOW	MEDIUM	Level 2	MEDIUM	LOW	MEDIUM

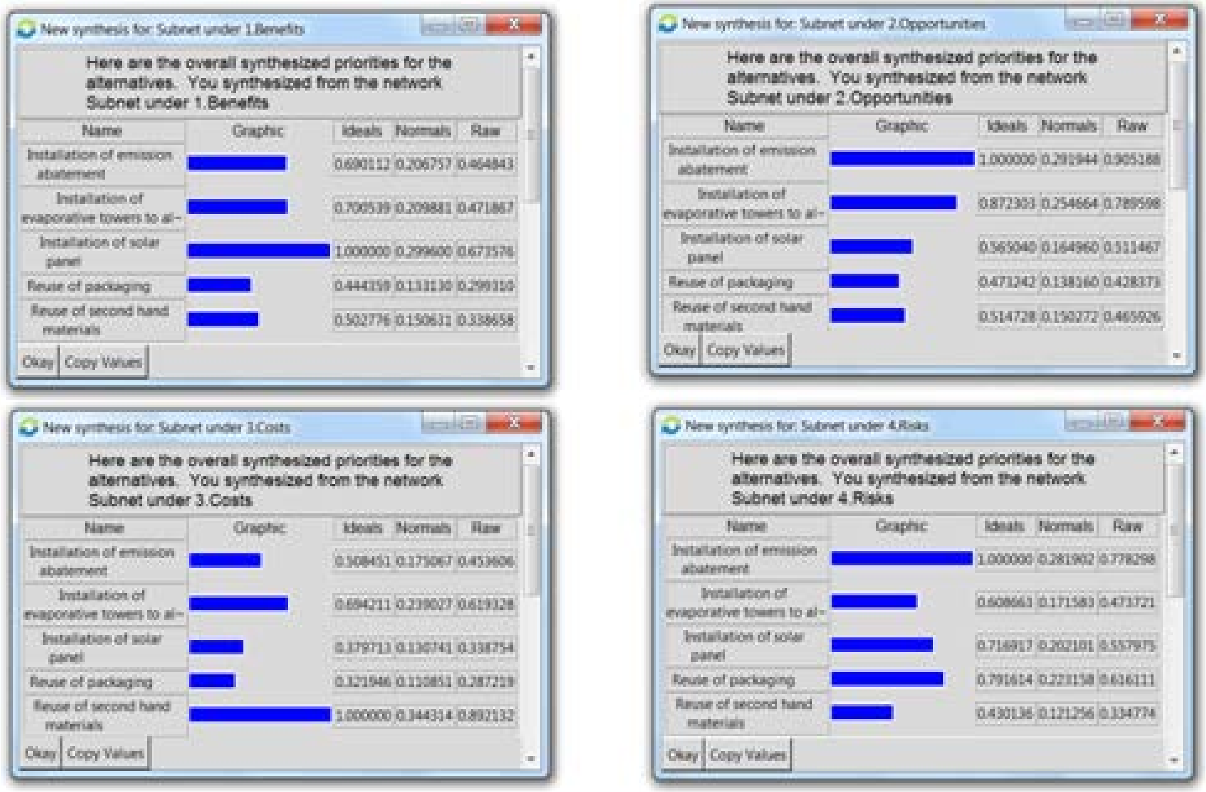

Figure 3.5 Local priorities

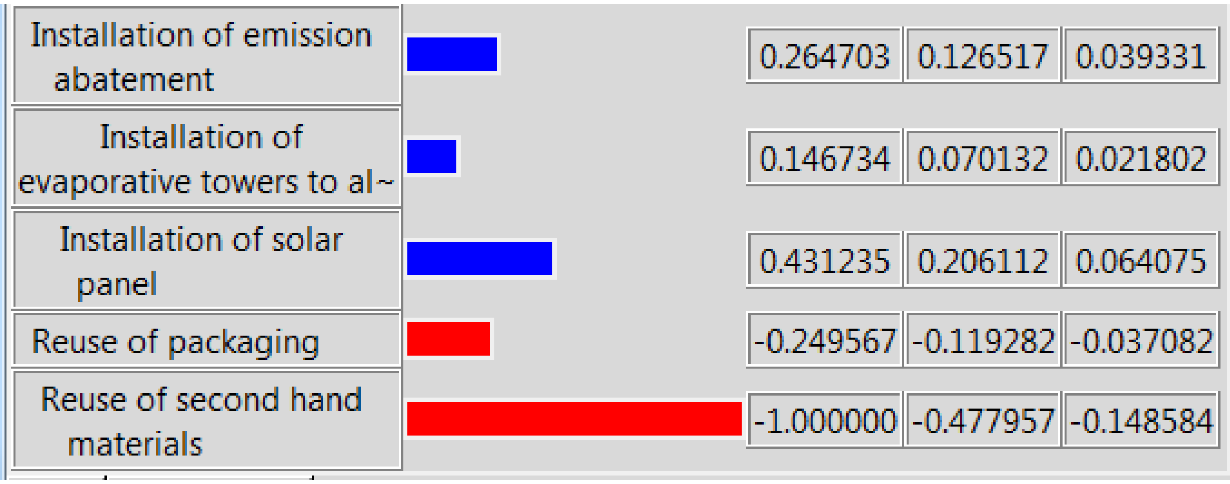

Figure 3.6 Global priorities - additive formula

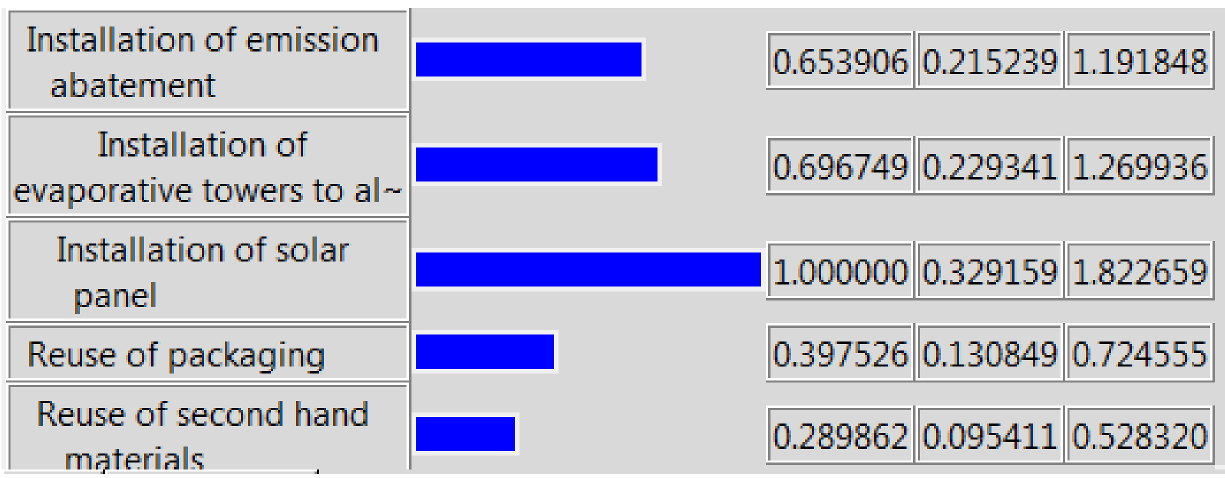

Figure 3.7 Global priorities - multiplicative formula

The alternative to install solar panels is the best alternative within the benefits cluster; within the opportunities cluster installing the installation equipment is the preferred alternative. The reuse of packaging is the least costly alternative, while the reuse of second hand materials is the least risky. When the model is synthesized in both the short term (multiplicative) and long term (additive) models the best option is to install solar panels.

To test the stability of our decision we performed sensitivity analysis (Figure 3.8) to test the robustness of the decision with respect to changes in the weighting of the benefits, opportunities, costs and risks. The graphs below show that for:

1. Under the Benefits and the Costs as the independent variable the optimum solution is the installation of the solar panels;
2. Under the Opportunities as the independent variable the optimum solution is the installation of the emission abatement equipment;
3. Under the Risks as the independent variable the optimum solution is the reuse of second hand materials.

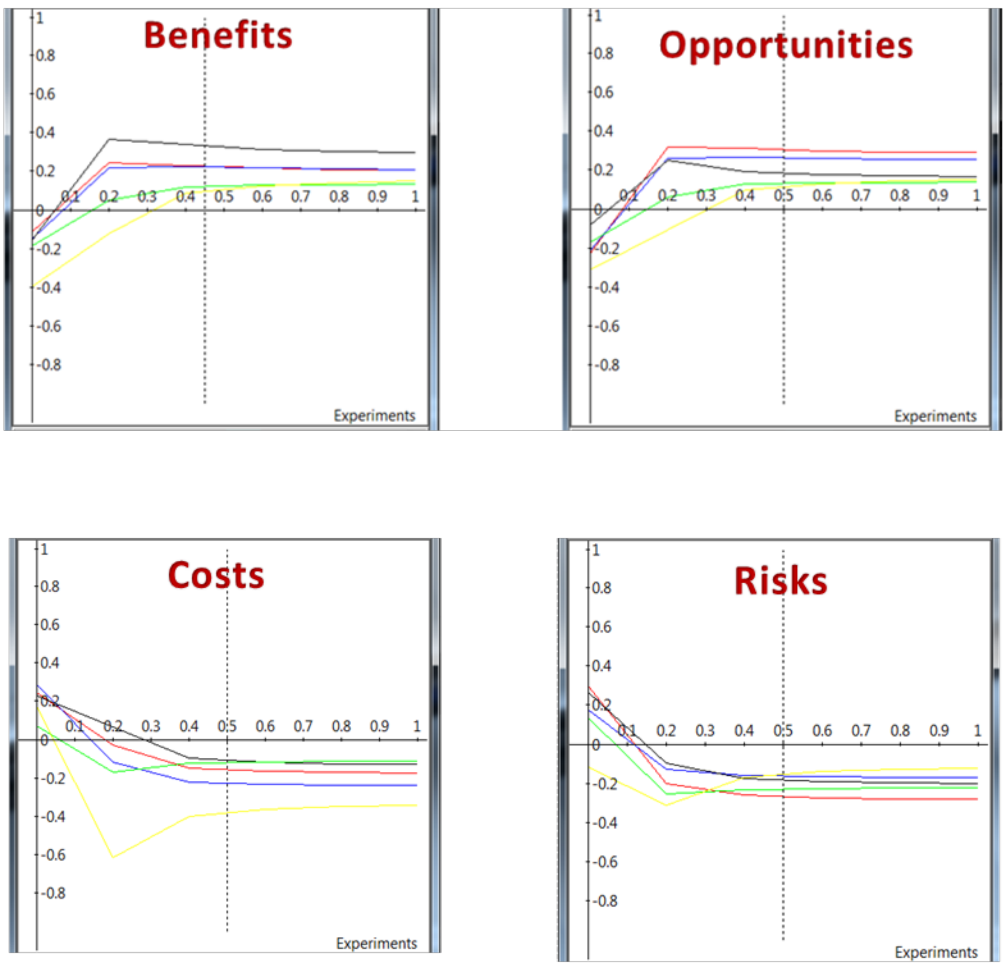

Figure 3.8 Sensitivity analysis

3.4 CONCLUSION

Green supply management is becoming more and more important due to the increasing number of economic events and to the great variety of assets involved. With the purpose of offering solutions to potential drawbacks, and of broadening the scope of current approaches, this new research line incorporates some methods from Multiple Criteria Decision Analysis (MCDA) to evaluate green supply chain decisions. Within this research line, this paper is an application of the Analytic Network Process (ANP) to the valuation of green supply chain. The ANP allows the incorporation of qualitative explanatory variables to the model and the organization of the evaluators' judgements

Based on the results of this model in the specific case study of the TV & audio and video supply chain the manufacturer should install solar panels. The general model and criteria can be adapted and applied to other supply chains and to include different alternatives. The model is an integrated approach to evaluate the environmental sustainability of a supply chain. The proposed approach involves the evaluation of the entire supply chain: the environmental performance of a product or a producer depends not only on its production process, but the whole life cycle has to be evaluated starting from the first supplier to distribution to the final customer and final recovery activities. The approach integrates index methods for Environmental Performance Evaluation (EPE) with a complex multi-criteria model, the Analytic Network Process (ANP). This proposed approach aims to optimize the development of the ANP model through a previous definition of EPE to identify significant factors of environmental aspects; in this way, the ANP model supplies effective information about critical factors/areas in the entire supply chain in order to optimize the sustainability level. The model has been tested in a real supply chain regarding the TV & audio video production. This supply chain is characterized by a simple structure as a company heavily influences SC performance; moreover, environmental sustainability issues are relevant in this SC. Results obtained have highlighted different capabilities. Further developments could be oriented in applying the approach to several industrial fields where SC structure complexity arises.

4.0 USING OPERATIONS RESEARCH IN ETHICAL DECISION MAKING

The purpose of this chapter is to show how tools and concepts developed in the field of Operations Research (OR) can strengthen Ethical Decision making (EDM) processes. The term "Operations Research" was coined in the build-up to WWII to describe the efforts of British scientists to develop strategies to survive the bombing attacks from the Hitler regime. The definition of OR was the application of the scientific method to executive decision making (Churchman et. al., 1957). The scientific method consists of three steps: observe, explain, and test; repeated as often as necessary (Capra, 2007, p. 157). Executive decision making refers to decisions made at the level that impacts the whole organization and is focused on integrating the activities of the departments in a way that optimizes the performance of the organization, its parts, and its environment.

There are three features that characterized the early OR efforts. First, there was a pragmatic bent with a clear focus on real world problems. Second, the projects were interdisciplinary; OR thrived on the multiple perspectives brought to bear by scientists from different specialties. In spite of different specialties, they had a common bond: all were trained in a rigorous, analytic approach to solving problems and they brought this training to address the challenge of saving their nation. The third feature was a whole systems perspective that examined the whole system and not just the individual parts. The focus was on integration of the parts into a whole, rather than studying the parts in isolation from each other.

The early founders had deep philosophic training and aptitudes combined with a sensitivity towards ethical concerns. C. West Churchman and Russell L. Ackoff, two of the dominant figures in the first 60 years of OR, both had doctorates in the philosophy of science. Both were influenced by the philosopher Edgar Singer, who was a student of the pragmatist William James. Churchman argued throughout his career (1997) that good effective decision making requires an ethical sensitivity. Ackoff (1974), using a whole systems perspective, identifies three distinct types of responsibility for an organization: 1) the organization itself, 2) the sub-systems, or parts, of the organization, and 3) the supra-systems of the organization, defined as those systems of which the organization is a part.

The inclusion of supra-systems by Ackoff led naturally to stakeholder management. Ackoff shared a common view with Freeman (1984, 2010) that the ultimate goal of stakeholder management is to satisfy the interests of all stakeholders:

> "If it is not possible to provide service to one group of participants or stakeholders without a disservice to another- I have not found many circumstances of this type - then a moral choice of whom to serve is clearly required. My own criterion for making it is based on serving the less advantaged of the parties" (Ackoff, 1974, p. 366).

This systems view of stakeholder management is consistent with the business ethics community views of stakeholder management coming from Freeman (1984) and many others, who argue that the ultimate goal of stakeholder management is to find ways to satisfy the interests of all stakeholders. Freeman places prioritization of stakeholder interest as a secondary issue compared to satisfying the interests of all stakeholders.

While the ultimate goal of stakeholder management is to satisfy the joint interests of stakeholders, a rigorous prioritization process can also stimulate the moral imagination required to find a win/win solution. For example, Badaracco observes that the credo of Johnson & Johnson is wise in establishing a much higher priority for mothers and doctors, compared to shareholders, because it "discouraged short-sighted profit seeking that risked the entire firm's reputation" (Badaracco, 1997, p. 95). The prioritization process led management to distinguish between long term and short term shareholders. In making this distinction, management realized that it was the long term shareholders they were most interested in attracting, and that the high priority for customers also met the interests of the long term shareholders.

In the quote by Ackoff above, it can be seen that he shares the viewpoint that the primary purpose of stakeholder management is to satisfy the interest of all stakeholders. However, he also recognizes that it cannot always be done for every decision and that a prioritization process can be helpful in optimizing the overall benefit to stakeholders when some interests may not be met.

To conclude the discussion of the prioritization process, it is worth noting that prioritization is an important step in the effort to accomplish the ultimate goal of the decision. In some situations, the prioritization process can stimulate the moral imagination required to find a win/win solution. In other situations where a win/win solution cannot be found, a rigorous prioritization process can optimize the degree to which all interests are satisfied.

At present, although there are two examples that exist in the literature, there have not been any serious attempts to integrate OR into EDM (Millet, 1998; Stein & Ahmad, 2009). One response to this discrepancy is that OR strayed from its foundation and in doing so made itself less relevant to EDM. Ackoff (1979) argues this passionately in his paper entitled “The Future of OR is Past.” Another possibility is that many perceive EDM as philosophical and OR as technical, leaving little room for common ground. It may also be the case that most EDM practitioners lack training in analytic methods, and from outside appearances, do not see how the two disciplines would connect.

From its inception, OR has devoted much attention to developing effective rigorous prioritization processes including math programming, goal programming, multi-attribute utility theory, multiple criteria decision making, data envelopment analysis, and evolutionary multi-objective optimization (Wallenius et al., 2008, p. 67). A truly effective prioritization process goes beyond establishing *preferences* to establishing *strength of preferences* (Kahneman & Tversky, 1979). While a rank ordering of criteria establishes preferences among the criteria, weighting those preferences also establishes the strength of preferences. Ordering the items C, A, and B establishes preferences of C over A, and A over B, but does nothing to determine if A is closer to B or to C or is somewhere in the middle. However, weights such as C=50, A=40, and B=10 provide information about strength of preferences. One of the first text books on OR (Churchman et al., 1957) dedicated an entire chapter early in the book to this very problem of assigning meaningful weights to describe strength of preferences.

The issue of assigning meaningful weights is at the heart of a controversy within the OR community (Dyer, 1990; Dyer & Wendell, 1985; Harker & Vargas, 1990; Saaty, 1990). Common methods of assigning weights include: utility functions, data envelopment analysis (DEA), and relative scales (Wallenius et al., 2008). The OR community is divided over the issue of relative scales. On one side, the literature argues for the use of utility functions, financial, and other easily quantifiable data (Dyer 1990; Dyer & Wendell, 1985). There are obvious advantages to assigning weights based on easily quantifiable data; however, many of the crucial elements of a decision cannot be easily quantified using common metrics. Some argue that in these cases the "intangibles" must be handled informally, outside of the formal decision model.

In contrast, those who argue that relative scales can be developed and included in formal decision models, would strive to create meaningful relative scales that can be combined with absolute scales. An example of this occurred in the 60's and 70's when a special task force in the US State Department was given the task of prioritizing nuclear disarmament strategies. According to one of the task force members (Saaty, 1994), all efforts towards creating credible absolute scales to measure the efficacy of different strategies were unconvincing. This led Saaty to ask different questions, which led to the development of ratio scales, which as Saaty argues, can be used to provide meaningful decision making information when no absolute scales are available (Saaty, 1996a).

The method that grew out of Saaty's new questions is called the Analytic Hierarchy Process (AHP). In recent years the AHP has been extended to the Analytic Network Process and both have become dominant tools for dealing with multiple criteria decision making (Wallenius et al., 2008). The work by Saaty (Saaty, 1980, 1996a; Saaty & Shang, 2011) is heavily grounded in research in cognitive psychology. According to Saaty, the research supports the validity of quantifying strength of preference judgments. These arguments will be discussed in detail after examining three examples, in order of increasing complexity.

The first is a personal moral reasoning example that has no numeric data. It emphasizes the prioritization process that is the foundation for Saaty's AHP. The second is an example of a group decision involving multiple stakeholders. Applying the AHP to this example leads us naturally to the concept of a stakeholder hierarchy, which provides a way of identifying stakeholders, and incorporating their priorities in greater detail while keeping the analytic requirements reasonable i.e. keeping the number of metrics manageable. This is a group rather than a personal decision and this example is used to illustrate the benefits of scenario planning, where scenarios are described in terms of different assumptions about the stakeholder hierarchy. Both of these examples are real life cases.

The third example, which is discussed in Chapter 5 is about a complex issue of growing importance: the benefits versus the potential environmental costs of hydraulic fracturing to recover shale gas, or 'fracking' for short. Fracking is the method of extracting natural gas (and other fossil fuels) that is buried deep within the earth's surface. The ethical issue in this case concerns the potential for human exposure to the proprietary chemicals used and the unknown health consequences of exposure to these chemicals. This case is characterized by high stakes for the gas and oil industries and for humans who may be exposed to the fracking chemicals. The case is also characterized by high uncertainty and risk. These three examples demonstrate of the kind of decisions that the founders of OR envisioned and that are amenable to good analysis using the tools and concepts of OR.

4.1 EXAMPLE 1: PRIORITIZING MORAL OBLIGATIONS

4.1.1 The dilemma of Steve Lewis

Steve Lewis, a recent graduate of an MBA program, was a financial analyst for a prestigious New York investment bank (Badarraco, 1997). He was invited to participate in a presentation to an important client. The client was African-American and liked to see at least one professional African-American on each team that presented to him. Steve, an African-American, had not been involved in this project and it became obvious to him that his only role in the presentation was to serve as a token black, or in Badaracco's words, to serve as an "African-American potted plant" (Badarraco, 1997, p. 67).

4.1.2 Analysis of the dilemma of Steve Lewis

Steve talked with his mentor, Andy Webster, about his reservations, and Andy, who is also African American, offered to go in his place if necessary. Steve initially declined the offer to take time to think through his decision. Steve used a decision making process recommended by Benjamin Franklin (Bigelow, 1887) to help him sort out the conflicting obligations he was feeling. The Franklin process begins by jotting down lists of pros and cons side by side. Steve's pros include:

- *Opportunity.* Steve knew when he accepted the job that the company had a strong focus on maximizing profits. Steve's participation in the project would help the company make money for shareholders and would also enhance his reputation as a team player.
- *Loyalty.* Steve felt a particular loyalty to his friend and mentor, Andy, who had offered to take his place on the team.
- *Capitalism.* Steve's MBA program emphasized the importance of market efficiency and the role of each organization to maximize their gain. The obligation to maximize gain had legal and ethical constraints, but Andy assured him 'bluffing' was okay legally and ethically.

  Steve jotted down the following items on his "cons" list:

- *Phony.* The phrase "the truth first" was frequently spoken in his home. His parents had raised him to tell the truth. He was also a devout Christian who believed in the golden rule and the importance of being honest in all his dealings with others. He wondered if the term "bluffing" used by Andy was just another word for "lying."
- *Malcolm.* This was in reference to civil rights activist Malcolm X, who had condemned "house slaves" (Badarraco, 1997, p. 12) for telling the owners what good masters they were in hopes of being assigned easier inside jobs rather than the more strenuous outside work. He wondered if he too was sacrificing his dignity by participating in the project under false pretenses.

Badaracco (1997, p. 13) describes six moral obligations that Steve was feeling:

1. Obligation to his mentor and friend Andy
2. Obligation to his firm's shareholders
3. Obligation to himself and his own career
4. Obligation to his parents
5. Obligation to his church teachings
6. Obligation to other African-Americans

All of these obligations were important to Steve, but some were more important than others. Steve realized that he would have to think carefully about his priorities before making a final decision. Badaracco focuses his ethical decision making strategies on philosophical arguments rather than analytic decision making processes, but still recognizes the value of assigning numerical weights to each consideration (Badaracco, 1997, p. 51). Badaracco argues that one must go beyond a simple rank ordering to a set of weights that provide information about strength of preferences as well. Badaracco emphasizes the relative nature of such weights:

> "There is no single objective table of moral weights and measures for everyone to use. At the core of right-versus-right dilemma are personal values, choices, commitments, and risks" (Badaracco, 1997, p. 51).

The personal and subjective nature of importance weights was a focus of early OR as they dealt with the challenge of integrating the interests of different parts of organizations, so it is not surprising that the OR community has developed several methods for establishing meaningful weights.

The ability of humans to make meaningful numerical judgments about strength of preferences has been a controversial topic in the OR profession. The arguments against using quantitative ratio scales to express preferences are that the scales cannot be proven to be meaningful. Saaty (1980) draws from early research in stimulus and response done by Weber (1846) and Fechner (1860) to strengthen the case that human beings can make meaningful strength of preference judgments.

Weber conducted experiments showing that humans could distinguish between a 20 and 21 gram weight but not between a 20 and a 20.5 weight. However, when the original weight was changed to 40, they could not distinguish a 41 gram weight, but could distinguish a 42 gram weight from the 40 gram weight. These two experiments show that the ability to distinguish two different stimuli is not based on an absolute increase but is based on a relative increase. Specifically, a 1 gram increase could be distinguished when starting at 20 grams but not when starting at 40 grams. In contrast, a 5% increase such as 1/20 or 2/40, could be distinguished for either starting point, whereas a 2.5% increase such as 0.5/20 or 1/40 could not be distinguished. Fechner (1860) verified Weber's results that noticeable differences follow a geometric progression, whose starting point is 1, rather than a linear progression, whose starting point is 0. Saaty used this research, and that of others, to argue for a using an absolute scale from which ratios are formed to measure human strength of preference.

The second issue that Saaty deals with is the limits of human cognition. He argues that human ability to make meaningful ratio judgments begins to deteriorate beyond ratios of 9. This is certainly true visually; and Saaty argues that human ability to judge visual ratios carries over to psychological judgments as well (2005). The number 9 is backed up by research in cognitive psychology. One of the most well-known studies is the paper by Miller (1956) who observed that humans could distinguish about 7 stimuli with a range of 7 plus or minus 2 leading to an upper limit of 9.

Saaty also conducted experiments to test the human ability to use different scales in making ratio judgments. In one case, involving distance measures between international cities, he compared human judgments with measured distances. He conducted the experiments using a variety of scales, one with ratio from 1 to 9 and another with ratios ranging from 1 to 27. His empirical results supported the psychological arguments for the efficacy of 1 to 9 ratio scales (Saaty, 1980, pp. 57-61).

Consider the comparison of Steve's moral obligations to his mentor, Andy, and to that of his parents. The two questions to ask about this pair to assign a meaningful judgment to this comparison are:

1. Which moral obligation is more important, the obligation to Andy or to Parents?
2. How much more important?

Badaracco provides information relevant to these judgments in this real life situation. Andy Webster was an effective mentor who helped Steve succeed in his professional work. Andy also served as a sounding board when Steve faced challenges such as the current dilemma, and he even offered to take Steve's place in this presentation.

On the other hand, Steve's parents had been active in the civil rights movement when it was dangerous to do so. His mother eventually won a bitter and costly lawsuit, suing her employer for discriminatory promotion practices. This incident played both ways in Steve's decision. On the one hand, he wondered if the current situation was an opportunity for him to walk through a door that "his mother had pried open" (Badarraco, 1997, p. 11). On the other hand, he wondered if he was setting back the efforts of his parents by participating in a project that had nothing to do with his experience, competence, and character when his parents had sacrificed dearly for people to be judged on such matters rather than their race.

Therefore, the short answer to the first question is that both obligations are important, but the powerful, up close and personal, consistent example of his parents runs longer and deeper and would probably be judged by Steve to be the more important obligation. These thoughts and feelings lead us to assume that his judgment would be a strong preference for his obligations to his parents, which leads to a 4:1 ratio favoring his parents over Andy.

Table 4.1 shows the full set of pairwise processes, the corresponding weights, and the rank order of Steve's obligations. The numbers on the main diagonal are always 1 since they represent an equal comparison of an obligation compared to itself. Judgments are made for cells above the main diagonal. For example, in the row for Andy and the column for Parents, one should enter a "1/4" meaning that Andy is ¼ times as important as Steve's parents; or to put it in another way, Steve's parents are 4 times more important as Andy: thus the 4 is entered in the row for Parents and the column for Andy.

Table 4.1 Inputs and outputs for Steve's pairwise proces of moral obligations

Comparisons	Andy	Owners	Self	Parents	Church	Race		Obligations	Relative Weights
Andy	1	1/2	1/2	1/4	1/6	1/1.5		Andy	0.0728
Owners	2	1	1	1/2	1/2	1.5		Owners	0.1351
Self	2	1	1	1/2	1/2	1.5		Self	0.1545
Parents	4	2	2	1	2	2		Parents	0.3001
Church	3	2	2	1/2	1	1		Church	0.2090
Race	1.5	1/1.5	1/1.5	1/2	1	1		Race	0.1284

The comparison of Andy to Parents is one of 15 judgments to be made above the main diagonal. Another comparison is Steve's obligation to Andy compared to his obligation to the Owners of the company. The number 1/2 in the row for Andy and the column for Owners means that Steve's obligation to Andy is half as important as his Steve's obligation to the Owners; and therefore Steve's obligation to the owners is twice as important as his obligation to Andy. The number in a cell always represents the dominance of the row element over the column element with the inverse in the transpose position. Once the numerical judgments that establish the strength of preference for Parents over Andy (about 4 to 1) and the strength of preference for Owners over Andy (about 2 to 1) are expressed then one could assume that Parents are about 2 times as important as Owners. This assumption could also be a mistake because, even though humans can make meaningful ratio judgments, this does not mean that humans can make these numerical judgments precisely (Saaty, 1980). The judgments are always fuzzy judgments that are approximately correct if done carefully and thoughtfully. Because of the lack of precision in making these judgments, it is strongly recommended that redundant judgments be made to lend more credibility to the overall weights that are derived.

The weights shown in Table 4.1 show the best match with the pairwise comparisons made for Steve's competing moral obligations. According to the derived weights, Steve's top priority is the obligation to be true to the teachings and actions of his parents. Next is the influence of his religious training. This is followed by the obligation to himself and his company, since Steve agreed to clear expectations about the importance of maximizing revenue to the company. The final two obligations, which are very close in terms of priorities, are the obligations to his race and to his mentor. The weights on these final two obligations still carry non-trivial weights, even though they are last in terms of priorities. These weights provide far better decision making information than a simple rank ordering. Steve can also use the ratio of the weights to derive other meaningful information. It is one thing to know that a certain element is more important than another (ranking), but from the pairwise comparison weights Steve can also measure how much more important one element is than another. For example, the relative weight of Self was 0.1545 and the relative weight of Andy was 0.0728 which means that his obligation to himself and his career is twice (0.1545/0.0728) as important as his obligation to Andy. Likewise Steve's obligation to his Parents and what they had taught him by example is 1.5 times more important than the influence from his religious training.

From doing the aforementioned comparisons Steve would know what is important to him in this decision and how much more important each factor is than another. Even though Steve Lewis did not actually go through the rigorous pairwise comparison process as illustrated above in Table 4.1, he may well have. Steve's actual decision was to participate in the presentation, provided that he would be involved in the presentation. He also committed to spend every available minute preparing for his part. He came to this decision using ideas from pragmatic philosophers such as Aristotle, Nietzsche, and Machiavelli. Badaracco (1997) made mention of three choices, or alternatives, that Steve could have made in this situation: to participate as a potted plant, "Potted Participation;" to not participate "No Participation;" or to participate and take part in the presentation "Active Participation". While there is no reason to not include additional options in this example it is worth noting how the comparisons weights could be used to evaluate the proposed alternatives. The individual tables in Table 4.2 contain sample pairwise comparisons of how well each alternative satisfies the specific criteria in bold. The resulting weighted vector of each individual set of comparisons is weighted with respect its criteria weight. The results contained in Table 4.3 suggest that Steve should choose to actively participate. The decision Steve made, guided by philosophical questions, is consistent and supported by the priorities derived from the pairwise process. Therefore, the pairwise analysis shown above may serve as a validation of the decision that Steve chose.

Table 4.2 Sample pairwise comparison

Andy	Potted Participation	No Participation	Active Participation	Weights
Potted	1	7	1/2	0.3660
No	1/2	1	1/7	0.0554
Active	2	7	1	0.4306

Parents	Potted Participation	No Participation	Active Participation	Weights
Potted	1	1/7	1/7	0.0554
No	7	1	1/2	0.3660
Active	7	2	1	0.4306

Owners	Potted Participation	No Participation	Active Participation	Weights
Potted	1	9	1	0.4737
No	1/9	1	1/9	0.0526
Active	1	9	1	0.4737

Church	Potted Participation	No Participation	Active Participation	Weights
Potted	1	1/8	1/8	0.0538
No	8	1	1/3	0.4019
Active	8	3	1	0.5167

Self	Potted Participation	No Participation	Active Participation	Weights
Potted	1	1/7	1/7	0.0554
No	7	1	1/3	0.3589
Active	7	3	1	0.4737

Race	Potted Participation	No Participation	Active Participation	Weights
Potted	1	1/9	1/9	0.0526
No	9	1	1	0.4737
Active	9	1	1	0.4737

Table 4.3 Results of the AHP pairwise comparisons

Obligations	Andy	Owners	Self	Parents	Church	Race	**Results**
Relative Weights	0.0728	0.1351	0.1545	0.3001	0.2090	0.1284	
Potted Participation	0.3660	0.4737	0.0554	0.0554	0.0538	0.0526	**0.1339**
No Participation	0.0554	0.0526	0.3589	0.3660	0.4019	0.4737	**0.3213**
Active Participation	0.4306	0.4737	0.4737	0.4306	0.5167	0.4737	**0.4666**

4.1.3 Lessons learned from the Steve Lewis example

The end result of a pairwise process is a weighted priority vector for the alternatives. Our experience and that of others (Hayes, 1969) is that the insight and understanding gained from engaging in a thorough analytic process is even more important than the specific numbers derived. The pairwise questions are provocative questions and an interviewee who engages seriously in the process will likely gain new insights that increase the odds of making a good decision. Steve enriched the original problem of do or don’t participate by considering the different factors that were influencing his decision. This kind of searching often provides insight into new angles of thought that can lead to new solutions. The following principles are useful in evaluating methods of assigning relative weights:

Principle 1: Develop relative evaluations: Recognize that *only* relative evaluations are required to establish priorities. Saaty goes back to stimulus/response research in the 19th century whose experiments suggest strongly that noticeable changes in stimulus follow a geometric rather than a linear progression, which implies relative percentage changes, rather than the constant absolute changes that occur in linear progressions, are what is important.

Principle 2: Make judgments as ratios: The basic unit of analysis for relative evaluations is a comparison of *two like elements* which can be compared against each other with respect to a specific criterion. By making a table of pairwise comparisons, one can derive a set of weights along with an inconsistency measure of the set of pairwise comparisons. Making pairwise comparisons is not a simple cognitive task, but it is a simpler cognitive task than comparing three or more elements at a time.

Principle 3: Use redundant judgments: Human numerical judgments are intrinsically imprecise; therefore, *redundancy* can serve as a buffer against the human inability to make precise numerical judgments.

The pairwise process shown in the Steve Lewis prioritization process is the only method available that exhibits all three principles described above. The analysis of the Steve Lewis dilemma suggests that AHP can help avoid the dangers of the Separation Thesis (Freeman, 1994; Harris, 2008), which is that business decision making has nothing to do with ethics and ethical decision making has nothing to do with business. When business decisions require that one establish priorities among objectives to be achieved, one might ask: Which is more important, objective A or B? In an ethical decision, such as the one confronted by Steve Lewis, one might ask: Which is more important, moral obligation A or B? The analytic process for these two questions is identical. In the next example of building a stakeholder hierarchy, it will be demonstrated how these ethical and business decision making processes can be integrated.

4.2 EXAMPLE 2: STAKEHOLDER HIERARCHIES AND SCENARIO PLANNING

In the Kardell case (Brooks, 2010, pp. 224-226), a plant manager must decide whether or not to replace current processing equipment with a new closed cycle process to prevent potential contaminants from getting into the river that the plant is built on. The information from the Kardell case will be used to illustrate how a stakeholder hierarchy can be built and how to use the hierarchy to establish priorities among stakeholders and among decision alternatives. This example is a natural extension of the prioritization process used in example 1, but with two important additions. First, this example is a vehicle for showing how to build a stakeholder hierarchy, which allows the decision maker to define more specific stakeholder groups without adding significantly to the computational burden. The advantage of hierarchies in general is that they allow a system to be analyzed in smaller chunks while using the hierarchy to preserve the structure of the whole system.

The second feature in this example that is different from the previous example is that this is a group decision in contrast with the personal decision faced by Steve Lewis. In the Steve Lewis example, the priorities were Steve's priorities. The challenges for Steve were to recognize and establish *his* priorities. In the Kardell case, the decision making process includes a variety of different interest groups which means that different individuals and groups may have incredibly different priorities that are held very strongly. In situations with strong and conflicting priorities, a decision process called Scenario Planning can be very helpful (De Geus, 1997; Schwartz, 1991; Senge, 1990).

The significant shift when one engages in scenario planning is that the prioritizations are not a reflection of what the whole group thinks. Instead, a multitude of scenarios are created, reflecting different priorities held by different subgroups at the decision making table. De Geus defines a scenario as "an imaginative story of the future" (De Geus, 1997, p. 44) suggesting that scenarios are verbal descriptions of such imaginary situations. However, a limitation of Verbal Scenario Planning (VSP) is that each scenario is fixed. This limitation can be overcome by introducing the scientific method into scenario planning. The centerpiece of the scientific method is a flexible decision model, described in a mathematical language rather than verbally. This flexible model will give the researcher the ability to experiment with different variations of each scenario, leading to greater understanding and insight than can be gained with a fixed verbal scenario.

4.2.1 Stakeholder theory

Stakeholder theory is a proactive approach to systematically manage the relationships of multiple entities who have a stake in the success or failure of the organization (Freeman, 1984; Freeman et al., 2010). This approach differs from focusing solely on the shareholders which are sometimes referred to as stockholders. Freeman (1984) argues the decision is no longer about just taking a product to the market, rather the decision must incorporate the short and long term considerations of each entity affected by the product. In stakeholder theory, the shareholders are no longer the only stakeholder whose value or benefit should be maximized; however there are clear distinctions between stakeholder theory and corporate social responsibility (Freeman et al., 2010, p. 93). The term stakeholder first appeared in the literature in 1963 referring to shareholders defined as "those groups without whose support the organization would cease to exist" (Cyert & March, 1963). This definition was quickly expanded by system theorists Churchman and Ackoff (Ackoff, 1972; Churchman, 1968) to look at multiple players within the system. Since its inception, stakeholder theory has been subject to many criticisms. In response to this skepticism the theory has been revised and empirical research has tested for the implication of the theory on an organization's performance. A brief overview of the main findings and implications of stakeholder theory is presented below.

The initial discussions about stakeholder theory focused on defining the extent of an organization's impact. The organization's impact could be narrowly defined as the returns it provides to shareholders. While shareholders are directly impacted by the organization's performance with the advances in information technology, there is also an increased societal awareness of the impacts an organization has on the larger community (Freeman et al., 2010, p. 5). Stakeholder theory addresses the following questions: For whom is value created and destroyed? Who is harmed or benefited by this action? Freeman et al. (2007) have grouped the answers to the previous questions into two categories: primary and secondary stakeholders as proposed in Figure 4.1.

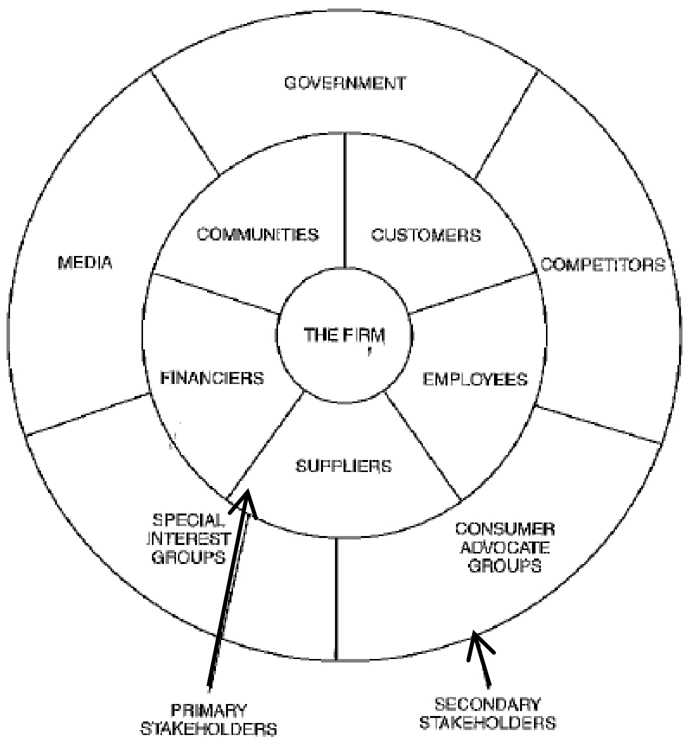

Figure 4.1 Primary and secondary stakeholders

Primary stakeholders are the groups that are directly impacted by the decisions a firm makes. For example, suppliers and employees will be directly impacted by the firm's decision to eliminate a product. Secondary stakeholders are those groups or individuals who are indirectly affected by the firm's decisions. A criticism of this approach in modeling and including any group who benefits or suffers from the actions of an organization is that it would require including everyone (Jensen, 2002; Sternberg, 1997). However, through a prioritization process of pairwise comparisons it would be simple to identify and include only the most relevant stakeholders of the many who might have an interest.

The other key argument stems around the issue of social responsibility and profit maximization. One might argue the social responsibility is nothing more than enlightened self-interest because an organization should not do something that does not ultimately benefit the shareholders. Friedman argues that if a business is located in a small community it would benefit from investing in the community; this benefit to the community is not in the name of corporate social responsibility (CSR), but rather in that of capitalism because it is in the corporation's self interest (Friedman, 1962, p. 132). While Freeman argues this approach is a stakeholder approach, he addresses differences between stakeholder theory and CSR. First, under a stakeholder theory approach an executive's job is to maximize the value for all stakeholders and, as needed, to confront the trade-offs between them (Freeman et al., 2010, p. 28). Second, CSR started by only looking at and valuing the "environment, special interest groups, social causes, community, employee interest" (Freeman et al., 2010 p. 95) which a corporation impacts in absence of any economic considerations. According to Freeman, CSR also strays from stakeholder theory by not also including the corporation, shareholders, suppliers, and customers as stakeholders in the decision. This more integrated approach is crucial to avoid steering an organization away from its core competencies and overall objectives.

Another criticism of stakeholder theory is the complexity it can add to a decision. The complexity of stakeholder analysis can be addressed by the AHP or Analytic Network Process (ANP). The ANP is an extension of the AHP. Freeman et al. (2010) list many of the additional considerations decision makers using stakeholder theory might address:

- The need to identify networks or large systems of interactions (p. 46)
- The stakeholders provide the firm with Opportunities and Risks (p. 36)
- The stakes of each stakeholder are multifaceted and inherently connected to each other (p. 27)
- The question of how to score and combine the stakeholder interests (p. 12)
- The relationships or interactions among the stakeholders (p. 24)
- The ability to look at both the short and long term impacts of decisions (p. 102)
- The ability to identify the groups that make a difference (p. 42)

As indicated by its name the ANP is particularly adept at analyzing large systems or networks; however, the most salient characteristics of the ANP is that it handles dependence and feedback among the elements in a decision. According to Freeman's suggestions the dependence and feedback in an ANP model allow the decision maker to capture the connections between stakeholder's stakes and the relationships and interactions among the stakeholders. The ANP has often been applied to analyze large systems where opportunities and risks can be combined with and analyzed side by side with the costs and benefits in a benefits, opportunities, costs, and risks (BOCR) model. In a BOCR network, decision makers separately design and individually evaluate sub-networks for the benefits, opportunities, costs, and risks. The ability to evaluate each network individually and then synthesize and combine them together allows the decision maker to focus specifically on the benefits an element or criterion provides and how it affects other elements in the benefits network. Then the costs of that element and its influence on other costs within the network are evaluated. Within each network the inherently connected stakes, suggested by Freeman, are identified and weighted through the pairwise comparisons; likewise the relationships among stakeholders can also be modeled and evaluated.

The results from the BOCR sub-networks are combined into a final vector of priorities using one of two formulas: the additive or the multiplicative formula. The additive formula is bB+oO-cC-rR where the lower case letters (b,o,c,r) refer to weights applied to each of the final vectors in the benefits, opportunities, costs, and risks networks. The multiplicative formula is BO/CR where the final vectors are combined. By using both the multiplicative and the additive methods the decision maker is able to look at the short term (multiplicative) and long term (additive) impacts of different options that are considered. Finally, the decision makers should be interested in the robustness of the results. Sensitivity analysis may be performed to determine which factors and/or stakeholders carry the most influence in the decision and the changes in the outcomes when their weights are changed. The relative influence of various criteria can be analyzed. As the weights are changed and new vectors are calculated it is easiest to plot the vectors and visually interpret the relative position of each alternative. Examples of sensitivity analysis will be given shortly.

Organizations that engage in stakeholder analysis can reap the following potential benefits (see Table 4.4) which Freeman terms "economic justification:"

Table 4.4 Economic justification for stakeholder analysis

The Ability to Avoid:	**Advantages:**
Legal Suits	Risk Management
Adverse Regulation	Adaptability
Consumer Boycotts	Contract Coordination
Strikes	Organization Flexibility
Walk Outs	Trustworthiness (Agency Theory)
Bad Press	Implicit Monitoring
	Competitive Advantage
	Excellent Customer Relationships
	Alliance Formation
	Long Term Contracts
	Joint Ventures
	Lower Transaction Costs
	Reputation

Freeman also explains that many of these benefits are not easily substitutable in contrast to technological advantages which competitors can adopt (2010). By developing non-substitutable advantages organizations create competitive advantages.

There is empirical evidence regarding the advantages of using a stakeholder theory approach. Preston and Sapienza (1990) analyze data provided by Fortune magazine which it obtained by surveying employees from the top ten performing companies in the following industries: Basic industries, Industrial products, Consumer goods, and Services. The data from each company is measured over a five year period 1982-1986 from which Preston and Sapienza identify eight dimensions of corporate performance that influence the following stakeholders: shareholders, employees, customers, and communities. Preston and Sapienza also extract an additional variable regarding the "ten-year total rate of return" from a separate Fortune Magazine survey. The correlation between the variables is listed in a correlation table. The results showed high correlations between the measurements indicating a positive association and strong intercorrelation and supporting the claims of stakeholder advocates that focusing on stakeholders will benefit the stockholder in the long run (Preston & Sapienza, 1990).

Greenley and Foxall (1997) tested the ability of UK organizations to address multiple stakeholders' interests and the impact of those efforts on the company's market growth. The sample included surveys of executives from 1000 companies with over 500 employees. Companies were categorized into three groups: high, medium, and low performance for each of the five clusters relating to stakeholder theory. The results suggest that it is worthwhile to allocate resources to address stakeholder's interests.

The results are also moderated by conditions in the external environment (Greenley & Foxall, 1997). This moderation should include a balanced approach to meeting joint stakeholder interests and not focusing on a single stakeholder. Furthermore while many companies that have a high emphasis on their stakeholder approach benefit from allocating resources to satisfying stakeholders' desires, few companies are able to find the right balance of stakeholder management that will improve their overall performance (Greenley & Foxall, 1997).

In the context of supply chain management, Brewer and Speh (2000) show that using the Balanced Scorecard (BSC) approach encourages coordination and focused efforts throughout the supply chain that can provide real benefits when both long term and short term motives are rewarded. A BSC can help organizations focus on qualitative and quantitative performance measures. The BSC is also designed to incorporate performance measures of the impact of multiple parties within the supply chain which allows managers to manage the entire supply chain more effectively. This focus on the other parties within the supply chain put forth by Brewer and Speh could be assimilated with managing the stakeholders within the supply chain. The benefits of applying the AHP to incorporate stakeholder analysis in the decision making process are demonstrated by the analysis of the issues at stake in the Kardell Case.

4.2.2 Kardell case

The essential features of the Kardell case are:

- Kardell is a paper company, built around 1900, situated on a river; several newer plants have been built in addition to the original, but the original plant is still the firm's largest profit center
- The original plant is still functional but was not designed with environmental protection in mind

- There is a residential community downstream from the plant
- The assistant production manager, an engineer and a father of two young children, conducted water quality tests all across the river, and found there were higher concentrations of an industrial chemical, sonox, near the plant than farther away from the plant
- The engineer proposed updating the plant to have a "closed cycle" to prevent sonox from getting into the river; replacing the old process would require a significant monetary investment and downtime for the plant's employees

The decision facing the plant manager was whether or not to replace the old system with a new system which ran a closed cycle to prevent contaminants from getting into the river.

4.2.2.1 Building a stakeholder hierarchy

A good starting point for a stakeholder analysis is to make a list of relevant stakeholders. Freeman notes that broad stakeholder groups like "Government" are not specific enough to identify stakeholder interests (Freeman, 1984, p. 54). He continues by noting that it is the specific agencies "who can take actions to affect the achievement of an organization's purpose" which must be identified.

Freeman observes that the generic stakeholders that often surface from a list are too broad to be useful in understanding stakeholder interests. Wolfe & Putler (2002) observe a similar principle when they argue that the role that a group plays is not sufficient to determine preferences for the decision alternatives. In the Kardell case, two shareholders may have the same role but may have different preferences for the decision alternatives; for example, the first shareholder might be interested in short term returns while the second is interested in long term returns. To make the definitions of the stakeholders more specific, Figure 4.2 partitions shareholders into short term and long term shareholders. These specific stakeholder groups are better suited than generic stakeholders for establishing the relative preferences for the competing decision alternatives.

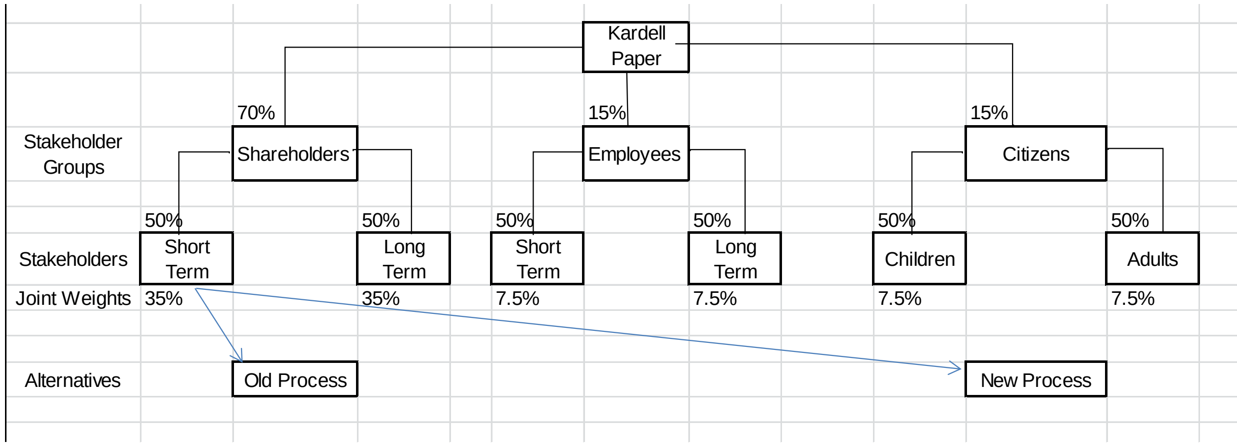

Figure 4.2 A stakeholder hierarchy for the Kardell case

The levels of the hierarchy in Figure 4.2 represent different degrees of specificity. Broad stakeholder groups such as shareholders, employees, and community are at the top of the hierarchy; as one moves down the hierarchy, the sub-stakeholder groups become more specific. The process of sub-dividing a stakeholder group continues until one identifies sub-stakeholder groups that are *sufficiently homogeneous* to consider their preferences for the available decision alternatives.

The term "stakeholder hierarchy" is used to distinguish broad stakeholder groups, near the top of the hierarchy, from more specific stakeholders nearer the bottom of the hierarchy. Relative weights are used to convey the relative importance of each of the stakeholders and sub-stakeholders. These weights can then be used to specify a set of scenarios.

Table 4.5 shows a baseline scenario that weights all stakeholders equally at all levels. Table 4.5 also shows the preferences for each bottom line sub-stakeholder group. For example, shareholders are 1 of 3 broad stakeholder groups and therefore are assigned 1/3rd, or 33.3% of the weight. But from the discussion above, shareholders are not sufficiently homogeneous in their preferences, so equal weights are assigned to short and long term shareholders. Since shareholders carry 33.3% of the weight and since short and long term shareholders are equally weighted in this scenario, they both carry half go the shareholder weight of 16.7%. Other total weights are derived in a similar manner, such that all six bottom line stakeholders carry 1/6th or 16.7% of the weights.

Scenario 1: Equal Stakeholders							
Stakeholder Weights							
Level 1 Stakeholders	Shareholders		Employees		Community		Total
Level 1 Weights	33.33%		33.33%		33.33%		100.00%
Level 2 Stakeholders	SH:Short	SH:Long	Emp:Short	Emp:Long	Com:Child	Com:Adult	
Level 2 Weights	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	
Level 1 & 2 Weights	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%	100.00%
Decision Weights							
Stakeholder	SH:Short	SH:Long	Emp:Short	Emp:Long	Com:Child	Com:Adult	
Stakeholder Weights	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%	Decision Weights
Old Process	0.8571	0.2000	0.8000	0.2500	0.1429	0.2000	0.4083
New Process	0.1429	0.8000	0.2000	0.7500	0.8571	0.8000	0.5917

Table 4.5 A baseline scenario with equal weights for all stakeholders

4.2.2.2 Quantifying stakeholders preferences

The next step in the analysis is to quantify the preferences of each bottom line stakeholder. These preferences can also be expressed through pairwise comparisons. For example, the 6 to 1 comparison for short term shareholders indicates that short term shareholders have a strong to very strong preference for the old process while the 4 times more preferable comparison for long term shareholders indicates a strong preference for the new process. The other four points can be interpreted in a similar manner.

Before moving to the final comparison step, it is important for the reader to remember that decision making only requires relative comparisons of the decision alternatives; it does not require rating each alternative on an absolute scale such as dollars or widgets. If you have a credible scale to use to compare decision alternatives, by all means, use it. But in many complex executive decisions with high moral content, decision makers deal with intangibles that are difficult to measure or for which no absolute scales exist. In these situations, relative comparisons of the alternatives provide sufficient information to identify the best alternative. The result of this weighting process is that the alternative to stay with the old process provides 41% of the value while the new process provides 59%. The conclusion of scenario 1 is that *if* all stakeholders are equally weighted, then there is a definite preference for the new process over the old process.

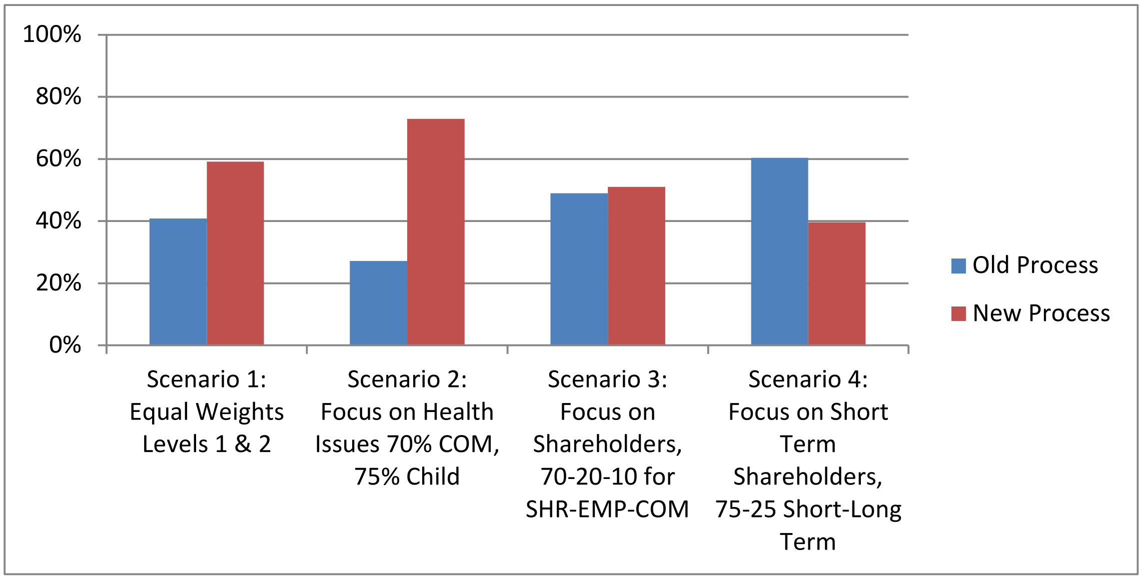

Figure 4.3 Outcomes under 4 scenarios

Figure 4.3 summarizes three additional scenarios. Scenario 2 focuses on community health issues by assigning 70% of the total weight to the community with 75% of that weight going to the children who are more at risk than adults in situations like this.

Scenario 3 focuses primarily on shareholder (70%) with a secondary focus on Employees (20%) with the remaining 10% of the weight assigned to the community. The surprising result is that the new process is very slightly better (51 to 49). The explanation for this is that by maintaining a 50-50 split for shareholders and employees, which means that long term shareholders and employees nearly neutralize the preferences of short term shareholders, while both children and adults in the community both favor the new process.

Scenario 4 focuses on short term shareholders by keeping the same level 1 weights as scenario 3 but assigning 75% of this shareholder weight to short term shareholders. With these assumptions, the old process is favored by a 60-40 margin as would be expected with over 50% (70%*75%=52.5%) of the weights on short term shareholders.

The patterns that surface by analyzing these four scenarios show that the only way to justify staying with the old process is to focus strongly on the short term for both shareholders and employees. This is exactly what happened in the real case (Brooks, 2009, personal communication). The decision making body consisted of representatives for shareholders and employees with no representation for the community health concerns. This body decided to stay with the old process using some variation of scenario 4 to rationalize the decision. Unfortunately, it soon became apparent that the health risks were real and were connected to Kardell production processes. Without the support of the community, the plant was shut down resulting in a loss of value for shareholders and a loss of jobs for employees.

4.2.3 Lessons learned from the Kardell case

The underlying ethical issue in this case is a desire to know the truth. Conducting a detailed stakeholder hierarchy suggests that the decision maker desires to know the truth, even if it points towards voluntary action that has negative short term effects. The corresponding vice on the other side of this virtue can be described as willful ignorance. It is easier to justify what may turn out to be a bad decision if one engages in willful ignorance. But even if the choice to avoid knowing some unpleasant facts is legal, the ethical issues remain.

In chapter 5 this issue of desire to know the truth will be covered in an even more prominent decision involving fracking. The ethical issue is similar to the Kardell case, pitting certain benefits to the industry for inaction against an uncertain health risk to the community. The difference in the fracking example is that much more is at stake and much more is unknown. These features involve a complex decision process which can benefit greatly from the use of the ANP.

One feature of the Kardell case that was glossed over in this section was the uncertainty about the connection between Kardell production practices and the health issues showing up in the community. The uncertainties in the link between production and illness were dealt with only through discounting the benefits of the new process. For example, a strong to very strong 7 to 1 comparison between the new and old processes for children in the community was used. If the link was certain, this preference probably would have been a 9 to 1 comparison. The preferences of the new process would also have increased for the adults in the community if the link had been certain.

4.3 ETHICS AND THE ANP

After presenting these two examples of ethical decision making, the Steve Lewis Dilemma and the Kardell Case, and demonstrating the benefits of using the AHP/ANP and pairwise comparisons, the question is whether ethical issues can be incorporated into complex ANP decision models in general. It is the author's opinion that ethical issues are naturally included in complex BOCR models. This natural step has not led to the distinct incorporation of an "ethics" or "ethical" cluster per se but with clusters and nodes that specifically address ethical issues. The specific ethical issues fit in with the clusters which contain other elements that are related to a specific cluster. To have separate clusters would return to the idea of the Separation Thesis where business and ethics are separate. According to Freeman et al., (2010) ethics should naturally be considered in business decisions as a value-adding core activity. The AHP and ANP naturally facilitate the direct incorporation of ethical issues and considerations.

4.3.1 Literature review of ethical issues in ANP models

There is a variety of ethical issues that have been addressed in previous ANP models. To investigate this point and to observe the frequency in which ethical issues have been incorporated the following tables present a literature review of the *Encyclicon* Volumes 1, 2, and 3 (Saaty & Cillo, 2008; Saaty & Ozdemir, 2005; Saaty & Vargas, 2011). which are compendiums of complex BOCR decision models. The *Encyclicons* contain detailed models and can be used as a reference to build similar models. Each application has a summary report with diagrams of the networks and elements, tables of the priorities and the final results. A total of 217 models were examined to obtain the information provided below. The first table (Table 4.6) is a set of summary statistics indicating how many models were reviewed and the average number of ethical elements in each model. Next, a list of criteria or clusters that addressed ethical issues is presented (Table 4.7). Finally, specific ethical elements are categorized and listed in 8 separate tables: Stakeholders (Table 4.8), Corporate Social Responsibility (Table 4.9), Image (Table 4.10), Health

(Table 4.11), Public (Table 4.12), Environment (Table 4.13), Diversity (Table 4.14), and General Ethical Elements (Table 4.15).

Table 4.6 ANP models addressing ethical issues

Number of Models	Ethical Elements Per Model	Models with Ethical Elements	Ratio of Ethical Models	Ethical Elements Per Model
217	5.26	98	45.2%	11.64

Table 4.7 Ethical clusters in ANP models

Abuse of Power	Development	Image - Brand	Political
Accountability	Ecology	Image - Business	Political Acceptance
Animal Rights	Education	Image - City	Political Actions
Behavior	Effectiveness	Image - National	Poverty
Beliefs	Employee Welfare	Image - Personal	Privacy
Bureaucracy	Environmental	Impact on Society	Protection
Civic Opportunity	Environmental Hazards	Individual Experiential	Psycho-Social
Civil Rights	Environmental Damage	Individual Psychological	Public Health
Class Structure	Equality	Individuals	Public Interest
Community Assistance	Ethics	Instability	Public Opinion
Community Relations	Family Time	Interactive/Interpersonal	Public Service
Consumer Safety	Foreign Policy	International Relations	Public Welfare
Costs to Constituents	Freedom	Jobs	Quality
Cultural Distance	Happiness	Labor	Quality of Life
Cultural Wealth	Health	Lifestyle	Religious Beliefs
Culture	Human Rights	Migration	
Customer Service	Human Well - Being	Organizational Cooperation	
Dangers	Identity	Perception of Fairness	

Table 4.8 Stakeholders in ANP models

Agents	Debt Holder	Neighborhood	Staff
Business	Employee	Partners	Stakeholder Satisfaction
CEO	Family	Patients	Stockholder
Children	Government - Federal	People	Supplier
Client	Government - Local	Product	Vendors
Community	Government - State	Refugee	Victims
Company	Humanity	Residents	Victims' Family
Country	Individual	Shareholder Wealth	
Customers	Insured	Skilled Workers	

Table 4.9 Corporate and social responsibility elements

Community Impact	Philanthropy	Social Responsibility
Corporate Citizenship	Quicker Commutes	Societal Benefits
Corporate Impact	Sense of Community	Trade Relations
Humanitarian Aid	Short Term Effect	
Long Term Effect	Social Capital	

Table 4.10 Elements addressing image in ANP models

Beneficial Press Coverage	Improvement	Social
Brand	Individual	World
City	Media Perception	
Corporate	Public	

Table 4.11 Elements addressing health in ANP models

Awareness	Human Psychology	Number of Fatalities
Chronic Health Issues	Injury	Obesity
Death	Life Expectancy	Psychological
Disease Eradication	Mental	
General Well Being	Mental Outlook	

Table 4.12 Elements addressing public issues in ANP models

Democracy	National, City Pride	Public Health	Relationships
Diplomatic Relations	Participation	Public Opinion	Residents Opinions
Foreign Relations	Property Rights	Public Relations	Unemployment
Foreign Trade	Public Acceptance	Public Safety	
Minority Parties	Public Good	Public Services	

Table 4.13 Elements addressing the environment in ANP models

Acid Rain	Energy Demand	Low Sulfate Emission	Safe Work Place
Air	Environmental Containment	Noise	Safety Regulations
By -Product Disposal	Environmental Effects	Nuclear Threat	Self-Dependent Fuel Economy
Cleaner Environment	Erosion	Ozone Depletion	Sustainability
Climate change	Gas Emission	Pollution	Ultra-clean environment
Disease	Global Warming	Protection	Water
Dust	Greenhouse Effect	Radiation	
Ecological	Land	Renewable	
Emissions	Low Nox Emission	Residuals	

Table 4.14 Element addressing diversity in ANP models

Civil Liberties	Hate Groups	Offender's Rights	Social Freedom
Class	Human Rights	Pay Gap	Social Norms
Cultural	Income Class	Profiling Concerns	Special Interest Groups
Ethnicity	Language	Race	
Gender	Minorities	Religious	

Table 4.15 Ethical elements in ANP models

Acceptance	Donations	Justice	Respect
Addiction	Economic Advancement	Leadership	Respect for Humanity
Agency Liability	Economic Redemption	Learning	Responsibility
Agricultural Sufficiency	Embarrassment	Legality	Revenge
Animal Rights	Emigration	Loyalty	Right to Know
Attitudes	Employee Retention	Mercy	Right to Punish
Awareness	Enforcement	Mistreatment	Satisfaction
Basic Needs	Equality	Morale	Security
Behavior Modification	Ethical Standards	More Time	Self Discipline
Birth Rate	Ethics	Motivation	Selfishness
Bounded Rationality	Eviction	Naturalist Treatment	Sense of Belonging
Brand Durability	Exposure to Future Generations	Open-mindedness	Service
Calling	Fairness	Opportunity Costs	Social Integration
Civic Conscience	Familial Well Being	Optimism	Social Justice
Civic Responsibility	Family Councils	Organizational Learning	Spillovers
Coherence	Family History	Peer Pressure	Spiritual Beliefs
Communication	Family Upheaval	Personal Beliefs	Spoils System
Competition	Fear	Personal Growth	Spread of Soft Power
Complacency	Financial Stress	Population Shift	Stability
Conflict	Flow of Information	Poverty	Standard of Living
Consumer Anxiety	Forgiveness	Preparedness	Status
Consumer Confidence	Free Decision	Prestige	Stigma
Control	Goodwill	Prevention	Stress
Convenience	Group Cohesion	Privacy	Subsidies
Cooperativeness	History	Productivity	Suffering
Cost of Living	Homogeneous Thought	Prosperity	Superiority Complex
Courteous Behavior	Identity	Public Programs	Sustainable Employment
Creating Contributors	Illiteracy	Punishment	Synergy
Crime	Image	Quality of Life	Technological Advancement
Cultural Awareness	Immigration	Redundancy	Torture
Cultural Integration	Impact on Work Ethic	Regulation	Trust
Customer Loyalty	Independence	Reliance	Volunteerism
Danger	Infrastructure	Religion	Wasteful Spending
Death	Innovation	Reputation	
Dependency	Integrity	Research	
Discipline	Job Security	Resource Availability	

The elaborative list of ethical elements in the tables demonstrates the vast array of ethical issues that have been included and addressed within complex ANP decision models. The variety of ethical issues that have been captured and incorporated with the ANP underscores the benefits that using the ANP can provide to ethical decision makers. These lists may also serve another purpose as a general reference for individuals developing ANP models who are looking to consider and include ethical elements in their models.

The example in the next chapter is essentially the same issue as the Kardell case: a right decision to put an important product into the marketplace vs. a right decision to conduct business in a way that preserves human health. The issue in example 3 addresses the modern method of choice for extracting natural gas that is buried deep beneath the earth surface, called hydraulic fracturing (fracking). The stakes are very high here since it involves an entire industry, can affect the national energy policy, and many more people are affected by fracking than by the original Kardell plant. The decision is greatly complicated by the high degree of uncertainty about the probability that fracking fluids end up in human water sources and the severity of the potential effects from fracking fluids if they do get into drinking water supplies. These conditions call for the best decision making tools and concepts available and the ANP has much to contribute to discussions of risk and uncertainty as well as dealing with problems that have impacts of various levels of severity.

5.0 GLOBAL EXAMPLE: HYDRAULIC FRACTURING, DEALING WITH HIGH STAKES AND HIGH UNCERTAINTY

Current energy demands in the United States are rapidly changing. Not only is there an increased demand for energy; but that increased demand is coupled with an increase in the stipulations demanded by the users. Some of the stipulations include pricing, the use of renewable energy sources, "cleaner" energy according to different environmental and health standards, and regional or political independence (Agbaji et al., 2009; Bierman et al., 2011). The issues around meeting the demand for energy while satisfying the stipulations and concerns of interested parties rapidly become very complex in terms of the economic considerations alone. As environmental and ethical concerns enter the decision the need for methods to compare and combine these concerns arises. In the context of the previous two cases it can be argued that the ANP is an effective OR tool to address complex decisions, and in particular those involving multiple parties and ethical issues. In this chapter, an ANP model is developed to capture and measure the economic, environmental and ethical concerns, which will be discussed in greater detail, with respect to their impact on the stakeholders.

One form of energy production that has garnered a great deal of national attention in the last few years is hydraulic fracturing (fracking). While fracking was developed 60 years ago, recent advances in technology significantly reduced the costs of extracting Natural Gas (NG) through fracking methods. At the same time the cost of NG had been sharply increasing (Lewin et al., 2011). It is this dual combination of events which created an opportune environment to tap into a previously economically infeasible source of NG. Fracking and NG have the potential to satisfy many of the stipulations demanded by energy users such as political and regional independence, pricing, stimulating the US economy and others which will be discussed in greater detail below. At the same time fracking has also been labeled as a practice with many potential downsides such as adverse health and environmental effects which will also be discussed in greater detail below. While most of the costs and benefits are clear and easy to identify, many of the risks have not been clearly linked and determined to be a cause and effect result of fracking. This level of uncertainty creates another level of complexity in the analysis of the issues regarding fracking. Simply put, this is a decision dealing with high stakes and high levels of uncertainty. Through the use of homogeneous clustering (Saaty & Shang, 2011) within an ANP decision model and a thorough sensitivity analysis it can be demonstrated how an intentional focus on stakeholders and their joint interests would benefit the NG industry and its customers in both the short term and the long term.

While it may seem obvious to recognize and work with stakeholders, one must ask, "then why isn't it being done?" In the literature there is an abundance of examples demonstrating that in fact the opposite is being done and stakeholders are not working together.

"Perhaps one of the biggest problems with [this] energy initiative is his conviction that industries will voluntarily adopt. As long as costs are not realized up front … Environmentalists and industry need to come to the table with government, and we need to quantitatively assess the data through unbiased eyes. Energy production certainly has its risks, but they can be mitigated through proper training and planning" (Gleich, 2011).

"However, it is important that all interested parties work together to solve the environmental concerns so that the benefits of shale gas development can be fully realized for generations to come" (Goldman, 2011).

"Natural gas is a critical chapter of our present and future energy story and hydraulic fracturing appears set to be an important character as the rest is written. The great potential of this practice is, however, bounded by significant public concern and scientific uncertainty. … Natural gas, like coal and oil, is destined to be a significant part of our nation's energy mix for years to come and so it is critical that we take the necessary steps now to ensure that it is a sustainable future for everyone" (Dammel, 2011).

One might argue that the question about why a stakeholder approach has not been implemented, or even argue that the question is irrelevant because the industry is only responsible to its shareholders and customers. However, similar to the Kardell case, mentioned in the previous chapter, in this example it is also demonstrated that the industry's best interest is to use a stakeholders approach which will be most beneficial to the shareholders in the long term.

With various stakeholders actively pushing their own agendas and the release of various reports stating opposing evidence, important decisions will be made over the next few years that will significantly impact the fracking and NG industry. Two common solutions proposed in the literature are almost polar opposites. The first solution is to maximize profits and use this natural resource to its full extent particularly because there is no clear evidence of any harm. The other extreme is to abolish all fracking or impose a moratorium until there is clear evidence fracking poses little to no risk. Neither of these solutions is practical given the current energy demands and solutions. Energy consumers are very sensitive to the decisions regarding energy policy which they feel directly impact them as citizens. According to Ferrey (2005), the public outcry regarding energy brown outs in California ultimately led to the recall election of the state governor. Likewise citizens and organizations are unwilling to turn a blind eye to the potential harm as demonstrated by recent movements in response to BP Deepwater Horizon oil spill (Liss, 2011) and sweatshops (Dara, 2006; Ebenshade, 2004).

If the NG industry is willing to take a stakeholder approach it has the potential to increase its current market share within the energy industry and remain a key contributor as additional forms of energy, and renewable sources in particular, continue to gain market share. As will be seen in the ANP model, during the short term additional costs are incurred in order to foster the stakeholder approach. A stakeholder approach can be viewed as an intangible form of capital that will place the NG industry in a position that when combined with other tangible benefits that NG has to offer will foster long term competition in the energy industry.

5.1 NATURAL GAS

NG is an abundant nonrenewable source of energy that exists in large abundance within the United States. NG is a byproduct of decaying material. Most nonrenewable sources are a result of organic matter that has been covered before it decomposed so that the byproduct of the decomposition has been trapped within the earth's crust. While most of the NG that is consumed within the US originates from wells that tapped into this trapped gas, new methods are also being developed to more rapidly "digest" and produce NG from organic matter (EIA, 2011b). According to the American Gas Association (AGA), NG accounts for ¼ of the energy consumption within the US, it is the cleanest and most efficient fossil fuel, and can be delivered throughout the entire US through underground piping systems. In 2009 there were 493,100 operating NG wells (EIA, 2011b). As more easily accessible sources of NG have already been extracted and exhausted new ways to extract NG have been developed. The timeline of the development of the NG industry is worth reviewing.

The first NG well is claimed to have originated in NY in 1821 (EIA 2011a). Since that time this type of more easily accessible NG has been tapped and used. Currently, hydraulic fracturing is the method of choice for extracting natural gas that is buried deep beneath the surface of the earth. This method, first used in Texas in 1947 (Bierman et al., 2011), operates by forcing water, sand, and chemicals into pipes that reach deep within the earth's crust to the source of the NG. The mix of fluids is pumped into the wells at very high pressures which fracture the rocks and earth immediately surrounding the well. The sand that has been mixed into the fracking fluid now plays a pivotal role as it moves into the cracks and forces the cracks to stay open. Keeping these cracks or "fractures" open facilitates greater amounts of the gas to escape from underground. The NG then rises to the earth's surface through the well piping. This process has provided access to huge gas reserves which were previously inefficient to extract.

The ability to perform horizontal drilling is the other critical advancement in drilling technology that has led to such a rapid expansion of hydraulic fracturing. An initial vertical well is drilled to depths of over a mile deep; and then the drill bit is turned horizontally and drilling continues for up to an additional mile (EIA, 2011b). Horizontal drilling provides a significant increase to the amount of NG that can be extracted from a single site. More gas from a single site not only increases the profitability of each well but also reduces the number of wells needed to extract the gas thereby not only reducing drilling costs, but also reducing the footprint on the surface (EPA 2011). The reduction in wells can be up to as many as 15 per square mile of land (Sweeney et al., 2009). Horizontal drilling also raises issues about property and mineral rights; however, in the current literature it appears the current contract and leasing rights address these particular issues (Lewin et al., 2011; Liss, 2011).

These new processes are important advancements because natural gas is a relatively clean and cheap fossil fuel which is still in abundance in the United States. There are four primary areas or sources of NG in the US (see Figure 5.1): Marcellus Shale (New York, Pennsylvania, Ohio, and West Virginia); Barnett (Texas); Barnett-Woodford (Oklahoma); Haynesville (Texas and Louisiana); and Fayetteville (Arkansas). Alaska has more NG than the lower 48 states combined (EIA, 2011c). Due to current legislation protecting the land where the reserves exist and the nonexistence of a pipeline to economically transport the NG to the lower 48 states the Alaskan reserves will not be considered further in this paper. It is worth noting there are no reasons the model and assumptions would change by including Alaska. The same risks and benefits would apply. An estimate of the amount of NG and extractable NG in each of these aforementioned regions is presented below in Table 5.1.

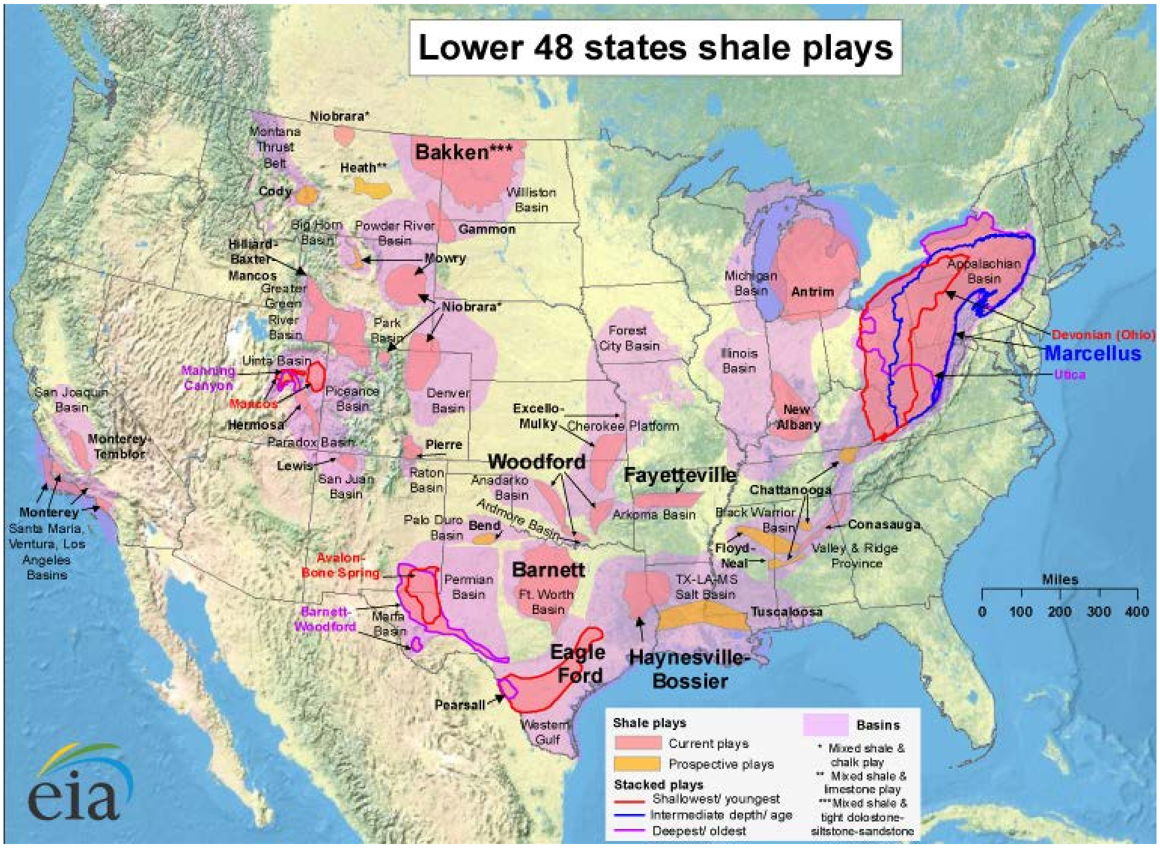

Figure 5.1 Shale plays in the US

Table 5.1 Trillion cubic feet (TCF) of natural gas in the lower 48 states

Shale Play	Shale Gas TCF
Marcellus	410
Haynesville	75
Barnett	43
Fayetteville	32
Barnett- Woodford	32
Others	158
Total	750

5.2 UNCERTAINTY

As was mentioned previously, the Hydraulic Fracturing case is similar in many ways to the Kardell Case. The fundamental ethical issue is the same: the conflict between providing a useful product involving synthetic chemicals while taking responsibility for unanticipated externalities that may cause health harm to innocent victims. Because of this similarity, stakeholder analysis would be a good starting point of analysis. Despite the similarities, there are also significant differences between the Kardell and the fracking examples. The stakes are much higher in the fracking case. While the Kardell case involved one division of one company in the paper industry, fracking is an industry-wide practice with a very large customer base, huge economic impact, large numbers of citizens with risks from direct exposure, and even more citizens that could suffer from indirect exposure that could occur hundreds of miles away. In response to the uncertainty and high stakes, the state of New York has imposed a temporary moratorium on fracking to prevent contamination to water in the Delaware River Basin which supplies water that is clean enough to be left untreated to the 8 million citizens of New York City (Liss, 2011).

The degree of uncertainty is also much higher in the fracking case than in the Kardell Company, where much was known. The chemicals used by Kardell were known, at least to the company engineer who conducted the studies and was lobbying for the new process. It was also known that concentrations of the chemical a\were higher nearer the plant than farther away from the plant. This information does not prove a connection between Kardell production and human health issues, but it provides some strong evidence that a link between the two may exist.

In contrast, the uncertainty in the fracking case is very high. First of all, there is uncertainty about how much fracking chemicals are making their way into local aquifers if at all. The second source of uncertainty is about the nature of the chemicals used in fracking. The lists and mixtures of synthetic chemicals are protected by trade secret laws. There are laws on the books that require some disclosure, but these requirements are costly, time intensive and difficult to enforce without full cooperation from the companies (Goldman, 2011; Rahm, 2011). These issues cause greater uncertainty about the risks and/or safety of fracking.

Another source of uncertainty is in the severity of the harm, if indeed fracking chemicals are getting into aquifers. Assessing the severity of health harm is problematic since the exact nature of many of the synthetic chemicals used in fracking is unknown. The Endocrine Disrupter Exchange has identified many of the fracking chemicals from spills and from some voluntary disclosure (TEDX, 2012). Some of these chemicals are known to be cancer-causing while others are known to be endocrine disrupters that could impact future generations as well as those in the present (Colborn et al., 2011). Again, it is essential to emphasize that all this speculation and circumstantial evidence does not prove that fracking is harmful; it merely points to a need for prudence in dealing with an issue where little is known about the probabilities of harm and the severity of harm.

The issues of likelihood and severity must both be dealt with in decisions made in the presence of uncertainty. A strong case for restricting fracking processes would rely upon an argument that the probability of harm is high or that the severity of the harm is high, or some combination of the two. Conversely, a case for allowing unrestricted use of fracking practices should be based on an argument that the probability and/or the severity of harm is low.

The trade-offs associated with these costs, benefits, opportunities and risks (BOCR) present a situation for which a complex ANP BOCR model is well equipped to address. The ANP networks for the BOCR are designed under a stakeholder cluster that links each stakeholder to its relevant criteria. The influence of the criteria on the stakeholders is also captured. This approach allows each different stakeholder to elicit and combine their different preferences. The priorities of each stakeholder can then be adjusted within each of the BOCR networks before the BOCR are synthesized as a final priority vector. The BOCR are weighted and combined using pivot comparisons where specific nodes within each network are compared to nodes within an adjoining network.

Within the BOCR networks homogeneous clustering is employed to build risk profiles to measure the expected risks and the expected opportunities. This approach addresses the issue that Badaracco refers to as “right vs. right” decisions: it is right to put valuable energy sources into the marketplace and it is right to protect innocent citizens from harmful externalities of modern business activities. What makes this right vs. right decision especially challenging is the high stakes involved and the high degree of uncertainty. To accurately measure and reflect the differences between small risks and life threatening risks it is necessary to include additional comparisons to link the events together. The ANP model is developed in detail in the next section. First the general model is introduced, followed by a detailed explanation of the structure, subnetworks, and nodes.

5.3 ANP MODEL

The goal of the ANP model is to select the approach the NG industry should take which will best meet the needs and wants of the stakeholders involved. The alternatives consist of the following options as defined by Mary Parker Follet as the three ways to deal with conflict: domination, compromise, or integration (Graham, 1995). The stakeholders that are considered relevant in this model include: NG industry, indirect economic partners, communities with direct exposure, and communities abroad. Each stakeholder is connected to the relevant nodes within the BOCR network that influence it and vice versa. The BOCR networks are presented and discussed in their relevant sections below.

5.3.1 Alternatives

Follet was an advocate of mutual problem solving. During her consulting experience it became apparent that when there was joint ownership in a problem that the solutions the group achieved were better than the solutions that were initially proposed. The solutions brought about an integration of interests rather than simply achieving concessions from each party. According to Follet, “As conflict – difference – is here in the world, as we cannot avoid it, we should, I think, use it. Instead of condemning it, we should set it to work for us. Why not?" (Graham, 1995, pp. 67-68) Currently, there is a great deal of conflict among the different stakeholders and their proposed solutions for dealing with the uncertainties of fracking. In response to this conflict in many cases it is "easier … to fight than to suggest a better way" (Graham, 1995, p. 82). However, fighting about fracking avoids the opportunity to come up with creative solutions (Graham, 1995) that can reduce or prevent the potential risks and realize the untapped profits.

By defining the separate subnetworks for each stakeholder this ANP model is able to take advantage of and assign weights to Follet's "right/different right" assumption where she suggests, "assume both sides are right, rather both sides are likely to give right answers but to different questions" Graham, 1995, p. 4).

As negotiations proceed and decision makers begin developing their preference models, Follet's principal message is that relationships matter. This principle is underscored in the specific case of fracking by Liss (2011) where several case studies of recent lease negotiations are presented. The NG industry had become labeled as "dishonest" and "deceptive" (Liss, 2011, p. 422). Landowners began forming alliances to increase negotiating powers, decrease information asymmetry, and seek competition in the leasing process. The first alliance was formed by a group of citizens whose property resides in the Barnett Shale Play. The success of this first group was communicated via the internet and used by other landowners to form their own alliances. This form of negotiation has led to increased profits for landowners, larger land tracts for the oil industry, and increased safety measures being built into the leases (Liss, 2011).

By forming such alliances, the citizens within the communities where drilling takes place countervail the power of the large NG companies. While free market competition and government regulation are solutions to the problem of mitigating economic power, Galbraith suggest a third solution of balancing one power with another (Gailbraith, 1952). The organization into community alliances is in ways similar to the formation of an employees union that provides a countervailing force against the NG companies (Gailbraith, 1954). While the citizens are able to negotiate better contracts and prevent exploitation as an alliance the NG companies can also benefit from a centralized contract versus piecemeal contracts, lower production costs as fewer well will need to be drilled Snyder, 2008). The costs, benefits, and opportunities of forming alliances are discussed in greater detail in the costs, benefits, and opportunities sections of the model.

The alternatives in this model are the three approaches to dealing with conflict proposed by Follet: domination, compromise, and integration (Graham, 1995). Domination, defined as a victory by one side is the easiest approach to implement. In the short term, domination will favor the NG industry. The industry is well positioned financially, legally, and in terms of market demand. To continue forward with the current approach would allow the NG industry to avoid incurring what it may term as unnecessary costs. The industry can also take advantage of the information asymmetry that exists. Through the model the long term effects will also be discussed. The second option, compromise, is the case where each side gives up a little in order to have peace. This solution will benefit the NG industry in both the short and long term and other stakeholders will have more to gain under this option. However, the impacts of what must be compromised can lead to a suboptimal solution. Rigid lines and boundaries will be defined which can be difficult to update with advances in knowledge and technology. Finally, the integration alternative is finding a new solution where neither side has to sacrifice anything. The contribution of the opportunities cluster and the reduction in risks cluster of this alternative significantly offset the increased costs associated with this third alternative. A more detailed analysis of the impacts of the different scenarios and assumptions of the stakeholders under each alternative is discussed below.

5.3.2 Stakeholders

The NG industry in and of itself is the key stakeholder in the model. A similar but separate stakeholder is the group of indirect economic partners (IEP). The IEP are the suppliers, manufacturers, and other industries that provide significant goods or services to the NG industry. With that separation defined the NG industry can be defined as the direct stakeholders involved in exploring, drilling, extracting, processing and transporting the NG whereas the IEP support the NG industry. Kleinhenz and Associates

(2011) estimate the economic impact of the natural gas industry on IEP in the state of Ohio over a four year period to be $14.0 billion. With similar estimates for the state of Pennsylvania also, the IEP are significant stakeholders. The next group of stakeholders is the communities with direct exposure to fracking (CDE). The individual citizens are assumed to form alliances based on the success of prior organizations exercising a countervailing power to negotiate better leases. These communities benefit from the economic booms, and landowners receive royalties. CDE are also the most at risk from the potential harms and damages caused by fracking. Citizens within CDE would most likely be the first to be exposed and suffer from the greatest amount of exposure. Finally, the communities and citizens abroad are also impacted, while less directly, by the positive and negative outcomes from fracking. Government could also be considered as a stakeholder in the decisions about the NG industry. However, because the government is more of a representative for the other stakeholders and not a direct player it is not considered in this model. While the government receives tax revenue from fracking activities, one might argue it is the local citizens and not the government who are impacted by the revenue. In the next section the specific benefits are explained in detail and also presented in table form to identify which stakeholders reap the specific benefits.

5.3.3 Benefits

The benefits clusters consist of economic benefits that are tangible and directly impact individual stakeholders; likewise there are also less tangible benefits that are equally important and therefore included. One of the most important, but intangible, benefits that can be obtained from fracking NG within the United States is the energy independence that domestic production can create. Energy independence has economic and political implications which should be considered and included alongside the direct economic benefits of fracking. The elements in the benefit cluster are presented below.

- *Lower energy prices.* The price of NG has dropped significantly in recent years since hitting a high of over $15.00 USD per million BTU in 2006 (British Thermal Units, which is equal to

1055.06 Joules). This drop has been attributed to the increase in reserves accessible through fracking. Current prices are $3.00 per million BTU (EIA, 2012).

- *Royalties to land owners.* While the royalties vary from location to location, the state of Pennsylvania requires a minimum 12.5% royalty (Sweeney et al., 2009). In another negotiation the royalty was 25% after clean up and transportation costs (Liss, 2011). The royalties are another component that has increasingly been negotiated to address issues such as the likelihood of finding NG on the property (which benefits the NG industry and landowners) and setting aside additional funds in risk management funds (which benefits the landowners). These negotiations have been beneficial to both the landowners and the NG industry to mitigate the risks and uncertainties involved in drilling for NG.
- *Land leases.* Land leases differ significantly depending on the strategy used by the drilling companies. A lease can be for as little as $50 an acre and as high as $15,000 an acre (Liss, 2011). The trade-offs in land leases primarily transfer funds between two stakeholders: the NG industry and the communities with direct exposure. The large differences in prices for land leasing is due in part to the estimates of how much NG can be extracted, but the primary driver in the increase has been a reduction in information asymmetry between the NG industry and the land owners (Liss, 2011).
- *Job creation.* Claims from different studies vary by a magnitude of ten as to the number of jobs that fracking creates (Agbaji et al., 2009; Lewin et al., 2011; Weinstein & Partridge, 2011). One key difference is a result of the different counting methods used in each study. For example, the land must be surveyed, roads built, drilling, piping, and so forth. While each of those activities is clearly a separate job and in most cases will be done by separate individuals there are important reasons such jobs should not be counted individually. Weinstein and Partridge (2011) argue that the number of jobs should be considered over a basis of at least a year. Hence when a driller moves from one project to another over the period of a year that combination of projects would be equivalent of a single drilling job created. Based on these revised estimates Weinstein and Partridge calculate that during the years 2004-2010 the NG industry brought 20,000 jobs to Ohio and a similar amount could be expected in Pennsylvania.
- *Tax revenues.* Local, state and federal governments stand to earn billions of dollars in the next few years from severance taxes on NG. In many jurisdictions local governments are unable to impose a severance tax because the tax authority belongs to the state; Texas on the other hand is an example of a state where local communities are able to impose local severance taxes (Liss, 2011). Tax revenues collected by the state of Pennsylvania in 2008 amounted to $238 million (Radow, 2011). Because the model does not count government as a formal stakeholder, the tax revenues are counted as a benefit to the communities with direct and indirect exposure.
- *Cleaner energy than coal or oil.* NG has fewer carbons and therefore when burned creates less emissions than other fossil fuels. From this perspective NG has been touted as a cleaner fuel which produces 80% less carbon emissions than coal (Lewin et al., 2011). Recent studies have begun to argue that while NG burns cleaner the overall carbon footprint is bigger than the carbon footprint of mining and burning coal. A significant source of the additional pollution comes from the sheer number of trips made to bring water (3-5 million gallons) to the drilling site and remove the drilling sludge. Trucking in the water alone requires 364 water truck trips which can be converted into 3,494,400 car trips (County, 2005) which provides a significant offset to the cleaner emission of the NG when it is burned.
- *Domestic production.* This intangible can be considered invaluable in comparison to other benefits. Weinstein and Partridge (2011) use the term “energy security.” Other benefits of domestic production include the economic impact on local economies and political independence. While the element “political independence” shares similarities with energy security the main difference is the political freedom that is a byproduct of energy security.

- *Revenue to the NG industry.* Initial production at a well is very high, but then the production rates decline exponentially over time. The EIA recommends using a five year average output rate of 1,900 cubic feet per day to calculate flow rates in new wells (EIA 2001). The profit margin for NG industry is approximately 6.65% (API, 2012).
- *Revenue to others.* Estimates of the economic output multiplier as a result of monies invested in fracking are as high as $1.94 for every dollar spent (Baumann et al., 2002; Considine et al., 2010).

5.3.4 Costs

Freeman suggests managers ask "have we allocated resources to deal with our stakeholders" (Freeman, 1984, p 69)? There are direct and indirect costs associated with the stakeholder process. One of the most simple and straightforward costs of a stakeholder approach is the cost related to the additional meetings that must be held. According to Liss (2011), the approximate cost of the additional meetings is $5,000.00 per meeting. In the short term accounting, a stakeholders approach will have negative impacts but the industry can anticipate longer term economic consequences (Freeman et al., 2010, p. 102). Most of the costs below would be incurred regardless of which approach is used but they are included so that after the pairwise comparisons are completed the relative differences between alternatives can be compared.

- *Pre-drilling research.* The first cost incurred by the NG industry is in surveying land and creating the models to develop estimates of the likelihood of finding extractible NG and the amount of NG there is in the area. Data can be obtained through performing geological surveys, seismic data extraction, pre-drilling to observe the composition of rock layers, and seismic imaging. The cost associated with pre-drilling research can be in the hundreds of thousands of dollars per square mile (640 acres) surveyed (NaturalGas.org, 2011).
- *Contract research by the community.* The alliances formed by communities can be likened to an employee union. The costs per member have been as low as $25.00 per acre. These fees include monies for research, legal, and negotiation costs (Liss, 2011).
- *Town hall meetings.* Under the compromise and domination strategies these costs can be eliminated. However, the synergy opportunity has the potential to offset the additional costs of "town hall meetings." The price for each of these meetings from one estimate is $5000.00 (Liss, 2011).
- *Drilling.* The US Energy Information Administration estimates that in 2008 the drilling cost per foot was $604.00. An average well is about 7,000 feet deep which translates into drilling costs of $4.25 million per well (2008).
- *Cost of living.* While an increase in the supply of NG will reduce the costs associated with home heating and production of goods where NG is used in production those benefits are captured in the benefits section. On another side the influx of economic resources into communities that were primarily agricultural communities has led to an increase in the cost of living within those communities (Kelsey, 2009).

- *Noise and traffic.* According to Francis et al. (2012) noise is a "novel, widespread environmental force." Noise and traffic intangible costs to the communities and land owners caused by the number of trips that drilling companies make to drilling sites with heavy equipment comes as a surprise and distraction to lessees and neighbors within the community. Additional costs from the noise caused by fracking are initially born by the environment but will reflect on the stakeholders. Noise from compressors at NG wells has been shown to adversely affect the seed dispersal of the *Pinus edulis* (piñons) which provide food and shelter to many animals in the western United States (Francis et al., 2012).
- *Water.* Each well requires between 3-5 million gallons of water for drilling the well and then injecting into the ground to pressurize the well. Water sources include ground water, fire hydrants, ponds, streams, and rivers (Seibert, 1985).
- *Wastewater treatment and disposal.* Current methods of wastewater disposal include digging and filling large ponds that are lined with protective liners to prevent contamination, pumping wastewater into trucks, disposal into local rivers, and returning some of the water into the ground either for reuse in the fracking process or long term storage. Some of the wastewater that is pumped into lined ponds evaporates and the rest is taken to water treatment plants (Fischetti, 2010). Research is underway to develop cost effective treatment methods that will allow more of the waste water to be reused in the fracking process(Kennedy et al., 2011).
- *Research and development to create sustainable development.* Research and Development (RD) spending are a part of most organizations' budgets. Over the last 20 years RD funding in the energy sector has been on the decline (Nemet & Kammen, 2007). If the NG industry uses the dominant approach it can reduce the RD spending. However, in a compromise or integration approach more funding will be spent on RD to find solutions that satisfy the demands of multiple stakeholders. The additional RD cost can be offset by the results of the research that will be captured in the benefits and opportunities networks.
- *Leases.* Refer to the Leases section under Benefits which are listed as benefits to property owners whereas the costs are incurred by the NG industry.
- *More expensive leases.* Companies in the NG industry have used a tactic called "landman" where a salesman offers to lease the property owner's land at a hundredth the market value with the "potential" that there may be valuable resources below the surface (Liss, 2011). Allowing land owners more time and the ability to collaborate reduces the level of information asymmetry and leads to the land owners to demand higher prices for the leases.
- *Environmental funds.* The alliances or collective bargaining groups that are forming within communities have begun asking that a certain percentage of the profits from the NG extraction be put aside to deal with environmental damages that may happen as a result of the fracking process. These funds can also be used to promote the restoration of the land around the drilling site to its original form. For example the weight of the heavy machinery packs the ground to the extent that plants and shrubs will not grow. This lack of growth leads to erosion of the top soil and requires significant landscaping to restore the terrain to its original form (Sweeney et al., 2009).

5.3.5 Opportunities

- *Transparency.* Landowners, communities, and special interest groups are calling for the disclosure of the chemicals used in fracking. Due to recent changes in legislation fracking companies are not required to disclose the chemicals that are mixed with the water to increase the productivity rates of oil extraction. The exemption is a result of what has been termed the "Halliburton Loophole" in the Environmental Protection Agency Safe Drinking Water Act

(Bierman et al., 2011; EPA, 2011; Goldman, 2011; Kelsey, 2009; Sweeney et al., 2009). The gel mixtures are protected by patent which provides some protection for "trade secrets." Transparency provides an opportunity to engage in mutual problem solving. Potentially harmful chemicals can be identified and through RD substitutions can be made.

- *Cheaper and better solutions.* Cost reductions can be the result of having fewer regulations, synergy (which is mentioned below as its own element), and as a result of the accessibility of the information to mutual stakeholders which create opportunities for joint ventures to develop new technology and processes.
- *Synergy.* One form of synergy is when alliances are formed and allow for a single negotiation for land tracts as large as 390,000 acres (Liss, 2011). The NG industry stands to benefit from having to negotiate fewer contracts and the ability to increase the level of consistency within contracts over large parcels of land. Another form of synergy is in the product and process development with the potential to not reinvent the wheel. If the specific chemicals are identified and stakeholders are working for a common goal, the stakeholder's creativity can create new solutions that will benefit the parties involved.
- *Trust.* With information from multiple sources being increasingly available via the internet individuals, particularly those who are directly involved in negotiations for use of their land and resources, have become skeptical of the NG industry. Trust is an important intangible factor in business and negotiation (Liss, 2011; Zaheer et al., 1998). Landowner alliances have outright refused to negotiate with certain companies because the members felt they were being manipulated (Liss, 2011). This intangible element is crucial for a successful stakeholder model. The perceived level of trust among the various stakeholders will differ significantly across the alternatives.
- *Less information asymmetry.* Every stakeholder stands to gain from a reduction in the information asymmetry. While in the short term there will also be additional costs incurred by the NG industry these costs are captured in the cost section e.g. a higher price for the land leases. The NG industry then has the ability to improve their image. On the other side of the land lease issue, the NG industry stands to gain from offering different leases depending on the likelihood of extracting the NG from different portions of land within the same area. The reduction in information asymmetry allows for additional stipulations in the contracts to reflect recovery rates. The other stakeholders stand to receive additional benefits as they make more informed decisions. They will also benefit from the modified leases.
- *Win/win solutions.* The lease that was negotiated between Hess Corporation and The Northern Wayne Property Owners Alliance is an example of how win/win solutions can come about. The NG company, Hess, was able to mitigate risk by paying higher but staggered bonuses that also varied by location as a function of the amount of NG available. Landowners benefitted from the higher bonuses, increased royalties, and strong provisions for environmental protection (Liss, 2011).
- *Out of the box solutions.* Follet shares an example of an out of the box solution to redesign an unloading station that would allow for simultaneous unloading of materials in place of the original proposal to create a priority system that would determine which party could unload first (Graham, 1995, p. 69). This solution not only provided the direct monetary benefit of increased productivity but also reduced the potential for future conflicts among the parties involved.

5.3.6 Risks

While many of the costs and benefits are reasonably clear and straightforward, there are also valid reasons for exercising caution about the extensive use of fracking. Bodily et al., (2011) expound on the uncertainty surrounding the potential risks:

- There were no definitive statistics or risk assessments on hydraulic fracturing; the chemicals' proprietary nature and the protection of the "Halliburton Loophole" have kept the specific impact of fracking relatively opaque.
- The U.S. Environmental Protection Agency (EPA) has only performed a barebones report in 2004 that some believed may have been watered down by political interests. In early 2010, however, concerned about reports of contaminated ground and drinking water, the EPA announced it would perform a thorough scientific study of the life cycle and the impact and effects of fracking. The study results would not be available until 2012.
- Parents in Pennsylvania are overall uninformed about their water and are overall satisfied with tap water but did express concerns about contamination due to shale fracking (Merkel et al., Forthcoming).

After explaining the risks, the methodology is set forth to explain how the risks networks are weighted and calculated. The particular challenges of weighting the risks revolve around: dealing with high levels of uncertainty as explained above, and the fact that the range of the potential impacts exceed the typical 1-9 rating scales, for example an outcome of being sick for a day vs. paralysis or death. Stakeholders on every side of the decision are using this uncertainty to push their own agendas. Drilling poses a threat to housing, ranching, and recreation industries (Brown, 2007) which, due to the explosive growth of the NG industry, are very concerned about the livelihood of their own industries going forward. The NG industry can also argue that there is no definitive evidence of any harm. The ability to perform robust sensitivity analysis regarding the probabilities of certain outcomes and the priority weights for the stakeholders is crucial.

- *Underground drinking water contamination.* While up to 99% of the fluids that are pumped into the ground is water, the other chemicals are potentially hazardous. Legislation protecting trade secrets and proprietary information has allowed companies to not disclose the particular makeup of their fracking fluids. In order to prevent groundwater contamination the well is encased with piping which is surrounded with cement. However landowners in Wyoming and Pennsylvania have begun complaining that their drinking water has been contaminated.

- Claims have ranged from a foul odor or taste to the extreme of being able to light tap water on fire (EPA, 2011; Holzman, 2011; Howarth et al., 2011; Lewin et al., 2011).
- Another source of contamination can come from naturally occurring radioactive chemicals that enter the well and drilling site from the ground during the drilling and extraction process (Entrekin et al., 2011; Marsa, 2012).
- Currently most water treatment plants are not designed to treat the chemicals in the water that has been used for fracking (Sweeney et al., 2009).
- Potential Carcinogens pose another potential threat. According to Brown (2007),

  "Benzene, toluene, ethyl benzene, and xylenes are naturally present in many hydrocarbon deposits, and may be present in drilling and fracking chemicals. These VOCs can cause symptoms such as headache, loss of coordination, and damage to the liver and kidneys; benzene is a carcinogen as well. VOCs help create ground-level ozone, which can contribute to severe respiratory and immune system problems."

  In 2012 the EPA is expected to release a more comprehensive study regarding the potential impacts of the chemicals used in fracking. Until further conclusive evidence is obtained the debate regarding the potential harm will continue.

- *Surface water contamination.* Surface water can be contaminated by spills during the drilling process, spills from pipelines, and leakage from water pits where fracking fluids are stored. In Pennsylvania there have been multiple incidents of fish and amphibian kills as a result of surface water contamination (Rahm, 2011).
- *Other chemicals and byproducts.* Beyond the fracking fluids there are other chemicals and byproducts that pose the risk to contaminate land and rivers surrounding fracking sites: salts that are extracted during the drilling process, norm contamination via trucks delivering to and leaving from the fracking sites, mud spills around drilling sites, and totally dissolved solids (TDS). TDS like calcium, sodium, and chlorides must be properly treated and contained to avoid changing the ph or salinity of streams to the extent that kill-offs of the species that live therein occur (Goldman, 2011; Rahm, 2011).
- *Property damage.* Drilling operations require land excavation, road building, containment site construction, well drilling, and storage facility construction. This activity can impact the ability to readily use the surrounding land for its original purposes without significant investment in restoration funding. The costs associated with restoration projects are captured in the costs section; however, if the funding is not negotiated, as in the dominant approach, for example, then other stakeholders are at risk to being the ones who incur these costs.
- *Increased regulation.* Multiple stakeholders are at risk for increased regulation that may or may not rule in their favor. Regulation can take the form of legal, self, or social regulations. While regulation is intended to correct market failures, Laffont and Tirole (1991) state that beyond "public interest" there is "capture" theory. Capture theory refers to when interest groups influence public policy to their benefit. The regulations imposed through capture theory will benefit specific stakeholders at the expense of others.
- *Lawsuits.* Citizens, communities, and environmental groups are taking legal action to push their agendas. In many cases their agenda could be considered as fixing wrongs that have occurred. In other cases the purpose is to gain access to the proprietary or sealed documents (Hopey, 2012). It can also be argued that some of the cases are solely to push individual agendas. The actions taken by the NG industry will impact the frequency and outcomes of future cases.

5.4 MAKING JUDGMENTS WHEN LITTLE IS KNOWN

Even when little is known, human judgments are required in decision making. The only way to avoid imperfect and imprecise judgments in decision making is to ignore all of the factors that cannot be measured. Making judgments in the fracking case is especially challenging. Many fracking chemicals are new and often protected from easy disclosure by trade secret laws (Bierman et al., 2011; Bodily et al., 2011; Goldman, 2011; Lewin et al., 2011). Also, few human experiments are available for obvious reasons. However, Case (1945) reports on scientists at the British Royal Navy Physiological Laboratories who voluntarily exposed themselves to DDT in order to better understand the impact of exposure to synthetic chemicals. One of the human guinea pigs described symptoms including heaviness and aching of limbs, muscular weakness, and insomnia. Another experienced occasional tremors that shook the whole body and missed 10 weeks of work and had not fully recovered from the effects after a year (Wigglesworth, 1945). In both cases exposure was more intense than most workers would normally experience.

These events do not constitute proof that fracking processes are a significant health hazard, but it should foster prudence in the production and use of products whose consequences are not fully understood. What is required is good critical analysis of whatever anecdotal evidence is available. The virtue ethics issues hanging over this is a desire a seek truth even when it may be inconvenient and to engage in the best and most credible decision making processes available to us.

5.5 PERSONAL JUDGMENTS AND DECISION MODELS

When one must make judgments when little is known, a formal decision model can be very helpful. Recall that the concise definition of OR was to use the scientific method to realize better executive decision making, executive decision making being defined as coordinating the activities of the parts of an organization to achieve optimal performance of the whole organization.

The scientific method is defined as an iterative process where a decision maker must observe, explain, and test, and repeat the process. The explanation part is literally and conceptually the center piece of the process, since the role of observation is to prepare for an explanatory model, while the role of testing is to identify the limits and accuracy of the explanatory model.

Fracking is new enough and opaque enough that it is hard to find data to help one make these judgments. Information derived about human impact of DDT could be helpful, but a huge extrapolation is required to transfer information about DDT in the 1940's to (mostly) unknown fracking chemicals in the 2010's. It is in decisions such as this that flexible decision models, designed to facilitate experimentation, can be extremely helpful in making decisions like the fracking case where so much is at stake and so little is known.

Byers (2010) who is an accomplished mathematician, argues that, in contrast to prevailing perceptions, mathematics is not about numbers, but is about ideas. He observes that most think that mathematics is characterized by a "certain mode of using the mind" (Byers, 2010, p. 5) which Byers calls the algorithmic mode. An algorithm is a step by step process that leads us from old truths, or things one assumes to be true, to new truths. Byers argues this perception is a very limited view of the role of mathematics in society. To him, the real value of mathematics is that it is a highly creative process that has the potential to apply mathematics, for example, in a way that helps us to prioritize conflicting moral obligations. It is in this way, that mathematics, often referred to as the language of science, is able to play a role in the explanatory step of the scientific method (Byers, 2010).

5.6 RELATIVE SCALES PROVIDE MEANINGFUL RESULTS

Relative scales are not unique to the field of decision making. Three examples of relative scales used in other fields include: the Kelvin scale of temperature, intervals of time on a calendar, and the psychological scale of loudness (Roberts, 1979). When an absolute scale does not exist one can either attempt to estimate exact measurements without a tool of measurement or make relative comparisons. According to Blumenthal (1977), "Absolute judgment is the identification of magnitude of some simple stimulus, … , whereas comparative judgment is the identification of the magnitude of some relation between two stimuli both present to the observer." One should not be left only to making relative comparisons but must as mentioned previously also check the consistency of one's comparisons. For example, if I say object A is twice as big as object B, and that object B is three times the size of object C, then it follows object A is six times larger than object C. As comparisons are made one can test how closely the relative comparisons follow the logic in the prior sentence as a measure of consistency. While consistency is important, demanding perfect consistency is impractical even with precise instruments (Saaty, 2005). Saaty explains that cardinal consistency ensures not only correct ordering but mathematical correspondence in weights; however, by allowing a limited amount of inconsistency the decision model can be used in practice while still providing meaningful weights (Saaty, 1980). To increase the level of consistency and incorporate redundancy as a second check, one should not just infer the weight of object C from the prior example; rather explicitly make the comparison between object A and Object C.

Economists are also interested in measuring preferences to explain behavior as in Prospect Theory (Kahneman & Tversky, 1979) and The Endowment Effect (Thaler, 1980). In both cases pairwise comparisons are made between various alternatives; this process is repeated until it is known, usually in a dollar amount, how much an individual values a certain object or gamble. Researchers have spent considerable time identifying biases and shortcomings that humans are subject to in the decision making process. Some examples include cognitive overload, anchoring bias, risk aversion/seeking behavior, framing effects and path dependency (Weber & Johnson, 2009). Although such limitations exist they are not universal and should not be used to conclude that decision makers are unable to perform relative comparisons. According to Weber and Johnson (2009), the concept of relative evaluations continues to gain increased attention and respect because of one's understanding at the neural level; "Since neurons encode changes in stimulation (rather than absolute levels), absolute judgments on any dimension are much more difficult than relative judgments."

5.6.1 Homogeneous clustering

One limitation of the pairwise process is that judgments are limited to a 9 to 1; the reason for this limit is that experiments in cognitive psychology reveal that human ability to make ratio judgments declines more rapidly as ratios go beyond a 9 to 1 ratio. Saaty (1980) conducted a series of pairwise processes allowing more than 9 to 1 ratios in settings where tangible measurements are possible. In one experiment, Saaty required participants to judge air travel distance between major global cities. He repeats the experiments with different ratio scales, the best results in terms of narrowing the gap between distances based on subjective judgments compared to the measured distances generally occurred around a 1 to 9 scale.

The limit of 9 to 1 for ratio judgments can be overcome with a divide and conquer strategy called *Homogeneous Clustering* (Saaty, 1994; Saaty & Shang 2011). If the ratio between the largest and smallest values exceeds 9, then other intermediate elements are added and organized into overlapping clusters in a way that all comparisons within the same cluster are within a 9 to 1 ratio (which is why the clusters are called homogeneous). The clusters overlap in a way that the ratio of the original elements can be derived from the ratios in the clusters. This clustering process is a key to having a pairwise process that creates very small and very large numbers in both the probability and severity columns. This is necessary in the building risk profiles in the fracking case, where the ratio of death to negligible health harm clearly exceeds the 9 to 1 limit.

5.6.2 Building a risk profile

In terms of its impact and irreversibility one of the greatest potential risks is the impact of groundwater contamination on human health. The stakeholder group citizens with direct exposure is the primary group to be impacted by this risk. Actuaries have developed various methods to calculate the value of human life, of losing a limb, or debilitating illnesses. In this model it would be a simple process to use a chart and calculate the expected cost of the loss a human life or the cost of an illness that lasts for 6 months. Beyond the financial costs there are additional inconveniences that can impact the stakeholders. There are also spikes in the risks that would relate to specific time intervals. For example when an individual exhausts their accrued vacation and sick time the cost of being out of work one additional day could include not only another day of wages but the individual’s job. Quality of life is another less tangible cost that should be incorporated into the model. These additional considerations can be captured and measured using the concept of homogeneous clusters. Figure 5.2 displays the organization of the time periods from zero days (no harm) to 50 years and death. Pairwise comparisons were used to determine Which is worse and how much worse is it to be harmed for two days versus one day?

Figure 5.2 Homogeneous clustering of time periods

A similar approach was used to calculate the likelihood of being affected under each time period under each of the three alternatives. The resulting risk profiles were then compared against each other using the direct data input feature in Super Decisions and compared against the other risks through the regular pairwise comparison process. In the next section the synthesized results of combining the benefits, opportunities, costs and risks are presented.

5.7 SYNTHESIZED RESULTS

The integration alternative provides the most benefits and opportunities for every group of stakeholders (Table 6.2 and Table 6.3). It is also the least risky alternative (Table 6.5). With those initial results one might return to the original question in this chapter "then why isn't it being done?" A simple answer to that question is the results of the ranking in the costs networks (Table 6.4); integration also has the highest priority in costs which means it is the most expensive alternative whereas domination is the cheapest alternative. The overall results clearly demonstrate that the integration alternative is the preferred alternative overall.

If the NG industry only looks at the tangible costs and benefits in the short term the integration approach has a lower profit margin than the dominant or compromise approach. But when intangible benefits and the opportunities are considered, integration is clearly the preferred alternative. According to Liss (2011) from the *Northern Wayne Property Owners' Alliance Experience* (a case study of a neighborhood alliance located in the Pennsylvania) while the NG company had to pay higher leases and royalties they were able to differentiate rates depending on the prospect of extracting gas and adjust the royalties to account for the liability protection and environmental compliance funding. Even with the increased costs under the sensitivity analysis the costs of the integration alternative must increase to equal the benefits before integration is no longer the preferred alternative.

The negotiations between the land owners and NG company allowed both parties to do as Follett explained as the difference between compromise and integration where rather than neither party getting what they wanted both parties are able to find creative synergies that create a win/win situation. The results of this case study and the ANP model support each other.

Table 5.2 Results from the benefits networks for each stakeholder

Benefits

Stakeholder	Alternatives	Ideals	Normals	Raw
NG	Compromise	0.3605	0.2419	0.1209
	Domination	0.1300	0.0872	0.0436
	Integration	**1**	**0.6710**	**0.3355**
IEP	Compromise	0.6034	0.3185	0.1593
	Domination	0.2910	0.1536	0.0768
	Integration	**1**	**0.5279**	**0.2639**
CDE	Compromise	0.3693	0.2432	0.1216
	Domination	0.1494	0.0983	0.0492
	Integration	**1**	**0.6585**	**0.3292**
CCA	Compromise	0.6712	0.3380	0.1690
	Domination	0.3144	0.1583	0.0792
	Integration	**1**	**0.5036**	**0.2518**

Table 5.3 Results from the opportunities networks for each stakeholder

Opportunities

Stakeholder	Alternatives	Ideals	Normals	Raw
NG	Compromise	0.4981	0.3136	0.1568
	Domination	0.0905	0.0570	0.0285
	Integration	**1**	**0.6295**	**0.3147**
IEP	Compromise	0.5653	0.3468	0.1734
	Domination	0.0645	0.0396	0.0198
	Integration	**1**	**0.6136**	**0.3068**
CDE	Compromise	0.4354	0.2940	0.1470
	Domination	0.0455	0.0307	0.0154
	Integration	**1**	**0.6753**	**0.3376**
CCA	Compromise	1.0000	0.4000	0.2000
	Domination	0.5000	0.2000	0.1000
	Integration	**1**	**0.4000**	**0.2000**

Table 5.4 Results from the costs networks for each stakeholder

Costs

Stakeholder	Alternatives	Ideals	Normals	Raw
NG	Compromise	0.4862	0.2516	0.1258
	Domination	**0.4463**	**0.2309**	**0.1155**
	Integration	1	0.5175	0.2587
IEP	Compromise	0.5000	0.3333	0.1667
	Domination	**0.0000**	**0.0000**	**0.0000**
	Integration	1	0.6667	0.3333
CDE	Compromise	0.2152	0.1614	0.0807
	Domination	**0.1181**	**0.0885**	**0.0443**
	Integration	1	0.7501	0.3750

Table 5.5 Results from the risks networks for each stakeholder

Risks

Stakeholder	Alternatives	Ideals	Normals	Raw
NG	Compromise	0.5503	0.2970	0.1485
	Domination	1.0000	0.5396	0.2698
	Integration	**0.30285**	**0.1634**	**0.0817**
IEP	Compromise	0.7631	0.3851	0.1926
	Domination	1.0000	0.5047	0.2523
	Integration	**0.2184**	**0.1102**	**0.0551**
CDE	Compromise	0.5014	0.2747	0.1374
	Domination	1.0000	0.5479	0.2740
	Integration	**0.3237**	**0.1774**	**0.0887**
CCA	Compromise	0.3787	0.2484	0.1242
	Domination	1.0000	0.6560	0.3280
	Integration	**0.14564**	**0.0955**	**0.0478**

Table 5.6 Synthesized Results

Name	Ideals	Normals	Raw
Compromise	0.0760	0.0397	0.0173
Domination	-0.84084	-0.4387	-0.1908
Integration	**1.0000**	**0.5217**	**0.2270**

5.8 CONCLUSION

Natural Gas has the potential to continue to gather market share in the United States energy sector. With the ability to reduce dependence on foreign countries, create jobs, and reduce emissions. There are also risks associated with the current preferred method of extracting the NG called fracking. Opposition is mounting against fracking because of the potential risks, in particular the use of chemicals in the fracking process and their potential environmental impacts. Until recently the NG industry has been able to move forward using a dominant approach against the other stakeholders that are impacted by fracking. While this is the least expensive alternative according to the results of this model it is not in the best interest of the NG industry to continue with the dominant approach. The most preferred result is the integration approach where the stakeholders work together and go beyond compromising to find new solutions. The integration approach creates additional benefits and opportunities for each stakeholder, especially the NG industry.

In April of 2012, another example of "how to do it right" referring to drilling projects has been applauded by environmental groups (O'Donoghue, 2012). O'Donoghue explains how the NG company *Anadarko* worked with the Bureau of Land Management, environmental groups, and tribes to collaborate and find "balanced solutions to complex issues" (O'Donoghue, 2012). The stakeholders are recommending this example be used as a national model for future oil and gas development where long term economic benefits can be realized while also protecting water quality, wildlife and scenery

O'Donoghue, 2012). By using an integration approach the stakeholders were able to cooperate and find what Follet termed "win/win" solutions. The ANP can be used as a great facilitator in future negotiations.

6.0 OPTIMUM FUTURE RELATIONS BETWEEN CHINA AND THE UNITED STATES: POLICY PRIORITIZATION WITH THE ANP

During the last fifty years the economic, social and political relationships between the People's Republic of China (PRC) and the United States of America (US) have progressed along a hilly journey of ups and downs. While there have been many ups and downs the overall direction has been upward and improving (Friedberg, 2005; Wu, 2009). In the last few years the PRC's economy has continued to grow dramatically despite an overall global downturn. This recent double digit growth along with the steady growth experienced over the last few decades has led the PRC to become the second largest economy in the world and has led some to predict the PRC's economy will surpass the US as early as 2015 (Milburn, 2005). The PRC has also continued to develop its military forces (Art, 2010; Evans, 2011; He & Feng, 2008); according to Art (2010) the PRC is also determined to climb the technological ladder. Because of this growth and investment, the US and the PRC have been referred to as a G-2 of superpowers (Pardo, 2009). Over the last few decades the US has been able to unilaterally decide monetary, trade, and military policies (Breslin, 2009; Evans, 2011). However, with continued budget deficits (Nederveen Pieterse, 2008), a wounded military (Art 2010), and the efforts of other nations to collaborate together (Friedberg, 2002; He & Feng, 2008) the US hegemony is weakening.

According to Friedberg (2005), friction between the two superpowers is mounting. Over the last 100 years when emerging economies have wished to flex their muscles, and the dominant economy has been unwilling to concede their place at the top, the primary mode of resolution has been conflict, armed conflict in particular (Copeland, 2000). While conflict between the two is inevitable, it is important to clarify what type of conflict is inevitable. According to Follet (Graham, 1995), conflict is nothing more than differences; and “as conflict- difference- is here in the world, as we cannot avoid it, we should I think use it” (Graham, 1995, p. 67). By no means should the term “conflict” within this paper be interpreted as any form of armed conflict. To the contrary, the act of addressing the differences and improving relations between the PRC and US can serve as a stabilizing force against armed conflict particularly with respect to tensions in surrounding nations.

The shift in economic power from Europe and the US to the East has been referred to as the “post-Vasco da Gama era” (Bracken, 2000). While economic factors have encouraged bilateral relations, according to Hunt (1983) the US realized the potential value of having a relationship with the PRC as early as the 18^{th} century. A brief overview of the key events during the economic development and political negotiations is provided below. While a great deal of progress has been made, the G-2 relationship is still considered by many to be very fragile (Ross, 1997; Shambaugh, 2000; Wu, 2009). With significant economic, political, and security issues at stake it is crucial that the efforts to continue to strengthen relations are prioritized and implemented. The resources that are available to improve relations are scarce and should be allocated wisely.

A rigorous prioritization process is essential to deal with these issues that are more “diffuse and illusive” than ever before (Shambaugh, 2011, p. 113), and to reduce what Evans describes as a “potential for mistakes and miscalculations” (Evans, 2011, p. 113) which could wreak havoc on many fronts. While Friedberg laments that scholars and analysts lack “powerful predictive tools” (Friedberg, 2005, p. 8) to predict a state of relations in five years, both the Analytic Network Process (ANP) and a specific subset of the ANP called the Analytic Hierarchy Process (AHP) have successfully been used to address complex economic and political decisions (Saaty & Vargas, 2001; Saaty & Zoffer, 2011; Tarbell & Saaty, 1980). The ANP is used here as the decision framework to prioritize the efforts and initiatives in the G-2 relationship. After reviewing the relevant literature, the model is presented with an explanation of the criteria and alternatives. The results along with a detailed sensitivity analysis present additional insight into the suggested solutions and finally the overall findings are summarized in the conclusion.

6.1 LITERATURE REVIEW

The key issues impacting the current relations are the PRC's economic growth and PRC/US relations. Double digit year over year increases in GDP has brought the PRC to the forefront as an economic leader. The PRC's influence is also apparent in military and political spheres. First, the history of the economic growth in the PRC is summarized followed by a brief history of the key events in the development of diplomatic and business relations. PRC and US relations have been developed over many decades. While the journey has not always been smooth both countries continue to make efforts to improve relations. Finally, a brief overview of the history and development of the Analytic Network Process is presented with specific focus on applications in the area of foreign policy.

6.1.1 PRC economic growth

As of the summer of 2010, the PRC economy became the second largest economy in the world (Barboza, 2010). While the PRC's economic growth has occurred over the last thirty years, according to Barboza (2010), just five years ago Japan's economy was twice the size of the PRC's economy. The PRC expects to continue experiencing strong growth in the coming years (Lee & Hong, Forthcoming). Experts predict PRC to become the world's biggest economy sometime between 2015 and 2030 (Barboza, 2010; Bracken, 2000; Milburn, 2005; Murray, 1998). This unprecedented growth began in the 1970's with significant policy reform and a new sense of openness to other nations. Special economic zones were created to permit direct foreign investment (Jao et al., 1986). Foreign investment was slow at first due to the lack of experience and legal structure but has increased significantly in recent years (Hill & Jongwanich, 2009). In the late 1990's reform efforts were focused on turning state owned enterprises over to "non public ownership" (Haveman et al., 2008). In 2001 PRC joined the World Trade Organization (Tong-qing, 2002). Most recently the PRC has tightened monetary policies to reduce inflation and prevent another housing bubble (Xu & Chen, 2012). The decision alternatives discussed in this paper deal directly with issues that will affect the continued growth and stabilization of the PRC economy.

6.1.2 PRC and US relations

US and PRC relations were initialized long before the PRC became a superpower. For over 30 years after the establishment of the PRC, the US would not recognize the PRC as the official government of China. Slowly the US recognized the strategic, political, and economic benefits to be obtained from a relationship with the PRC. From 1954 to 1970 multiple meetings were held between ambassadors from the two countries; however, it was not until Kissinger's "secret trip" in 1971 that government relations were opened (Su, 1983). The *Shanghai Communiqué*, a statement on future relations, was signed by the leaders of both nations. This agreement immediately provided both countries with an additional sense of security against the Soviet Union and with commitments to open trade (Glaubitz, 1976).

Relations were fragile during the coming years as each country had very different opinions about matters such as the Vietnam War, Taiwan, and human rights. In 1989, as a result of the violence in Tiananmen Square, the US and other nations imposed sanctions against PRC (Cooper Drury & Li, 2006). The sanctions were slowly lifted and relations again began to improve. However, as part of the hilly journey, relations were once again strained with the bombing of the PRC embassy in Belgrade and the collision of a PRC fighter jet and a US spy plane over PRC land (Baynham, 2005; Gries, 2006). In 2001, the terrorist attacks in the US on September 11th brought another key issue to the surface that provided both countries with an issue they jointly opposed (Friedberg, 2002). A benefit of fighting against terrorism is that these efforts would also improve geopolitical relations with neighboring countries. Both countries have since worked together on the issues of nuclear weapons in North Korea, economic issues, and climate change (Li, 2012; Madhani, 2012; Mason & Parsons, 2009).

With an improving relationship both countries need to focus their energy and direction on issues that will be most productive. In the next section a prioritization decision method that can capture and measure this complex relationship, the ANP, is reviewed.

6.1.3 The Analytic Network Process

The Analytic Network Process (ANP) was originally developed by Thomas Saaty as the Analytic Hierarchy Process (AHP) in the late 1970's (Saaty, 1977a). Saaty's efforts to develop a rigorous prioritization process stemmed from his experience working on complex strategic planning for the US State Department. According to one of the task force members, all efforts towards creating credible absolute scales to measure the efficacy of different strategies were unconvincing (Saaty, 1994). This led Saaty to ask different questions, which led to the development of ratio scales, that Saaty argues, can be used to provide meaningful decision making information when no absolute scales are available (Saaty, 1996b). The ANP has had a controversial history, but in recent years has become a dominant tool for dealing with multiple criteria decision making (Wallenius et at., 2008).

The ANP has been applied within a whole range of complex decisions in the arena of supply chain management, resource allocation, policy making, investment strategies, and predicting market shares. There are six published articles, in particular, that have dealt with issues that are similar to the US and PRC relations. The first addressed the conflict in South Africa between the minority white government and black majority (Tarbell & Saaty, 1980). Saaty and Vargas analyze the future of the Soviet Union by considering the actors, forces, objectives and policies at play (Saaty & Vargas, 2001). Zoffer et al. (2008) use a benefits, opportunities, costs and risks (BOCR) model to address peace in the Middle East between Israelis', Palestinians, the US, and other interested parties with a two state solution. Saaty and Zoffer (2011) use the AHP to weight and prioritize concessions from each party in the Palestinian–Israeli conflict. The AHP was particularly helpful for both parties to "evaluate and moderate" their extreme positions on the issues being considered.

In 1995, Saaty and Shang (Saaty, 2002), determined that the US definitely should not impose sanctions on the PRC over piracy and intellectual property rights. An ANP model with benefits, opportunities, costs, and risks (BOCR) networks was used to determine what trade relation status to grant the PRC. The three alternatives considered were: yearly extensions, permanent normal trade relations status, and to amend normal trade relations. From the analysis the decision was clearly in favor of granting the PRC permanent normal trade relations status (Saaty & Cho, 2001).

Details on the mathematical foundation of the ANP model can be found in Saaty (1999); the fundamentals are summarized here for completeness. An ANP model consists of the control hierarchies, clusters, elements, interrelationships between elements, and interrelationships between clusters. The modeling process is better understood by dividing it into several steps which are described as follows:

Step 1: Pairwise comparison and relative weight estimation. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion based on the principle of AHP. Saaty (1980) suggested a scale of 1-9 when comparing two components (see Table 6.1).

Intensity of importance a_{ij}	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it

Table 6.1 Saaty's scale for pairwise comparisons

The result of the comparison is the so-called dominance coefficient a_{ij} that represents the relative importance of the component on row (i) over the component on column (j), i.e., $a_{ij} = w_i / w_j$ $a_{ij} = w_i / w_j$. The pairwise comparisons can be represented in the form of a matrix (Saaty & Peniwati, 2007). The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j.

After all the pairwise comparisons are completed the priority weight vector (w) is computed as the unique solution of Aw = λ_{max}w, where λ_{max} is the largest eigenvalue of matrix A. Matrix A is defined as:

$$A=\begin{bmatrix} W1/W1 & \cdots & W1/Wn \\ \vdots & \ddots & \vdots \\ Wn/W1 & \cdots & Wn/Wn \end{bmatrix} = \begin{bmatrix} 1 & \cdots & a1n \\ \vdots & \ddots & \vdots \\ 1/a1n & \cdots & 1 \end{bmatrix}$$

Step 2: Consistency index estimation. To more accurately represent judgments, the comparisons need not be entirely consistent. However, if a set of comparisons are too inconsistent one could just as well have used random entries and the information from the comparisons would not be useful. In order to provide a balance, the consistency index (CI) of the derived weights could then be calculated by: CI = (λmax−n) n−1. In general, if CI is less than 0.10, one may be satisfied with the judgments that were derived (Saaty & Ozdemir, 2005).

Step 3: Formation of the initial supermatrix. Elements in the ANP represent the entities in the system that interact with each other. The determination of relative weights mentioned above is based on pairwise comparisons just as in the standard AHP. The weights are then put into the supermatrix (see Figure 6.1) that represents the interrelationships of elements in the system. The general form of the supermatrix is described here below where CN denotes the N^{th} cluster, e_{Nn} denotes the nth element in the N^{th} cluster, and W_{ij} is a block matrix consisting of priority weight vectors (w) of the influence of the elements in the i^{th} cluster with respect to the j^{th} cluster.

		C_1				C_2				…	C_N			
		e_{11}	e_{12}	…	e_{1n}	e_{21}	e_{22}	…	e_{2n}		e_{N1}	e_{N2}	…	e_{Nn}
C_1	e_{11}	W_{11}				W_{12}				…	W_{1N}			
	e_{12}													
	…													
	e_{1n}													
…	…	…				…				…	…			
C_N	e_{N1}	W_{N1}				W_{N2}				…	W_{NN}			
	e_{N2}													
	…													
	e_{Nn}													

Figure 6.1 Supermatrix

Step 4: Formation of the weighted supermatrix. The initial or "unweighted" supermatrix consists of several eigenvectors each of which sums to one. The clusters in the initial supermatrix must be weighted and transformed to a matrix in which each of its columns sums to unity.

Step 5: Calculation of global priority vectors and weights. In the final step, the weighted supermatrix is raised to limiting power to get the global priority vectors as in Equation (1).

$$\lim_{n \to \infty} (W)^n \qquad (1)$$

The robustness of the decision can then be tested by performing sensitivity analysis. One can also identify the most pertinent and influential criteria in the model. In the subsequent section the Model for the US PRC decision is developed and explained.

6.2 MODEL

The ANP model consists of five options (alternatives) that are evaluated to determine which initiative would be most effective for the US and PRC to focus their efforts and resources on. The alternatives are presented and explained in detail below. The strategic criteria are also set forth followed by a brief description of the clusters that are used to organize the specific criteria within each of the benefits, opportunities, costs and risks networks. The individual criteria and their relationships to other criteria in the networks are displayed in figures in their respective sections. The priorities within each network are also presented in tables within their respective sections.

6.2.1 Alternatives

The five alternatives considered in this model were identified from issues discussed in the current news, political dialogue, and academic publications. The titles were chosen as key words that summarize the issues; however, to make the comparisons and analysis meaningful specific actions are described in greater detail. The relevant issues surrounding each initiative are also presented and cited in their respective sections. After the alternatives are discussed the criteria used to evaluate them are presented in the next section.

- *High technology.* This term refers to cutting edge technology. The technology can exist in any field; however, primary sources of dissonance are military, energy, and business, technology. The US has been reluctant to share its technological advantages with other countries (Zhou, 2008). The US has banned high technology exports to the PRC. This ban has political and economic repercussions. One obvious repercussion is the impact on the trade deficit (Xu, 2012). Walsh (2007) explains how the PRC is at a crossroads where it has been developing infrastructure and regional economic zones similar to “silicone valleys” and it is critical for the PRC to play in this “field of dreams.” Much of the technological developments to this point **have** come from foreign direct investment; and reliance on outside sources has its shortcomings. The growth of the PRC’s economy has underscored the need for accelerated technological upgrades (Graulier et al., 2007; Gilboy, 2004). According to survey research conducted by Fang et al. (2008) trust and technological expertise were among the three most important factors to determine the success of business negotiations in the PRC. These criteria are reflected in the networks. In summary, the importance of this alternative is underscored by Chinese Premier Wen Jiabao said, “China is prepared to buy more from the United States" (Xu, 2012).

- *Climate change.* The PRC is the world leader in carbon emissions followed by its G-2 counterpart the US. Advocates of climate change claim the effects of climate change will be devastating (Karl et al., 1996). Flooding and droughts will increase in different areas, severe weather will become more intense, and sea levels will rise (Lieberthal & Sandalow, 2009). Both countries are taking strides to implement tighter regulations and develop green technologies. Even with all the efforts considered there are still significant hurdles to overcome. Cost and technology are two of the greatest hurdles. The PRC is emerging as a world leader in green technology. Both countries would benefit from increased cooperation in this area (Oster, 2009). The Kyoto Protocol is one example of attempts to address the climate change (Bodansky, 2010). Cooperation can lead to energy security, increased trust, and reduce the likelihood production will be transferred elsewhere (Lieberthal & Sandalow, 2009).
- *Foreign policy.* There are many politically sensitive issues between the US and the PRC, i.e. the South China Sea Gallagher, 1994), the Korean Peninsula (Shambaugh, 2003), and the China-Iran relationship (Dorraj & Currier, 2008). However, the “Taiwan question” is still the most sensitive issue between the two countries. On the one hand, Beijing claims that one day Taiwan will be reunified with the PRC either peacefully or by force. On the other hand, the US sales arms to Taiwan to improve their military forces (Dumbaugh, 2007). These competing messages increase the tension around the Taiwan question and could lead to armed conflict. According to Freeman (1998) attempting to sustain a military balance in the Taiwan Strait may cause a new arms race that Taiwan cannot win in the long run, hence the primary goal of the US should be to ensure the Taiwan question is resolved peacefully. Deepening economic cooperation across the Taiwan Strait and between the PRC and the US is also necessary. This conflict would severely disrupt economic ties and impose huge costs that neither the PRC and the US can afford (Saunders,

2005). Thus, the cooperation and negotiation on this issue holds great importance in the PRC and US relationship.

- *Trade policy*. Trade volume between the PRC and the US was $409 billion in 2008. There is an enormous imbalance in the trade between both countries. Part of this gap is due to export bans imposed by the US towards the PRC; both countries stand to benefits from increasing the number of exports from the US to the PRC (Ju et al., 2010). According to Peng (2011) language in the World Trade Organization Non-automatic Export Licensing rules allows both countries to restrict certain exports. Trading is also adversely effected by tariffs, export controls, and value added taxes; the US has taken a protectionist approach in contrast to the PRC's offensive approach to this sort of protection measures. Both countries have submitted complaints to the World Trade Organization against such measures (Hufbauer & Woollacott, 2012). Further action to avoid the tariffs or value added taxes can be seen in discrepancies between trade statistics of the two countries. Tariff evasion was estimated to cost $6.5 billion between 2002-2008 (Ferrantino et al., 2012).
- *Financial policy*. As the PRC emerges as an influential world power the US and other countries insist that the PRC no longer peg the value of its currency (Krugman, 2010). Critics cite job loss, trade deficits, and financial bubbles as the results of the currency pegging (Gilboy, 2004; Krugman, 2010). At the same time both countries benefit from the current circumstances. The PRC has vast foreign reserves totaling over US$2 trillion in 2008 alone (World Bank, 2009). The vast amount of foreign reserves creates a dependency between the US and the PRC. According to Gilboy (2004), the PRC has a long way to grow before becoming a superpower; and imposing additional protectionist policies will only adversely effect the US economy. Gilboy demonstrates how US companies and consumers have saved hundreds of millions of dollars because of the low cost advantage the PRC provides; the US has also benefitted from job growth in the technology industry (2004). While the PRC has benefited from having a huge export economy it has also suffered from high inflation and the influx of foreign capital. How each country responds will

have implications not only towards the opponent's economy but also on their own economies (Liew, 2010). This complexity creates additional risks that some economists have related to the "Arab Spring" (Archie, 2011). Liew (2010) explains the costs and risks for both countries are significant and will require a great deal of mutual cooperation.

6.2.2 Criteria

The strategic criteria which are used to weight the priority vectors from the benefits, opportunities, costs and risks (BOCR) networks are detailed below. Many of the individual criteria apply to both the PRC and the US; however, there are specific issues that apply only to one country or the other. The BOCR networks are broken into two subnetworks: the PRC and the US. Within each subnetwork the relevant criteria are organized into their respective clusters with other similar elements. The inner and outer dependence, or influence, between the elements are identified and displayed in the figures below. The specific elements and clusters in each BOCR network will be discussed in their respective sections. Let us begin with the strategic criteria.

6.2.2.1 Strategic criteria

The four networks from the benefits, opportunities, costs and risks, must be integrated into the overall goal which is to rank which alternative is the best issue for the PRC and US to focus on. In order to consider the different weights of these four networks strategic criteria are used to compare and prioritize each network. The strategic criteria are listed and described below.

- *Common values.* While the political and social systems are very different both countries still share common values. In order to effectively work together it is crucial that both countries can share key common values.
- *Economic growth.* The economic crisis of 2008 caused economic havoc throughout the entire world. The US has suffered from the effects of the recession and the double digit growth in the PRC has also slowed. Economic growth is the primary concern of each country.
- *Human rights.* As the PRC economy continues to grow debates about improving human rights in the PRC are escalating. The US and other countries have criticized the PRC

government for not taking sufficient action to improve human rights among its people. The PRC government argues that while it does not copy western standards it is actively making improvements.

- *Peace and safety*. This is a mutual goal between the PRC and US; and as the G-2 powers they have an increased responsibility to promote world peace and stability. The benefits of actively facilitating peaceful negotiations are also in the countries' self interest.
- *External relations.* As both powers continue to grow it is increasingly important that they foster and develop strategic and economic relations with other countries. There are opportunities for new investments and synergy.

6.2.2.2 Benefits

The alternatives within the benefits networks for both the PRC and the US are evaluated with respect to the criteria that have been organized into five clusters: commonality, economic, military, political, and social. The specific elements are displayed in Figure 6.2. The results of the pairwise comparisons for the benefits are presented in Table 6.2.

Figure 6.2 Benefits networks

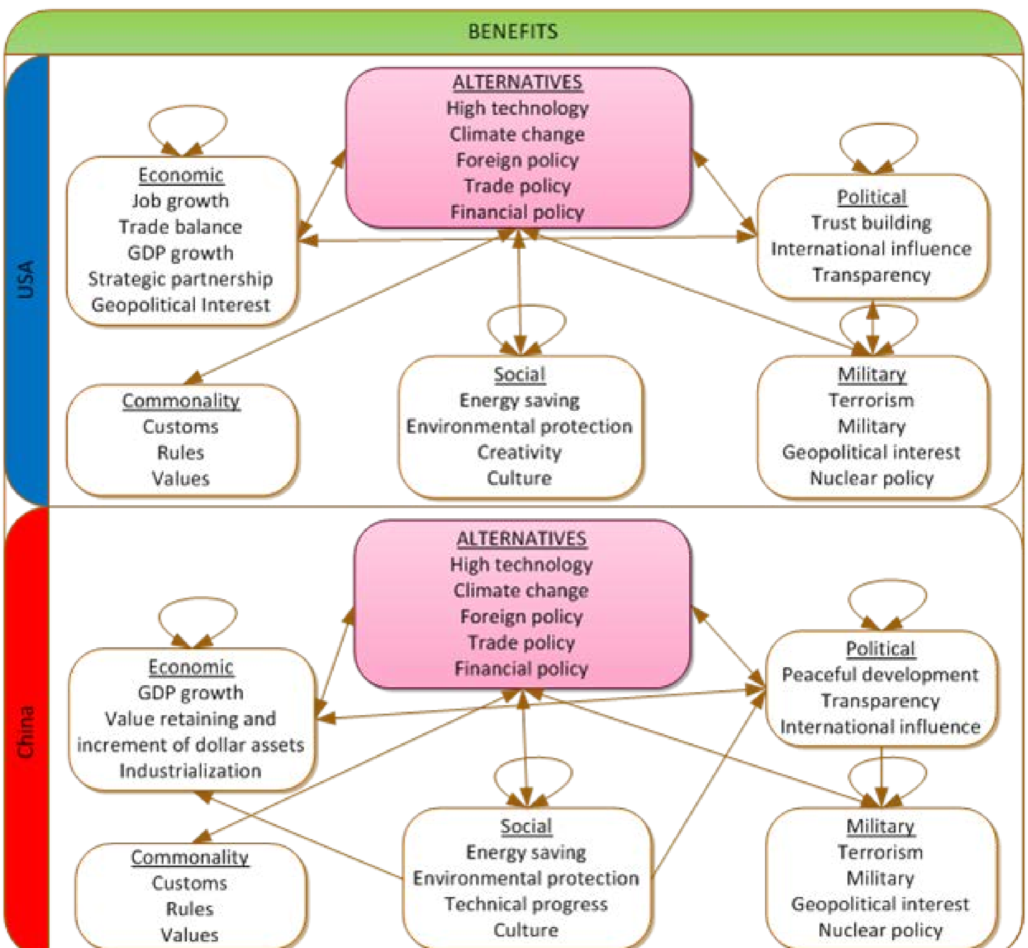

Table 6.2 Benefits network's synthesized results

Benefits

Country	Alternatives	Raw	Normalized	Ideal	Rank
US	**High Technology**	**0.0759**	**0.2470**	**1.0000**	**1**
	Climate Change	0.0570	0.1854	0.7508	4
	Foreign Policy	0.0723	0.2352	0.9521	2
	Trade Policy	0.0674	0.2194	0.8883	3
	Financial Policy	0.0347	0.1130	0.4574	5
PRC	High Technology	0.0374	0.1311	0.4235	4
	Climate Change	0.0154	0.0539	0.1742	5
	Foreign Policy	0.0792	0.2780	0.8979	2
	Trade Policy	**0.0882**	**0.3096**	**1.0000**	**1**
	Financial Policy	0.0648	0.2273	0.7339	3
Combined	High Technology		0.1956	0.7539	3
	Climate Change		0.1271	0.4899	5
	Foreign Policy		0.2542	0.9797	2
	Trade Policy		**0.2594**	**1.0000**	**1**
	Financial Policy		0.1637	0.6309	4

The top alternative in the benefits network for the US is High technology; for the PRC the top alternative is Trade policy. When the US and PRC are combined with equal cluster weights of 50% the alternative Trade policy then becomes the most beneficial alternative.

6.2.2.3 Opportunities

The alternatives within the opportunities networks for both the PRC and the US are evaluated with respect to the criteria that have been organized into three clusters: economic, political, and social. The specific elements are displayed in Figure 6.3. The results of the pairwise comparisons for the opportunities are presented in Table 6.3. Financial policy has the potential to provide the US with the most opportunities; however, similar results could also come from the Foreign policy and Trade policy alternatives which have similar priorities. The PRC would strongly benefit most from the High technology option. The combined results show Financial policy providing the most benefits with High technology finishing in a very close second.

Figure 6.3 Opportunities networks

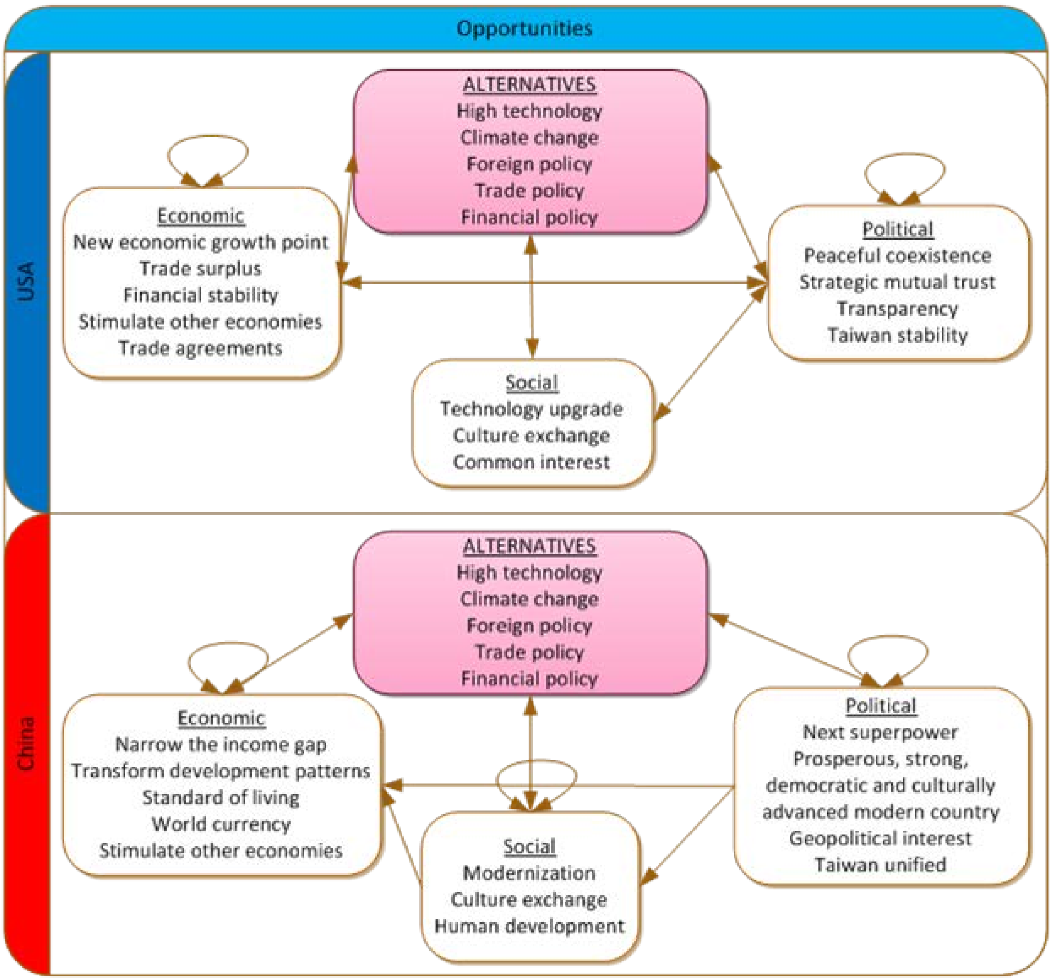

Table 6.3 Opportunities network's synthesized results

Opportunities

Country	Alternatives	Raw	Normalized	Ideal	Rank
US	High Technology	0.0464	0.1087	0.3713	4
	Climate Change	0.0361	0.0847	0.2894	5
	Foreign Policy	0.1161	0.2722	0.9299	2
	Trade Policy	0.1031	0.2417	0.8255	3
	Financial Policy	**0.1249**	**0.2927**	**1.0000**	**1**
PRC	**High Technology**	**0.1827**	**0.4249**	**1.0000**	**1**
	Climate Change	0.0311	0.0723	0.1702	5
	Foreign Policy	0.0643	0.1495	0.3519	4
	Trade Policy	0.0779	0.1811	0.4262	2
	Financial Policy	0.0740	0.1721	0.4051	3
Combined	High Technology		0.2377	0.9759	2
	Climate Change		0.0797	0.3271	5
	Foreign Policy		0.2222	0.9123	3
	Trade Policy		0.2170	0.8909	4
	Financial Policy		**0.2435**	**1.0000**	**1**

6.2.2.4 Costs

Similar to the opportunities network the costs network consists of three criteria clusters: economic, political, and social. The US and PRC costs networks are displayed in Figure 6.4. The synthesized results are presented in Table 6.4. The most expensive option for the US is the Foreign policy which would be more than twice as expensive as its next closest alternative Financial policy. Trade policy is the most expensive alternative for the PRC which also has Financial policy as the next most expensive alternative; however, by a much narrower margin. The combined results are that Foreign policy would be the most costly alternative to implement.

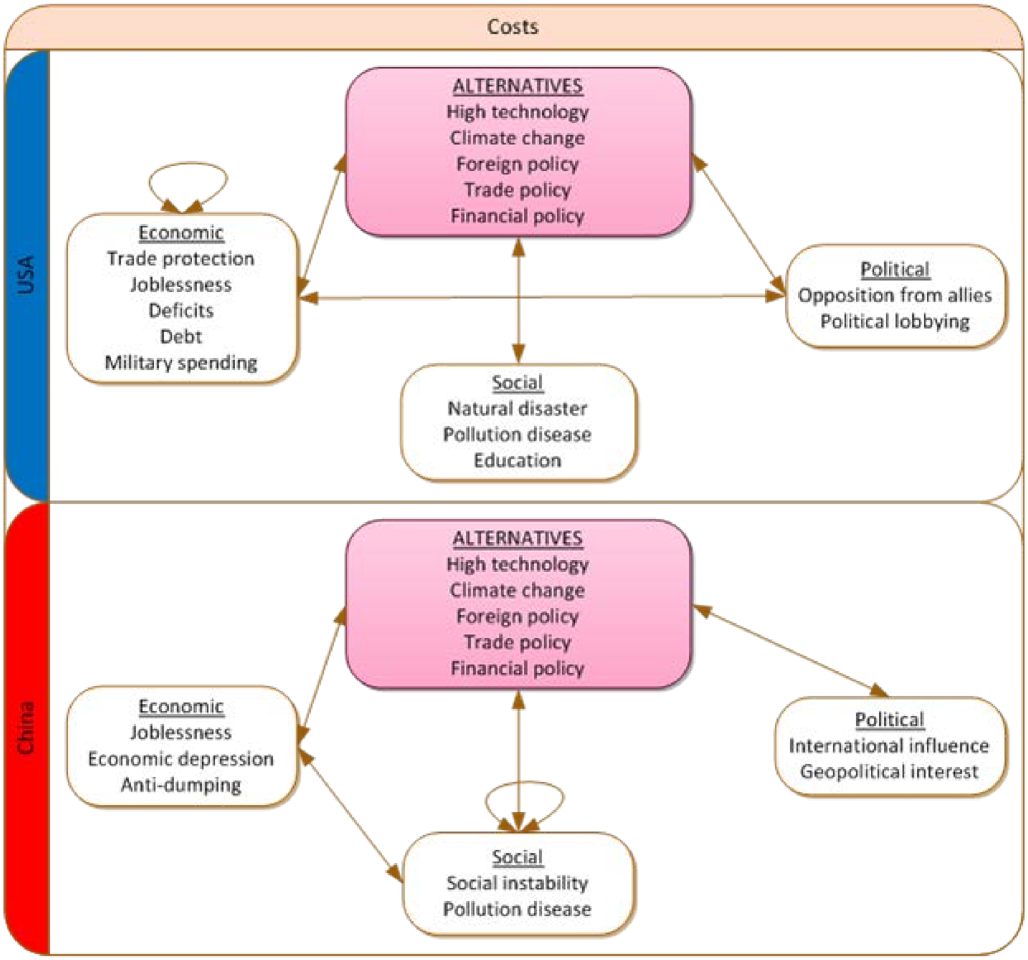

Figure 6.4 Cost networks

Table 6.4 Costs network's synthesized results

Costs

Country	Alternatives	Raw	Normalized	Ideal	Rank
US	High Technology	0.0384	0.1344	0.3116	4
	Climate Change	0.0160	0.0558	0.1294	5
	Foreign Policy	**0.1234**	**0.4315**	**1.0000**	**1**
	Trade Policy	0.0501	0.1752	0.4060	3
	Financial Policy	0.0581	0.2031	0.4707	2
PRC	High Technology	0.0890	0.2232	0.6922	3
	Climate Change	0.0072	0.0182	0.0563	5
	Foreign Policy	0.0683	0.1715	0.5317	4
	Trade Policy	**0.1285**	**0.3225**	**1.0000**	**1**
	Financial Policy	0.1055	0.2646	0.8206	2
Combined	High Technology		0.1852	0.6553	4
	Climate Change		0.0343	0.1212	5
	Foreign Policy		**0.2827**	**1.0000**	**1**
	Trade Policy		0.2595	0.9180	2
	Financial Policy		0.2383	0.8431	3

6.2.2.5 Risks

The risks that could affect the US or PRC are grouped into the following clusters: economic, social, political, and military. The specific elements can be found in Figure 6.5; and the synthesized results can be found in Table 6.5. An interesting pattern emerges from the comparisons in the risks networks. For both the US and the PRC the ranking of the alternatives is identical and the intensity of the alternatives is similar between both countries. These results of course also lead to the same ordering for the combined results where the Financial policy is the riskiest alternative to pursue. Climate change was both the least risky and cheapest alternative to implement. As will be seen in the synthesized results Climate change initiatives fail to provide as many benefits and opportunities as the other alternatives.

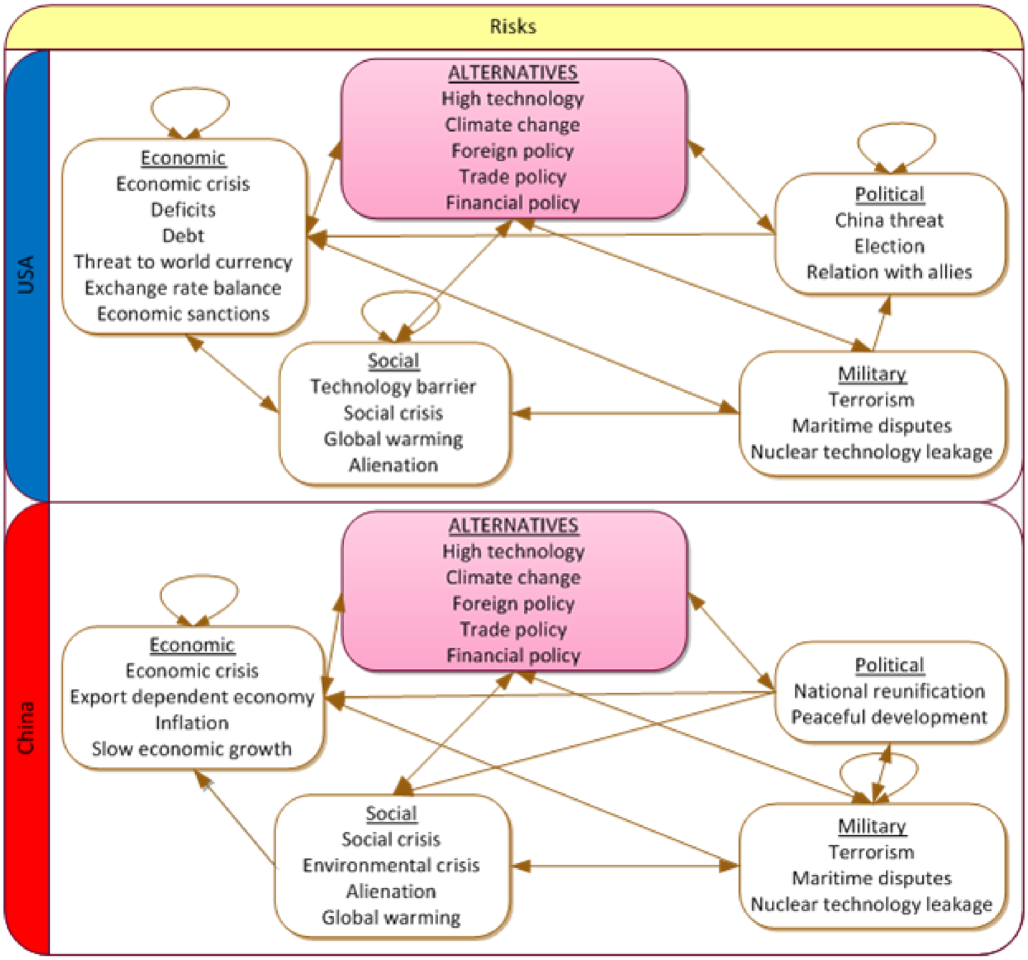

Figure 6.5 Risks networks

Table 6.5 Risks network's synthesized results

Risks

Country	Alternatives	Raw	Normalized	Ideal	Rank
US	High Technology	0.0463	0.1022	0.2908	4
	Climate Change	0.0398	0.0878	0.2498	5
	Foreign Policy	0.0946	0.2086	0.5935	3
	Trade Policy	0.1133	0.2500	0.7114	2
	Financial Policy	**0.1593**	**0.3514**	**1.0000**	**1**
PRC	High Technology	0.0436	0.1169	0.3886	4
	Climate Change	0.0408	0.1094	0.3636	5
	Foreign Policy	0.0724	0.1942	0.6455	3
	Trade Policy	0.1039	0.2785	0.9255	2
	Financial Policy	**0.1122**	**0.3009**	**1.0000**	**1**
Combined	High Technology		0.1101	0.3397	4
	Climate Change		0.0994	0.3067	5
	Foreign Policy		0.2009	0.6195	3
	Trade Policy		0.2654	0.8184	2
	Financial Policy		**0.3242**	**1.0000**	**1**

6.3 COMBINED RESULTS

The strategic criteria which were explained previously are now used to weight, prioritize, and combine the priority vectors of the alternatives within each of the benefits, opportunities, costs, and risks networks into the overall synthesized results. The respective weights of the strategic criteria and benefits, opportunities, costs, and risks are displayed in Figure 6.6.

	Priorities	1Common values 0.083560	2Economic growth 0.323247	3Human rights 0.135234	4Peace and Safety 0.242596	5External relations 0.215363
1.Benefits	0.342614	Medium	Robust	Increase	Increase	Increase
2.Opportunities	0.236974	Medium	Strong	No change	No change	Increase
3.Costs	0.190964	High	Below average	No change	No change	Increase
4.Risks	0.229448	High	Below average	No change	Increase	Increase

Figure 6.6 Strategic criteria

The results of the model are calculated first by using the short term analysis called multiplicative synthesis (Benefits * Opportunities/Costs * Risks) (Figure 6.7). The preferred option under the multiplicative synthesis is Climate change with High technology as the next most preferred. The relatively low costs and risks for Climate change lead to the higher ratio under the benefits and opportunities. High technology on the other hand is the next cheapest and least risky but provides average to high benefits and opportunities.

Name	Graphic	Ideals	Normals	Raw
1High technology		0.765762	0.300394	2.856064
2Climate change		1.000000	0.392281	3.729700
3Foreign Policy		0.333832	0.130956	1.245092
4Trade Policy		0.275358	0.108017	1.027001
5Finacial Policy		0.174244	0.068353	0.649878

Figure 6.7 Short term multiplicative results

The long term impact is calculated with the additive approach (b*Benefits + o*Opportunities - c*Costs - r*Risks) where each network is weighted according to the weights (b,o,c,r)and combined to obtain the final results (Figure 6.8). Under this approach High technology is the most preferred alternative followed by Foreign policy and Trade policy. Because one should be more concerned with the long term results in this decision the additive formula provides the preferred results. The sensitivity analysis in the next section is based on the additive formula.

Name	Graphic	Ideals	Normals	Raw
1High technology		1.000000	0.329528	0.232012
2Climate change		0.537366	0.177077	0.124675
3Foreign Policy		0.772666	0.254615	0.179268
4Trade Policy		0.645454	0.212695	0.149753
5Finacial Policy		0.079156	0.026084	0.018365

Figure 6.8 Long term additive results

6.4 SENSITIVITY ANALYSIS

To test the robustness of the High technology alternative as the preferred option sensitivity analysis will be performed under multiple scenarios. First, the weights of the benefits, opportunities, costs and risks networks will each be varied from 0-1, where zero is not important to 1 being all-important (Figure 6.9 and Figure 6.10). In the benefits sensitivity analysis when the priority of the benefits exceeds 0.3106 Foreign policy becomes the preferred option until the priority of the benefits exceeds 0.5210 when Trade policy becomes the preferred Option. Under the opportunities sensitivity analysis High technology is the preferred alternative until the opportunities priority exceeds 0.8900 when Financial policy becomes the preferred alternative. However, it is worth noting that after the opportunities priority exceeds 0.5 the alternatives become almost indistinguishable. In the cost sensitivity analysis High technology is the preferred alternative until the cost priority exceeds 0.2000 after which Climate change becomes the preferred alternative. Financial policy is the worst option until the costs priority exceeds 0.4877 where it is similar to the other three alternatives. Under the risks sensitivity analysis the High technology is the best option until the risks priority is greater than 0.6806 and then Climate change becomes the preferred alternative.

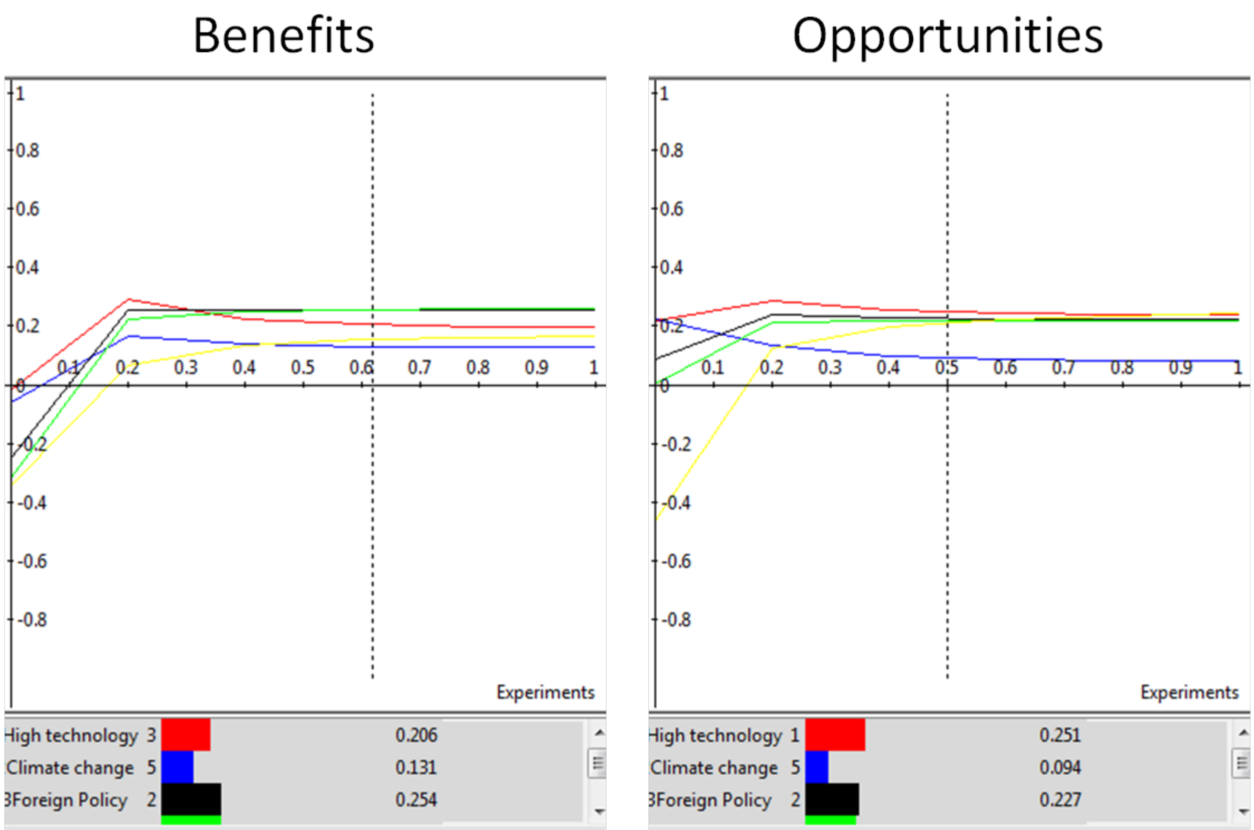

Figure 6.9 Sensitivity analysis: benefits and opportunities

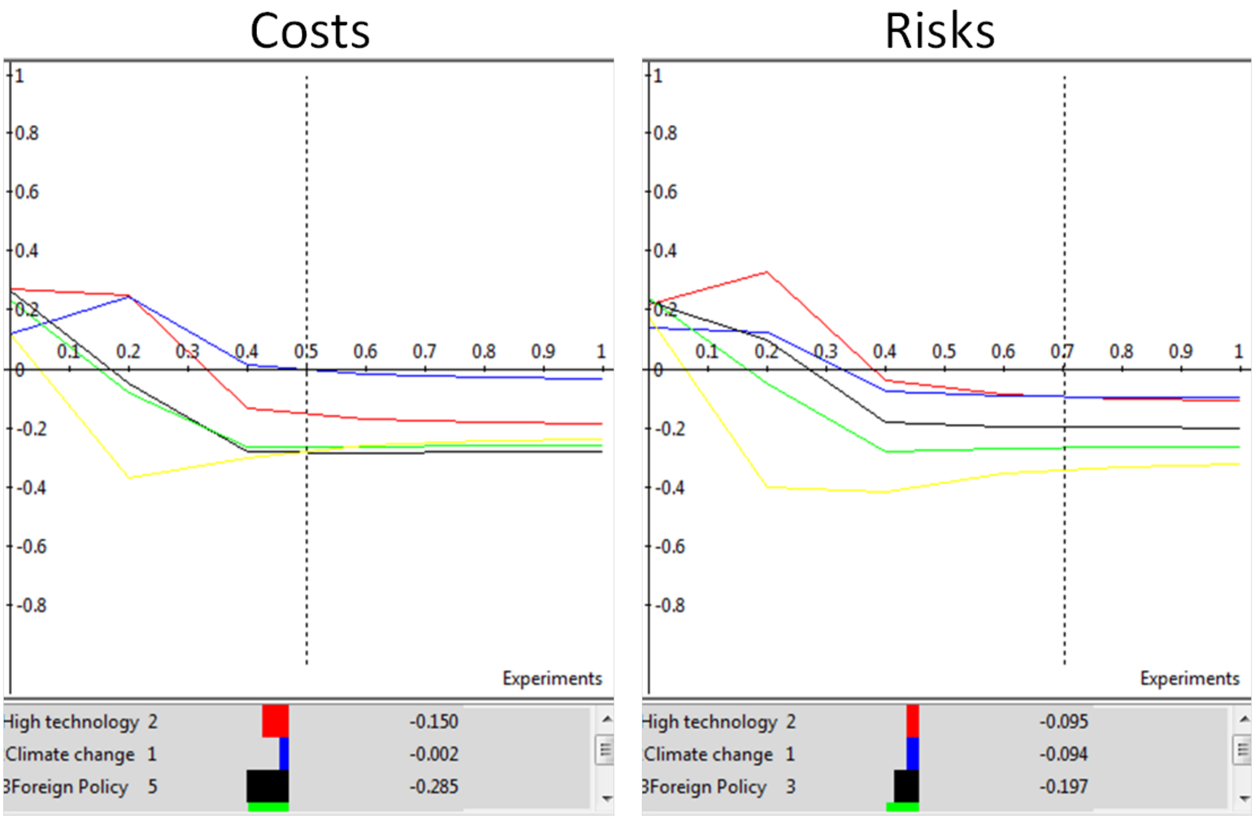

Figure 6.10 Senstivity analysis: cost and risks

One of the most important considerations to evaluate is to change the priority weight of each country. The original results are calculated under the assumption that each country should be considered equal. Interestingly enough, changing the priority weights from all the priority allocated to the PRC to all the priority allocated to the US does not result in a change in the ranking of the top alternative (Figure 6.11). As the priority is shifted towards the PRC High technology becomes even more important and Foreign policy becomes the second most preferred alternative.

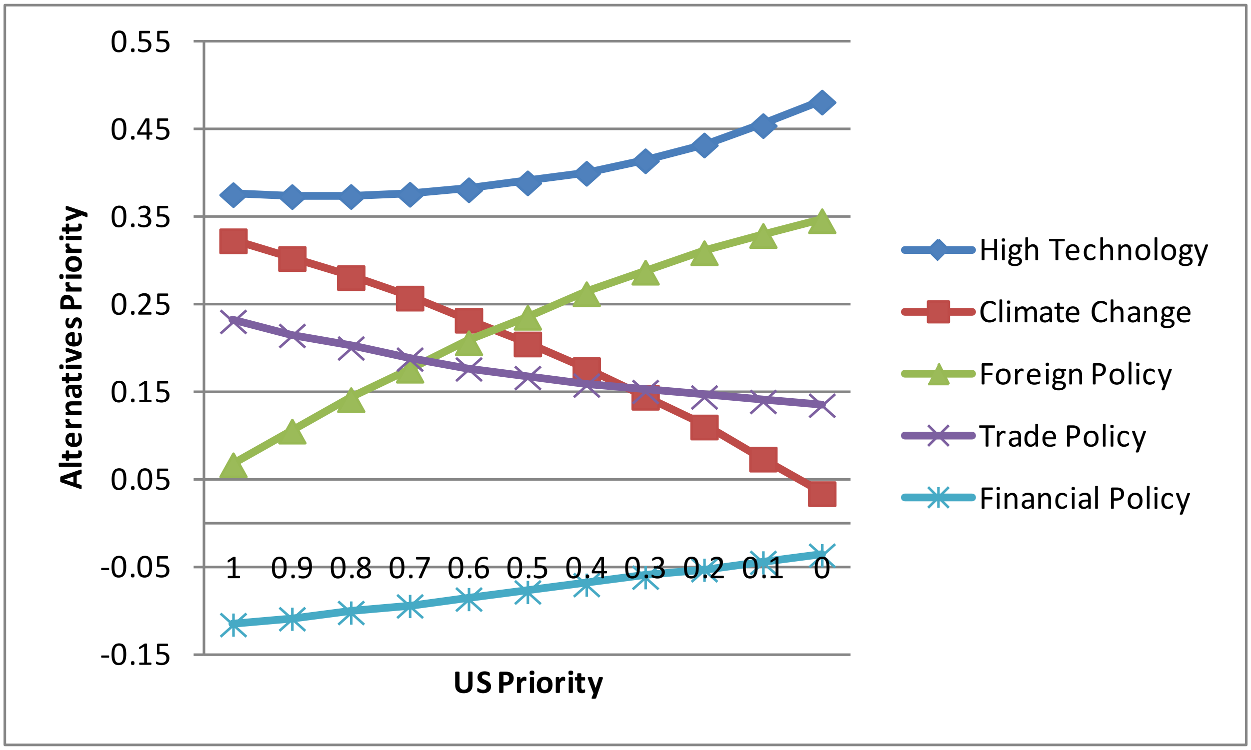

Figure 6.11 Sensitivity analysis priority weight of country

The impact of changing the weight of the economic clusters in both countries and throughout every network has a clear impact on the second and third alternatives. If the priorities of the economic cluster are increased 100%, Trade policy is preferred over Foreign policy; however, if the weight is decreased 100%, then Foreign policy is preferred to Trade policy. Regardless of the shift between the Trade and Foreign policy, High technology is always the preferred alternative despite changes in the priority of the economic cluster.

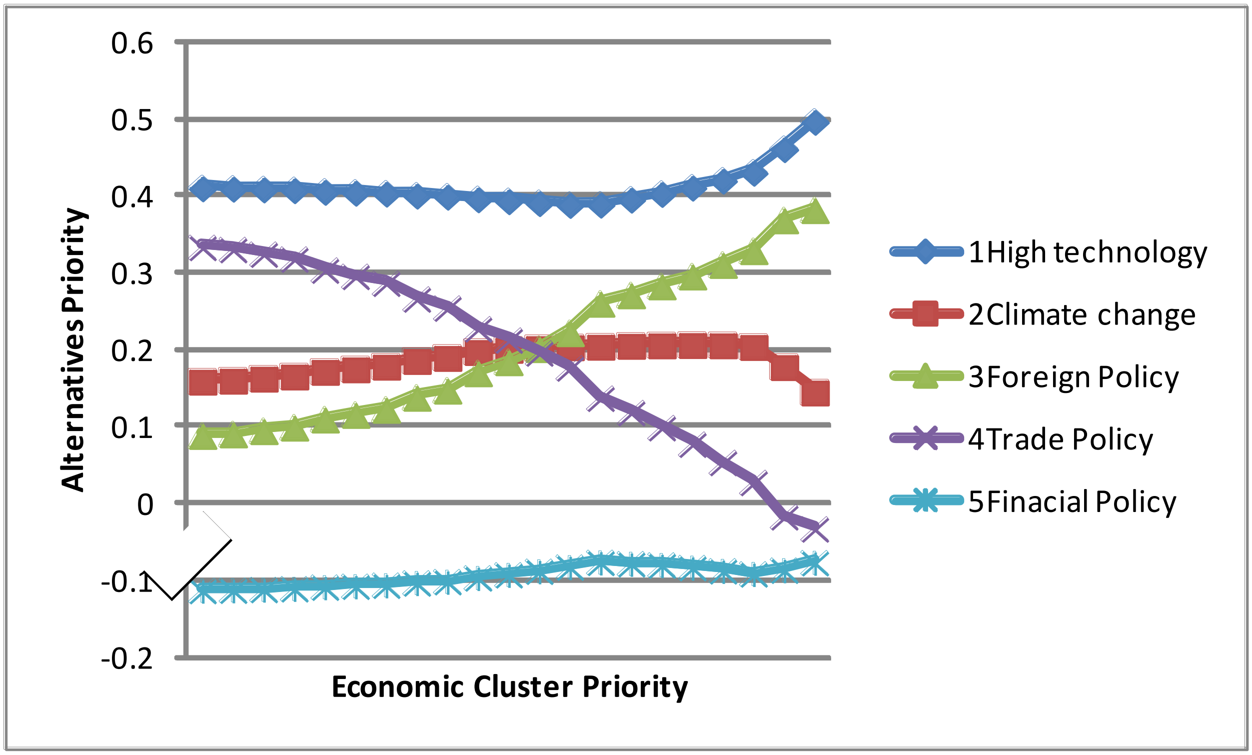

Figure 6.12 Sensitivity analysis weight of economic clusters

The robustness of the High technology alternative is again portrayed as the weight of the Social cluster is changed. The social implications of Climate change are apparent as it approaches first place with a higher weighting on the social clusters whereas when the weighting decreases so does the preference for Climate change.

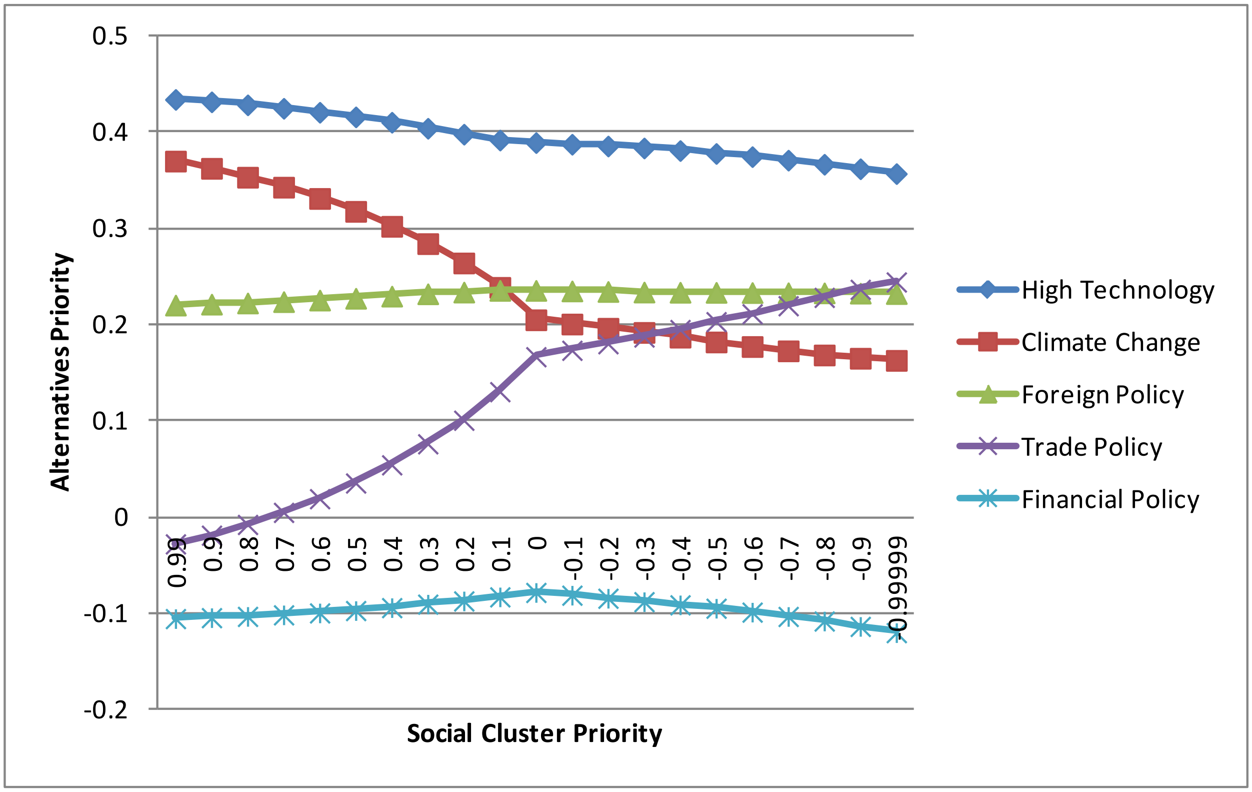

Figure 6.13 Sensitivity analysis weight of social cluster

Foreign policy is a political hot topic. The issues surrounding the status of Taiwan are political in nature. It is no wonder then that as the weights of the Political clusters are increased Foreign policy is the preferred alternative. The impact of High technology is also demonstrated again when the priorities of the Political clusters are increased by less than approximately 40% of their original values High technology again becomes the preferred alternative.

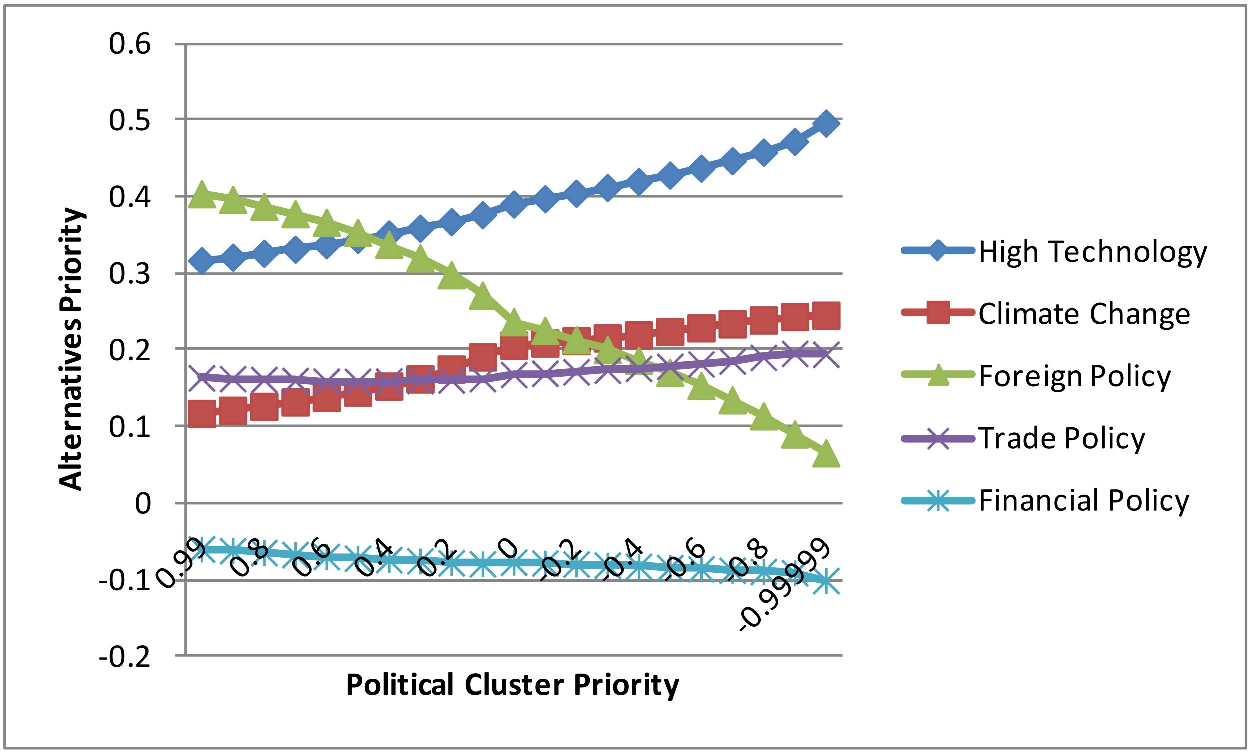

Figure 6.14 Sensitivity analysis weight of political clusters

One of the primary areas of technology trade that is currently banned is in the area of military technology. As the priority for Military clusters increases so does the priority for High technology; however, with the additional benefits this alternative provides it is still the preferred alternative regardless of the weighting of the Military cluster.

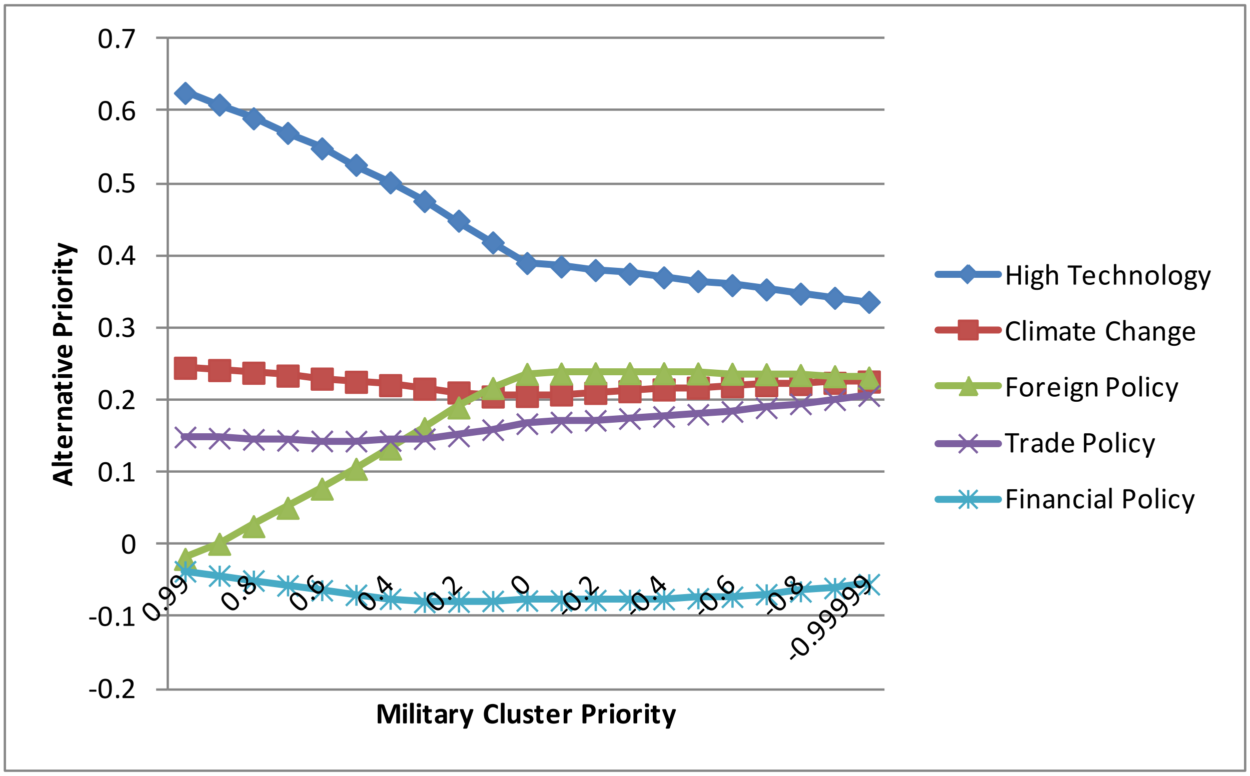

Figure 6.15 Sensitivity analysis weight of military clusters

6.5 CONCLUSION

The potential benefits and opportunities the PRC and US have to gain from continuing to develop and improve relations outweigh the costs and risks that surround such efforts. In particular both countries should focus on High technology exports. The robustness of this decision can be seen from the results of the sensitivity analysis in the previous section. The ANP BOCR model with subnetworks to evaluate the specific criteria from each country provides a framework to model and evaluate what Shambaugh described as the "diffuse" and "illusive" challenges the PRC and the US face (Shambaugh, 2000, p. 113). Furthermore in contrast to Friedberg who argues that "analysts lack the kinds of powerful predictive tools" (Friedberg, 2005, p. 8) the ANP is a powerful predictive tool that experts can use to solve complex problems because of the method's ability to tap humans innate ability to measure intensity of preference. While the results in this model cannot be formally validated like a scientific experiment, the successful application of the ANP in other instances carries significant weight in the argument. Multiple examples were cited and reviewed in the ANP literature review section of this paper.

The results of this model suggesting High technology as the preferred alternative should not be interpreted to mean that every single embargo should be lifted. It would be more beneficial to create another ANP model to evaluate and prioritize the specific products and technologies according to the individual costs and benefits. This analysis would provide order and direction for policy makers to move forward and address specific tradeoffs in a manner similar to the Israeli-Palestinian negotiations conducted by Saaty and Zoffer (2011). This analysis could also be extended to include a G-3 analysis or to include other emerging economies like BRICS (Brazil, Russia, India, China and South Africa).

7.0 CONCLUSION AND FUTURE WORK

The applications of the ANP within this work underscore the versatility and advantages of using the ANP for complex decision making. In chapter 2 the ANP was used to select a third party logistics provider. Chapter 3 also dealt with decisions in supply chain management by demonstrating how to select which alternative would green a supply chain. Along the lines of green supply chain and corporate social responsibility, chapter 4 introduced ethicists to the advantages of using the ANP in ethical decision making. In chapter 5 the ANP incorporates ethical issues and stakeholder theory to determine which approach the Natural Gas (NG) industry should take to work with stakeholders in regard to fracking. Then in chapter 6 the ANP and a stakeholder approach details what issues the PRC and US should allocate political and economic resources towards. The main contributions from each chapter are summarized below.

7.1 THIRD PARTY LOGISTICS

Managers from a large pharmaceutical company were interested in improving the number of perfect orders while reducing supply chain costs. The present metric system was simple and potentially inadequate. In addition leases were expiring on warehouses and the management was interested in pursuing the option of outsourcing the logistics so they could focus on core competencies. An extensive literature review was conducted to identify the most important performance measures to evaluate third party logistics providers both for selection and then for ongoing evaluation. Sources of the metrics included the supply chain management, third party logistics, and the Grocery Manufacturers Association literature. These metrics were then organized according to the temporal flow of the product into the Metrics Arrow.

The very act of identifying the relationships and influences of the performance metrics in the Metrics Arrow provided managerial insight about the impact of each metric. After completing the pairwise comparisons to determine the influence of each metric on the other metrics, management is left with another useful trouble shooting tool. By using the ANP the entire network of metrics can be analyzed together rather than in isolated stages. This is particularly important because of the dependencies between the metrics; for example, reducing the Weeks forward coverage can have an impact downstream on the Fill rate. Because the ANP can model inner and outer dependencies when performance with respect to a specific metric exceeds the desired limits management can return to the weighted supermatrix to determine which metrics have the most influence on another metric. The eigenvector of priorities can then be used to prioritize where to direct troubleshooting efforts. The organization of the performance metrics into Metrics Arrow and the managerial insight gained from using the ANP make this an excellent method to select a third party logistics provider.

7.2 GREEN SUPPLY CHAIN

Another current trend in supply chain decision making deals with greening the supply chain. Ways to green a supply chain include: reducing the carbon imprint, recycling materials, producing products with less harmful chemicals, and reducing waste. The reasons for greening the supply chain can include marketing, meeting environmental directives or standards, corporate social responsibility, and capturing previously untapped profits. A conceptual model was developed that can be used to analyze and order a list of proposed greening projects. The general model is then applied in the specific context of a TV and audio video supply chain.

The specific alternatives considered in the case study are: installation of emission abatement equipment, installation of evaporative towers to recycle water, installation of solar panels, reuse packaging, and reuse second hand materials. Based on the results of the model the manufacturer should install solar panels. Research in the area of green supply chain is relatively new and will continue to benefit from the application of the ANP to greening decisions.

7.3 ETHICAL DECISION MAKING

According to the separation thesis business has nothing to do with ethics and ethics has nothing to do with business (Freeman, 1984). This chapter is directed to ethicists to fill a gap in the current ethics literature. Philosophies about what ethical issues should be considered in a decision abound. The "how" to analyze an ethical decision is much harder to quantify and implement because ethical issues can be considered intangible which are difficult to measure. A strength of the ANP is the ability to deal with intangibles. Two ethics cases: Steve Lewis (Badaracco, 1997) and Kardell (Brooks, 2010) are summarized and then ANP models are built using the criteria suggested by their respective authors. The criteria are weighted and the alternatives are compared with respect to how well they satisfy each of the criteria. In both cases the models support the conclusions suggested by the authors; however, the ANP also provides these solutions backed by a method with a solid mathematical foundation.

The Kardell case underscores additional strengths of the ANP with its ability to naturally facilitate a stakeholder theory approach. Freeman et al. (2010) list the following considerations decision makers using stakeholder theory might address:

- The need to identify networks or large systems of interactions (p. 46)
- The stakeholders provide the firm with Opportunities and Risks (p. 36)
- The stakes of each stakeholder are multifaceted and inherently connected to each other (p. 27)
- The question of how to score and combine the stakeholder interests (p. 12)
- The relationships or interactions among the stakeholders (p. 24)
- The ability to look at both the short and long term impacts of decisions (p. 102)
- The ability to identify the groups that make a difference (p. 42)

This list of seven suggestions serves not only as a list of issues to address with stakeholder theory, it underscores the greatest strengths and advantages of the ANP. The final decision in the Kardell case is then evaluated by performing scenario analysis. The results overwhelmingly support creating a closed system for the waste. The company chose not to implement the closed system and as a result was forced to close a short time later. Had the Kardell company used the ANP and scenario analysis to see the overwhelming support for a closed system the outcome may have been different.

As a final argument in support of using the ANP to analyze ethical decisions a literature review of 217 ANP models in the *Encyclicons* (Saaty & Cillo, 2008; Saaty & Ozdemir, 2005; Saaty & Vargas, 2011) reveals that an average of 5.26 ethical elements were included in each ANP model. Tables with specific arrays of ethical elements are also provided as a reference for decision makers interested in including ethical elements in their models. By beginning with simpler ANP models to analyze existing cases from the ethical literature and demonstrating how decision makers have naturally included ethical elements in their decision a strong case has been made to encourage ethicists to embrace the ANP.

7.4 FRACKING

In a decision similar to that of the Kardell case, the natural gas industry is facing a difficult decision about fracking which is the current practice of pumping water and trade secret protected chemicals into the ground to access natural gas. The most salient risk or controversy pertains to the potential to contaminate groundwater with chemicals which can potentially disrupt the endocrine system and cause adverse health effects. The results of the decision of how to proceed affect multiple parties or stakeholders. The natural gas industry's success both in the short and long term will be directly impacted by this decision. The indirect economic partners will also be impacted. The potential risks will have the greatest impact on the communities that are directly exposed to the fracking process. Finally, communities and citizens abroad will be impacted as a result of the decisions and actions taken by or against the natural gas industry.

The ANP model considers three approaches the natural gas industry can proceed with: domination, compromise, or integration (Graham, 1995). The benefits, opportunities, costs, and risks for each stakeholder are evaluated and then combined to demonstrate that integration is the best approach. In the risks section the uncertainty regarding the potential health risks are obtained from risk profiles that use the concept of homogeneous clustering to compare both the probability and the affects of harm ranging from a day to years of illness. There are two examples that support the results of this model. First a case study of negotiations within the Marcellus Shale region show how when communities form alliances to negotiate with the natural gas companies synergies that benefit both parties arise. Second, a recent example from the Greater Natural Buttes infill project in the western US demonstrates how stakeholders used the integration approach to develop a plan for additional drilling. The US Bureau of Land Management suggests using this approach as a template for future negotiations (O'Donoghue, 2012).

7.5 PRC AND US RELATIONS

The economic, political, and social relationships between the PRC and the US have dramatically improved over the last 50 years. While the journey has not always been smooth relations continue to improve. The PRC has experienced double digit economic growth and surpassed other national economies to become the second largest economy in the world. The PRC is also determined to advance technologically and reduce its dependence on other countries for technology. With this growth the PRC and US are now considered the G-2 of superpowers. The superpower relationship has the potential to benefit both countries and provide peace and stability throughout the world or as has happened throughout the ages become a competition between the two powers to cede the other.

Neither country is free from weakness. The US is suffering from a weakened military, huge budget deficits, and the loss of its unilateral decision making power. At the same time the PRC is a fragile superpower, has seen a decline it its growth rates, and must deal with human rights issues. The model focused on what the PRC and US should focus on to work together that will benefit each country the most.

An ANP BOCR model is organized into subnetworks for each country where these five alternatives are compared: High technology, Climate change, Foreign policy, Trade policy, and Financial policy. The High technology alternative which specifically refers to the countries removing bans against sharing technology with each other is the preferred alternative. US companies stand to gain increased sales which will close trade deficits. Jobs will be created; and the military will be better equipped to fight against terrorism. The PRC can develop its infrastructure, benefit from technological advances, and further develop its economy.

The sensitivity analysis demonstrates the robustness of this alternative. First the assumption that each country should be weighted equally is removed. Regardless of the shift in weight from all the priority on one country to the other, High technology is the preferred alternative. In subsequent sensitivities the priorities of clusters like economic, social, political, and military are changed. High technology is generally the preferred alternative. With High technology as the preferred alternative it is important to specifically look at which bans should be lifted. This analysis is the first suggested extension to the current dissertation.

7.6 EXTENSIONS

A research project is almost never done to the point that another study or project wouldn't provide additional insight. A number of extensions to the current work contained in this dissertation are highlighted below. The first extensions discussed is the next step in the PRC and US relations chapter to analyze alternatives of High technology to implement. From the ethics chapters, first, just as the ethics community can benefit from using the ANP management can also benefit from addressing the other side of the Separation thesis that business decision making has nothing to do with ethics. Second, an extension of the Steve Lewis model to a complex ANP model is proposed to take full advantage of the ability to capture inner and outer dependencies.

7.6.1 Prioritizing High technology alternatives

It would be foolish to generalize from the result that High technology is the preferred alternative for the PRC and US to focus on and remove all bans immediately. Many of the restrictions pertain to military technology and pose a particular threat to national security. There are additional economic and political ramifications that must be carefully weighted. The next step should be to gather diplomatic leaders from each country to identify specific products or areas of High technology that they believe are most critical to the continued progression of each nation. From those meetings a separate ANP model can be developed to address the economic, social, political, military, and security concerns of each nation. Difficult trade-offs will need to be discussed and considered to evaluate the proposed alternatives. The recent work of Saaty and Zoffer (2011) regarding the Middle-East conflict could be used as a model for confronting the trade-offs that will arise in the High technology negotiations. Finally, the ANP can be used to incorporate stakeholder theory into supply chain management decisions.

7.6.2 Separation thesis

One side of the Separation Thesis, that business has nothing to do with ethical decisions, was addressed in chapter 4. The cases and literature review provide evidence of how tools from operations management, the AHP and ANP, have a lot to do with ethical decisions. Many of the models in *Encyclicons* (Saaty & Cillo, 2008; Saaty & Ozdemir, 2005; Saaty & Vargas, 2011) are business decisions. Under the assumptions of the Separation Thesis the ethicists may primarily focus on the intangibles and in a business decision in management the focus tends to be on the tangibles. There are a multitude of examples that show how the ANP has been successfully applied in business decisions (Whitaker, 2007). A paper with a similar scope as chapter 4, yet targeted to the business community, could demonstrate how the ANP can naturally facilitate the incorporation of ethical issues into decision models. This extension would further strengthen the support of the ANP and provide managers with a tool that they can use to incorporate ethical issues into their decisions.

7.6.3 Steve Lewis ANP model

The model of the Steve Lewis case in this work was tailored as an introductory model for an audience unfamiliar with the ANP. It is successful in that purpose, additional insight and a mathematical justification is provided to support the decision that Badarraco proposes; however, by using a more detailed ANP model with inner and outer dependence additional insight can be gained. The Steve Lewis decision model could be extended to include separate economic, social, personal, and religious clusters. Under each cluster the specific elements that compose the broader criteria used in the original model can be provided. In addition to the detailed criteria, the relationships between the criteria can be identified and prioritized. This additional information is likely to underscore and more clearly delineate the current solutions.

7.6.4 Supply chain stakeholders

A supply chain is a complex organization of multiple parties with different needs and purposes. With the globalization of supply chains these relationships become even more complicated. One might imagine a diagram of the relationships among members of a supply chain. If arrows were used to display the direction of the dependency among those relationships the image that comes to mind looks very much like an ANP network. Materials, products, and cash may flow in one direction, while forecast accuracy, product for remanufacturing, and again cash may flow in another. The suppliers, manufacturers, logistics providers, etc. all have a stake invested in the success of the supply chain network; in other words they are stakeholders. Just as the stakeholders in the Kardell case and the fracking model had different competing objectives so do the stakeholders in a supply chain. Research regarding push and pull contracts have been used to calculate upon whom the costs, risks, and benefits are distributed under each type of contract. These models have been limited to only consider tangible impacts; however, there are additional measures like trust, long term relationships, and reliability that also matter to management. Using the ANP and stakeholder theory to capture the inner and outer dependencies in a supply chain will provide valuable insight.

In this work the ANP has been applied to decision making within the supply chain to select a third party logistics provider, then social responsibility was incorporated to decide how to green a supply chain. The ANP was then applied beyond the ethical ideology of social responsibility to deal with ethical decisions in general. Finally, a decision with social, political and economical impacts regarding the PRC and US relationships was analyzed. Throughout this work the unique capabilities of the ANP are demonstrated; because of the ANP's ability to use relative measurements and measure intangibles it has the ability to change humanity's way of thinking and how decisions are made.

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