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SUPPLIER SUSTAINABILITY EVALUATION UTILIZING MULTI ATTRIBUTE UTILITY MODELING

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SUPPLIER SUSTAINABILITY EVALUATION UTILIZING MULTI ATTRIBUTE UTILITY MODELING

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
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By
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ABSTRACT OF THESIS

SUPPLIER SUSTAINABILITY EVALUATION UTILIZING MULTI ATTRIBUTE UTILITY MODELING

Conventionally, the focus during supplier evaluation has been to assess cost, quality and delivery effectiveness due to their impact on profitability. In recent years, there has been increased emphasis on promoting more sustainable business practices that focus on reducing environmental impact and improve societal well-being, in addition to economic benefits. However, most of the existing supplier evaluation methods in literature as well as those used by leading companies fall short of comprehensively assessing suppliers from a Triple Bottom Line (TBL) perspective. TBL defined as holistically looking at the economic, environmental, and societal aspects of an entity. This paper presents a review and selection of metrics for economic, environmental and societal sustainability evaluation. In addition, this work proposes a methodology for combining the scores into a comprehensive score that can be used to compare two entities performance relative to the TBL.

KEYWORDS: Sustainability, Supplier Selection, Triple Bottom Line, Multi Attribute Utility Model, Triple Bottom Line Metrics.

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Dedicated to:

My wife, my family, my friends, and a very special Ranger who inspires me to never, ever give up.

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CHAPTER ONE

Introduction

Historically, corporate supplier relationships have been transactional, exchanging goods or services for a fee – as opposed to being partners the relationship was therefore based on the economic impact of the collaboration (Dixon, 1966).

As supplier relationships developed, companies have realized the critical nature of these relationships to the point that many companies refer to their suppliers as partners. Supplier selection and management of suppliers is recognized as being critical for companies in maintaining a strategically competitive position (Chen et al., 2006). The competitive position of good suppliers consists not only of being the source for goods and services required to generative profit, but also includes the environmental and societal manner in which these suppliers provides said goods and services. The TBL factors by which the goods and services are provided "play a vital role for the long term resiliency of a supply chain" (Seuring et al,. 2008). TBL defined as holistically looking at the economic, environmental, and societal aspects of an entity. However, the environmental and societal review still typically occurs after the choice of a supplier has already occurred and tends to be very qualitative in nature. This review of the environmental and societal aspects tends to look for compliance to a minimum level of acceptance.

1.1 Supplier Selection

Supplier selection is the process by which a given entity chooses by whom services and / or items will be supplied. The decision has a direct effect on profitability, as the cost of an item or service directly affects the cash flow of the company procuring the service. It is important to note that the financial impact must also be weighed against the risk that is inherent in any supplier customer relationship. (Tahrir et al., 2007). Supplier selection has been a topic of academic research for more than 50 years and is, in essence, decision making problem. (Huang & Keskar, 2007). The primary focus of initial academic research in the supplier selection was on optimizing profit while minimizing risk. Huang and Keskar identified five methods that are used for the optimization: Linear Programming, Mixed Integer Programming, Goal Programming, Multi-objective Programming, and Non-linear Programming.

1.2 Supply Chain Management and the Sustainable Supply Chain

Promoting sustainable practices in business operations requires making the entire supply chain more sustainable. Supply chain management (SCM), the process of managing internal business practices as well as those across organizational boundaries, has emphasized generating value for the company's shareholders with economic value-added (Lambert, 2008) being the main metric of performance. However, the transition towards more sustainability-oriented practices requires a shift towards sustainable SCM (SSCM) practices and use of sustainability value-added to evaluate performance. As such SSCM has become a topic of significant discussion with increasing research. Most of the definitions however, do not capture all aspects needed to promote sustainability in the supply chain. One of the more comprehensive definitions describes SSCM as "the planning and management of sourcing, procurement, conversion, and logistics involved during the pre-manufacturing, manufacturing, use, and post-use stages in the life cycle in closed-loop through multiple life-cycles with seamless information sharing about all product life-cycle stages between companies by explicitly considering the social and environmental implications to achieve a shared vision" (Metta & Badurdeen, 2009).

This comprehensive definition considers the total life-cycle of the product, including the post-use stage, often disregarded in conventional SCM and most important from a sustainability perspective. Incorporating the total life-cycle enables considering closed-loop flow of materials, also important from a sustainability perspective. One approach to integrate the flow across the life-cycle stages is by applying the 6R's which refer to Reduce, Reuse, Recycle, Redesign, Remanufacture, and Recover (Jawahir, 2006). By encompassing the 6R's, companies can better plan for and manage the resources across life-cycle stages – so that virgin natural resources requirements can be minimized. A holistic approach to viewing the supply chain through this framework is presented in Figure 1.2.

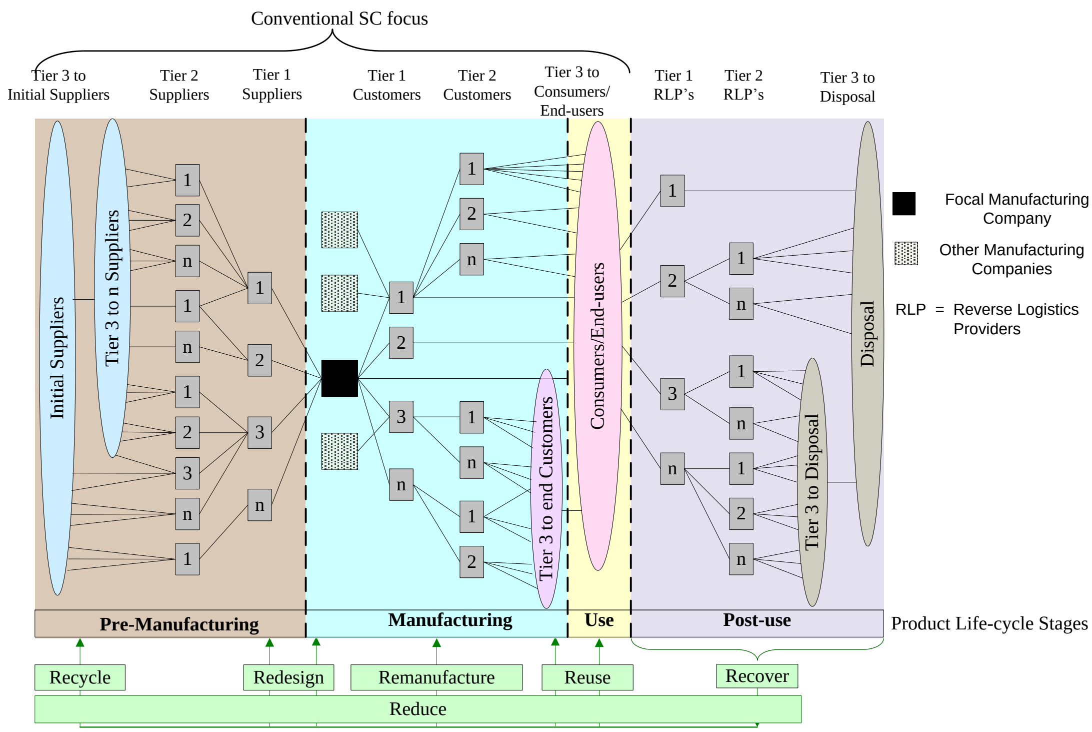

Figure 1.2 Integrated Approach to SSCM (Badurdeen et al., 2010)

1.3 Impetus for Sustainable Supplier Selection

Increasingly more consumers and therefore retailers are seeking out products that are sustainability compliant. As a result, supplier selection and evaluation practices have evolved beyond this financial and transactional relationship into reviewing the environmental (Humphreys et al., 2003) and societal (Badurdeen et al., 2010) ramifications of having a relationship. This trend can be clearly illustrated by Wal-Mart’s use of Supplier Sustainability Assessments (SSA, Wal-Mart corporate website). Included in the SSA are fifteen questions divided into four categories, Energy and Climate (ascertaining a supplier's greenhouse gas emissions and whether or not there is any effort underway to reduced said emissions), Material Efficiency (packaging and water waste), Nature and Resources (whether a supplier to Wal-Mart has looked into its supply chain for regulatory compliance with environmental certifications for production and products) and People and Community (reviews company's awareness to the societal impact of a company's supply chain). Though not strictly quantitative in nature, the SSA signals the retail giant's focus on sustainability and the demands that are likely to be placed on suppliers.

An example of how companies are being held accountable for the actions of their suppliers is the incident in which McDonald’s was selling glassware in conjunction with the release of the movie “Shrek Forever After”. Unknown to McDonald’s, the supplier of the glassware used cadmium – a toxic metal and likely carcinogen – in the paint used to decorate the glasses. This was brought to the attention of U.S. Consumer Product Safety Commission (CPSC) and in addition to the negative publicity, McDonald’s recalled 12 million glasses that were being sold (Mead, 2010).

In addition to McDonald's, Apple Incorporated has also received criticism due to the employee treatment practices of one of the largest suppliers, Foxconn. Although Apple indicates a preference that employee's at their suppliers do not work more than 60 hours per week, a report published by the South China Morning Post in October 2010 showed that employees at Foxconn are "forced to work double or triple the legal limit on overtime". Further evidence of issues with employees is that there were 14 suicide attempts by employees during the first six months in 2010. The publicity caused by these incidents contributed to protestors attending the launch of the new I-pad, the new I-phone, and the annual shareholder's meeting with signs asking Apple to make "ethical" devices. These issues caused Apple to take action and require Foxconn to undergo an independent audit by the Fair Labor Association that was documented by ABC Television's Nightline on February 21, 2012. As a result of the Fair Labor Association audit and the public outcry, on March 29, 2012 after a visit from Apple CEO, Tim Cook, Foxconn announced it will hire tens of thousands of workers, clamp down on illegal overtime, improve safety protocols and upgrade worker housing and other amenities, (ABC News Web-site, accessed May 10, 2012).

1.4 Reasoning for Sustainable Supplier Selection

Given the view of SSCM depicted in Figure 1.3, it is imperative that companies adopt a more holistic view in selecting suppliers and managing relationships with them. Instead of the conventional practice of focusing merely on the supplier's financial capability as the basis to assess their ability to provide the materials, components or other services, it is necessary to focus on how the partnership can help or hinder promoting the other goals of sustainable business practices: environmental protection and societal well-being. This means, for example, it is necessary to consider supplier's practices such as the use of more energy efficient manufacturing processes, water usage, and recycling of waste. In terms of societal well-being this means evaluating practices such employee health and welfare, contributions to local community, and promoting diversity. This research, therefore, was built upon this existing view of SSCM and evaluating suppliers from that perspective.

1.5 Problem Statement

Despite the increased emphasis on sustainability considerations (Lamming et al., 1996) most supplier evaluation methods—those practiced by companies as well as reported in literature—still have a heavy economic emphasis (Sonmez, 2006). However, if business practices are to be more sustainable, it is necessary that companies begin evaluating supply chain partner compliance and improvement across the triple bottom line (TBL) of economic, environmental protection and societal well-being (Badurdeen et al., 2010). There have been developments in considering the environmental aspect (Humphreys et al., 2003) and societal aspects (Ehrgott et al., 2011) of the TBL when addressing supplier selection; however these methods only address the single aspect under review. The research and literature is lacking in considering all three aspects of the TBL simultaneously in a holistic approach.

The objective purpose of this research is to develop a methodology for supplier sustainability evaluation and combining the three TBL elements for a comprehensive assessment. The specific goals are: (1) to develop a quantitative supplier sustainability assessment tool that incorporates the TBL aspects, (2) to ensure the ease of use by companies, and (3) to identify and incorporate fairly readily available metrics for supplier sustainability assessment.

The remaining sections of this thesis provides a review of literature and corporate practices on supplier selection, (economic, environmental and societal) supplier selection metrics, and the mathematical modeling process that is developed to evaluate suppliers for their sustainability performance.

CHAPTER TWO

Literature Review

In order to assess current practices of supplier evaluation, a selection of both academic literature and industry practices was reviewed for general content, depth of the content, and the general approach being taken to supplier assessment. A large body of literature centered on evaluating suppliers on a financial basis. More recent work relates to assessing environmental aspects of interactions with a supplier. In a few cases there are environmental and societal items considered together, but the literature is lacking with respect a comprehensive approach to all three of the TBL criteria at the supplier level. There has been work addressing the TBL at the enterprise supply chain level (Badurdeen et al., 2010), but the literature is still lacking at addressing the relationship with individual suppliers.

2.1 Supplier Selection Literature Review

In his work "A Review and Critique of Supplier Selection Process and Practices", Sonmez (2006) reviewed 147 academic journal articles. In this work the articles were classified into five categories: decision criteria that should be used, use of decision making / support techniques and tools, buyer / seller relationships, international supplier section practices, and e-procurement. It was noted that the evaluation of suppliers is a multiple criteria decision making (MCDM) problem that can have the complexity of having both qualitative and quantitative criteria (see figure below).

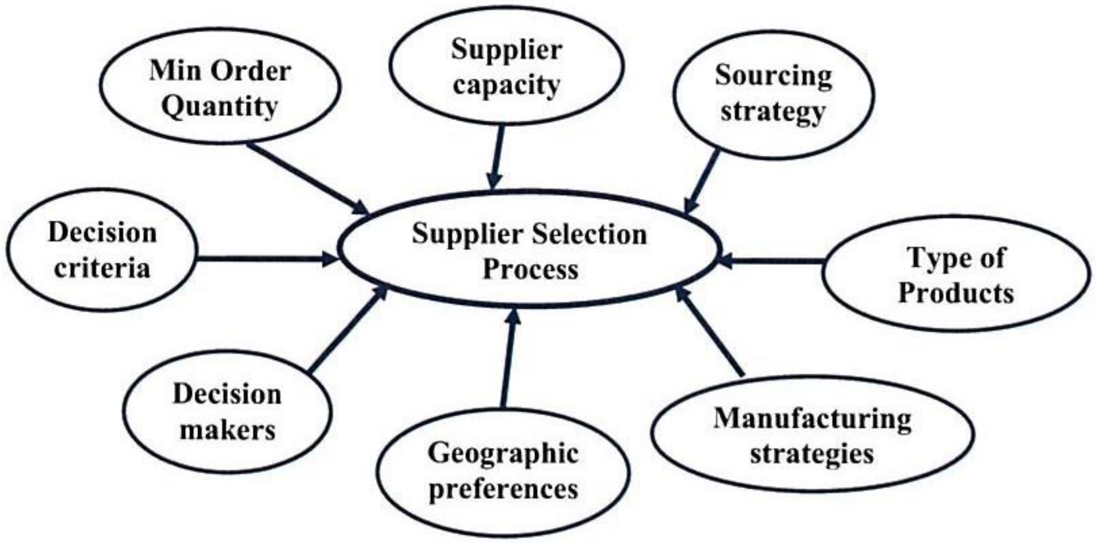

Figure 2.1.1 MCDM for Supplier Selection (Sonmez, 2006)

In this work, it is noted that the general trend on supplier selection is a five-phase process (see figure below): “realization of the need for a new supplier; determination and formulation of design criteria; prequalification (initial screening and drawing up a shortlist of potential suppliers from a large list); final supplier selection; to the monitoring if the suppliers selected”.

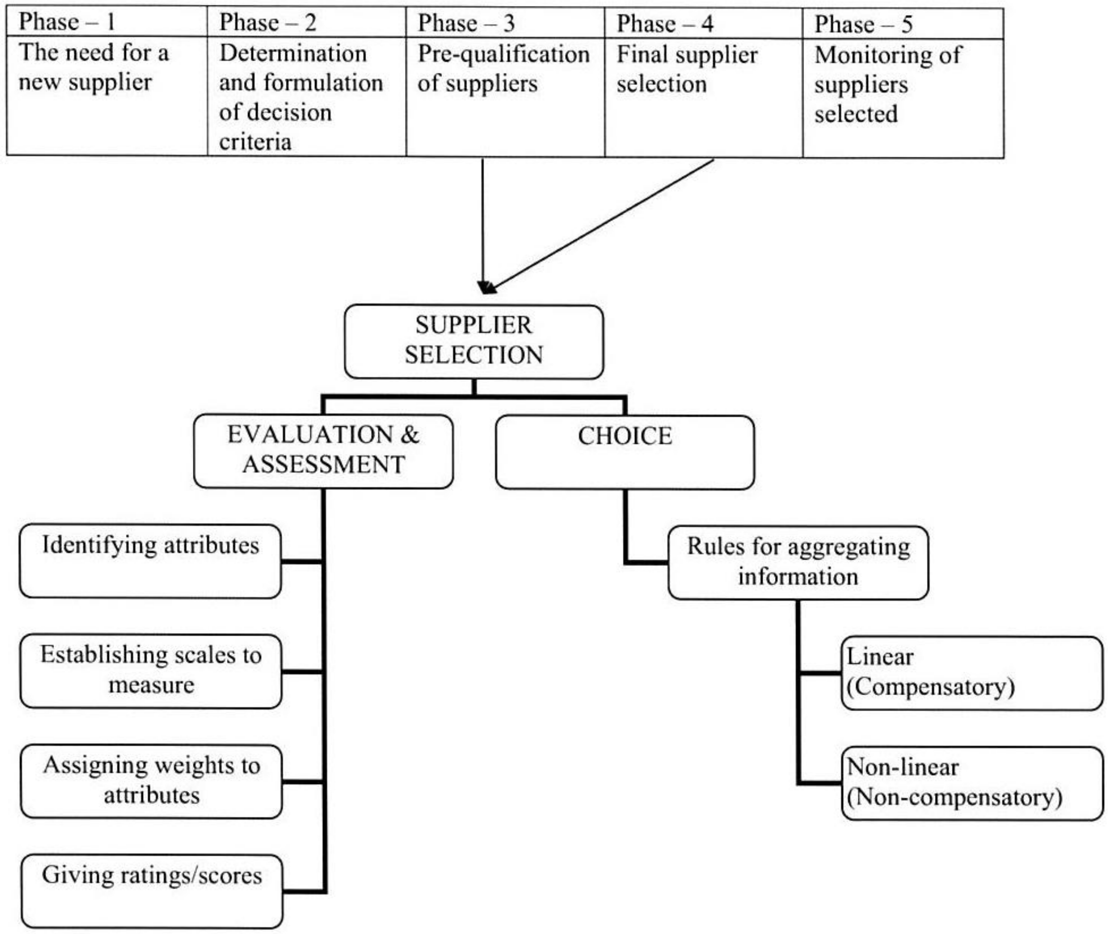

Figure 2.1.2 Five Phases of Supplier Selection (Sonmez, 2006)

Sonmez also categorizes the types of models used in supplier selection literature that was reviewed and provides a list of the corresponding methods used for each type of category (see figure below)

Category	Method
Artificial Intelligence & Expert Systems	Neural networks Case-based reasoning Bayesian Belief Networks
Mathematical programming	Total cost based approaches Non-linear programming Mixed integer programming Linear programming Integer programming Heuristics Goal programming DEA
MCDM	AHP Outranking methods MAUT Linear weighted point Judgemental modelling Interpretive Structural Modelling Categorical method Fuzzy sets
Multivariate statistical analysis	Structural equation modelling Principal component analysis Factor Analysis Confidence interval approach
Other decision making tools	Group decision making Multiple Methods

Figure 2.1.3 Supplier Selection Methods (Sonmez, 2006)

Sonmez also noted that supplier selection, like all decision making problems, has two main tasks: the process of evaluation and assessment and summarizing this information to allow for the choice to be made.

As in most of the supplier selection literature, Choi and Kim (2008) model a financial decision model in attempting to provide a method for supplier selection. This work classifies the criteria into two major categories: qualitative and quantitative. Choi and Kim's work is significant to the research done in the work here, due to the emphasis placed on the final selection of a supplier being 'multi-objective' in nature. The multi-objectives that are being considered by Choi and Kim's work are all relative to what can be called economic criteria, but nonetheless it places significant emphasis on the MCDM discussed previously.

Zhang (2010) proposes a multi attribute utility (MAU) model approach to selecting suppliers, but in the work only provides a detailed mathematical method for performing this evaluation and has no criteria or metrics reviewed or listed.

2.3 Economic Metrics for Supplier Evaluation

Academic literature reviewing the financial impact of supply chain and supplier relationships tends to be detailed and quantitative in nature (Sonmez, 2006).

A variety of criteria have been used for supplier selection and the most common include cost, delivery, and product quality (Jain et al., 2007). Jain et al (2007) create six 'criteria' for supplier selection which are cost, quality, service, relationship, organization, and cycle time. Each of the criterion have sub-criteria, metrics. A sampling of the sub-criteria is outlined in Table 2.3.1. However, Jain proposes no ranking or weighting of the metrics, they are simply listed.

Table 2.3.1 Sub-Criteria for Supplier Selection (Jain et al., 2009)

Criterion	Sub Criteria
Cost	Logistics costs
	Price
Quality	Simplicity of operation
	Quality Performance (ISO 9000 Accreditation)
Service	Reaction to demand
	Ability to modify product
Relationship	Expectation of continuity
	Financial stability
Organisation	Performance history
	Production facilites and capacity
Cycle Time	Delivery lead time
	Development Speed

The economic health and fiscal security is crucial for any supplier relationship (Bryne, 1992) as a financially unhealthy supplier can cause significant disruptions in the supply chain and business in general. Bryne (1992) proposes generating four types of ratios to access the financial health of a given supplier. These ratios are liquidity ratios, leverage ratios, activity ratios, and profitability ratios. All of these ratios are defined as coming from readily available information.

The liquidity ratios measure a company's ability to meet the immediate financial needs of the business; and include factors such as salaries, interest on debt, and taxes. Leverage ratios indicate the extent to which a company's funds are provided by creditors. These leverage ratios give an approximation of the financial risk of a company. The activity ratios show the correlation between sales and assets of a given supplier. It is a way of quantifying the revenues generated from its resources. The profitability ratios are a way of accessing if a company generates enough profit to have long term viability. Table 2.3.2 lists the specific formulas that can be used for each of the ratios.

Table 2.3.2 Financial Ratios Summary (Bryne, 1992)

Ratio	Formula for Specific Ratios in Category
Liquidity Ratios	Current Ratio = current assets ÷ current liabilities
	Acid Ratio = (current assets - inventories) ÷ current liabilities
Leverage Ratios	Debt Ratio = total debt ÷ total assets
	Times interest ratio = gross income ÷ interest charges
Activity Ratios	Inventory turnover ratio = sales ÷ inventory
	Fixed asset turnover = sales ÷ fixed assets
Profitability Ratios	Profit margin on sales = net profit ÷ sales
	Return on total assets = net profit ÷ total assets

It is also significant to note that Bryne (1992) stresses the importance of comparing these ratios to industry specific "standards" and to perform a year to year comparison to establish a trend line.

Significant work has been done to document and control both the supply chain and individual supplier relationships (Lambert & Pohlen, 2001), but these works do not consider the TBL objectives and view the relationships as strictly financial in nature.

2.4 Environmental Metrics for Supplier Evaluation

There have been both academic and professional literature generated which address the issue of suppliers being required or asked by their customers to become "green". A significant piece of relevant academic literature incorporating some TBL aspects into the supplier selection process is that of Humphreys et al., (2003). Humphreys et al (2003) create a decision support system to evaluate suppliers based on a seven environmental categories separated into two groups, quantitative environmental criteria and qualitative environmental criteria.

The quantitative environmental criteria include two categories: environmental costs 'pollutants effects' and environmental costs 'improvement' with five metrics listed for each category. For environmental costs 'pollutants effects' the metrics are: solid waste, chemical waste, air emission, water waste disposal, and energy, while the five metrics for environmental costs 'improvement' are buying environmental friendly material, buying new environmentally friendly equipment, redesign of product, staff training, and recycling.

The qualitative environmental criteria are divided into five categories and these categories and metrics are detailed in Table 2.4.1.

Table 2.4.1 Qualitative Environmental Criteria (Humphreys et al,. 2003)

Management Competencies	*Green Image*	*Design for Environment*	*Environmental Management Systems*	*Environmental Competencies*
↓	↓	↓	↓	↓
Senior management support	Customer's purchasing retention	Recycle	Environmental policies	Clean technology available
Environmental partners	Green Market Share	Reuse	Environmental planning	Use of environmental friendly materials
Training	Stakeholder's relationship	Re-manufacture	Implementation and operation	Pollution reduction capability
Information exchange		Disassembly	ISO 14001 certification	Returns handling capability
		Disposal		

From an industry perspective 'most green supply chain initiatives are the result of customer requests or government regulation' (Katz, 2009) and tend to look for compliance after the decision to have a supplier- customer relationship has already been determined. This compliance is not insignificant and can be expensive, as it is estimated that $3 billion is spent annually by the electronics industry alone to conform to the European Union regulations (Katz, 2009). Companies such as Toyota (Toyota web-site) and Wal-Mart (Wal-Mart website) have developed and use some type of "Green Supplier Guidelines", but these guidelines look for compliance and tend not to be considered in conjunction with the other elements of the TBL.

The stated reason for the Toyota's Green Supplier Guidelines is "thorough compliance with all applicable laws, regulations, and social norms and consideration for the environment" (Toyota website, 2009). Toyota's "Green Supplier Guidelines" have eleven questions contained within six environmental categories. The six environmental categories are ISO 14001 certification, substances of concern (e.g., hazardous chemical use), Eco-VAS (e.g., environmental impact of Toyota's vehicles), environmental compliance, reduction of carbon dioxide emissions, and reduction of packaging and wrapping materials. These requirements are part of an assessment performed on each supplier and they are monitored on the performance relative to these expectations, however no indication is given that Toyota considers compliance with this document as a consideration in determining whether or not to initially choose to have a relationship with a given supplier or to use the information in choosing between two suppliers.

Wal-Mart's Sustainability Supplier Assessment consists of four categories with a total of fifteen questions. The four categories are Energy and Climate, Material Efficiency, Nature and Resources, and People and Community. The People and Community category is reviewed in the section 2.5 of this research. The stated goal for each of the categories is as follows: Energy and Climate – reduce energy costs and greenhouse gases, Material Efficiency – reduce waste and enhance quality, and Nature and Resources – to ensure acquiring high quality, responsibly sourced raw materials. In this document Wal-Mart acknowledges that the assessment is not comprehensive as it relates to sustainability, but they do state intentions of rewarding suppliers for addressing the metrics contained within the assessment. The explanation of the document and the questions attempt to direct every item towards some type of eventual cost advantage for both the supplier and Wal-Mart. In other words, Wal-Mart attempts to make the business case for sustainability.

2.5 Societal Metrics for Supplier Selection

When considering the societal aspects of the TBL, there are few academic resources as far as it relates to suitable metrics. A significant amount of literature on the societal sustainability aspects for suppliers comes from the Journal of Business Ethics. This literature however tends to look at what can be called brand protection, being concerned with the image portrayed (Amaeshi et al., 2008) or look at the pressures which cause a company to review its suppliers from a societal point of view (Ehrgott et al., 2011). According to the work of Ehrgott et al (2011), there are six reasons that companies choose to be responsible from a societal standpoint in selecting suppliers: intensity of customer social pressures, intensity of government social pressures, intensity of social middle management pressure, supplier strategic capabilities, buying firm reputation, and extent of organizational learning in supplier management.

There has been work which has attempted to quantify some of the societal aspects of business models (Darby et al., 2006), but the research is broad in nature and does not go into the metric level. Darby et al (2006) state that there are six "accounts" that need to be reviewed in evaluating what is called the "social accounting" of a given entity. They are a report on performance against stated objectives, an assessment of the impact on the community, the views of stakeholders on objectives and values, a report on environmental performance, a report on how equal opportunities are implemented, and a report on compliance with statutory quality and procedural standards.

The 2002 United Nations Johannesburg Summit – Global Challenge Global Opportunity provides a framework from which metrics can be derived (Summit, 2002). This framework accomplishes this by reporting on what The Summit believes to be the most critical issues facing the future of the planet: population growth, poverty and inequality, food and agriculture, freshwater, forests, energy, climate change, health as it relates to water, and health as it relates to air pollution.

The most comprehensive academic literature on societal metrics is contained in a working paper titled "ESAT: A Framework and Metrics for Corporate Sustainability Assessment" (Badurdeen et al., 2013). Unlike the previous works discussed in this section, Badurdeen et al's work present very detailed metrics and provides computational methods for calculating a value for each metric while indicating the desired trend for each metric to improve societal sustainability. The metrics are structured under nine performance criteria which are anti-corruption/anti-bribery, supplier development and training practices, employee development and training, customer satisfaction, customer awareness, compliance and product responsibility, employee well-being, community development, and diversity and equal opportunity. The paper does not define an acceptable level for metric score. This is typical when reviewing environmental and societal metrics, as they tend to be specific to a particular industry or facility.

From industry standpoint, societal metrics are included in Wal-Mart's Supplier Sustainability Assessment. There are many other companies who address the societal aspects of the TBL, but Wal-Mart's is significant in that unlike most companies, the metrics are scored and provide a scale by which the companies can be measured. The four questions or metrics included in the Wal-Mart Supplier Sustainability Assessment are do you know the location of 100% of the facilities that produce your products, do you have a process for managing social compliance at the manufacturing level, do you work with your supply base to resolve issues found during social compliance evaluations and also document specific corrections and improvements, and do you invest in community development activities in the markets you source and/or operate within?

Industry literature (e.g., company websites and CSR reports) were reviewed in the process of identifying environmental and societal issues being utilized by industry. This information tended to be very qualitative or binary in nature. More specifically, the tendency is to look at compliance with standards or membership in industry associations. An example of one of the common standards adhered to by the consumer electronics industry is the Electronics Industry Citizenship Coalition (EICC). The company websites that were included in this review are Toyota Motor Corporation, Apple Inc., and Hewlett-Packard. In addition, the societal and environmental considerations appear to be part of reviewing the supplier after a decision has been made to have a relationship. However, some companies are detailed and specific with regards to their suppliers' environmental and societal practices. Among the corporate practices reviewed, those of Hewlett-Packard and Apple were most comprehensive in terms of their coverage of the TBL aspects. Those of Apple were more specific and quantitative, as Apple goes into great detail in these regards and has specific measurable metrics when it comes to the environmental and societal aspects of the TBL. A summary of metrics of these two companies was generated for this work and is shown in Table 2.5.

Table 2.5 Industry Metric Examples

Company	Category	Metric
Hewlett Packard	SC and Environmental Responsibility	comply w/ Electronics Industry Citizenship Coalition (EICC)
	Supplier	made themselves responsible for supplier performance
		measure tier 1 Greenhouse Gas Emissions (GHG)
		2009 rolling out tier 2 GHG
		2010 remaining suppliers
	Supplier Labor Standards	freely chosen employment
		child labor avoidance
		working hours
		wages and benefits
		humane treatment
		non-discrimination
		freedom of association
	Supplier Health and Safety Standards	occupational safety
		emergency preparedness
		occupational injury and illness
		industrial hygiene
		physically demanding work
		machine safeguarding
		dormitory and canteen
	Supplier Environmental Standards	environmental permits and reporting
		pollution prevention and resource reduction
		hazardous substances
		wastewater and solid waste
		air emissions
		product content restrictions
	Human Rights	comply with UN's Universal Declaration of Human Rights
		HP's Global Citizenship Policy
		HP's Policy on Human Rights and Labor

Company	Category	Metric
Apple	Labor & Human Rights	Antidiscrimination
		Prevent Involuntary labor - no forced labor, must be allowed to leave with reasonable
		Fair Treatment - harassment free workplace
		minimum age is 15, minimum age for country or age for completing compulsory education (whichever is highest)
		except in emergency no one is to work more than 60 hours per week
		must pay minimum wage
		Allow for freedom of association
	Health and Safety	occupational Injury prevention
		Prevention of chemical exposure
		Emergency prevention, preparedness and
		Occupation Safety Procedures and Systems
		Ergonomics
		Dormitory and Dining
		Communication
		Worker Health and Safety committees
	Environment	Hazardous Substance Management and
		Water and Solid Waste Emissions
		Air Emissions
		Permits and Reporting
		Pollution Prevention and Resource Reduction
	Ethics	Corruption, extortion, or embezzlement
		Disclosure of info
		No improper advantage
		Fair Business, advertising, and competition
		Whistleblower protection and Anonymous Complaints
		Community Engagement
		Protect IP
	Management System	Require the presence of a system by which complaints can be logged and a way by which the programs can grow and develop

2.6 Mathematical Modeling Literature Review

Several items were considered and reviewed when evaluating the choice of a mathematical model for this research. The items considered were ability to weight metrics and the TBL elements relative to each other, simplicity of use, and the degree of compatibility with a user-friendly Microsoft Excel tool.

Initially, various mathematical methods of supplier selection were reviewed and considered (de Boer et al., 2001; Tahriri et al., 2007), including grey-based decision making (Li et al., 2007), multivariate analysis (Lasch & Janker, 2005), hybrid decision models (Sevkli et al., 2007; Choi & Kim, 2008), and fuzzy decision making (Chen et al., 2005). These modeling techniques were eliminated using the three decision criteria presented in the previous paragraph. However the primary reason for not utilizing the mathematical methods discussed here is that they required the user of the tool being created to have to high of a level mathematical modeling. In addition, these tools did not provide a clear, easy to understand method for weighting the different metrics.

The initial model selected was a modified Quality Function Deployment (QFD). QFD, first described by Akao (1990), is a means of ensuring quality throughout each stage of the production process. Although several articles were reviewed: "Extended QFD and Data-Mining-Based Methods for Supplier Selection in Mass Customization (Ni et al., 2007), "Modern QFD-Based Requirements Analysis for Enterprise Modelling: Enterprise –QFD" (Ozdagoglu & Salum, 2009), and "Application of Fuzzy QFD for Enabling Leanness in a Manufacturing Organisation" (Vinodh & Chintha, 2009), the primary source for reviewing the QFD process and methodology was the textbook, The Management and Control of Quality by Evans & Lindsay (,2005).

Keeping with the three main objectives for selecting a modeling technique further research was conducted into possible modeling processes. An article by Jie Weiss, David Weiss, and Ward Edwards titled ‘A descriptive multi-attribute utility model for everyday decisions’ (Weiss et al., 2010) pointed the research towards using a MAU model to achieve the desired results as it relates to this research. Two additional articles ‘Multiple Attribute Group Decision Making’ (Zhang, 2010) and Multi-attribute utility models; a review of field and field-like studies (Huber, 1974) provided the complete framework for the mathematical modeling to be used in this research.

2.7 Significance of Research and Work Presented

This research describes a void in the field of Sustainable Supplier Selection and thus addresses a comprehensive approach or modeling tool that considers all three TBL elements simultaneously. This work is also unique in that it proposes using the Societal and Environmental TBL elements as part of the supplier selection process, instead of the common industry and academic practice of reviewing these two elements after the supplier selection has been made based of the Financial Element. This research provides a methodology for the metrics within a TBL element to be weighed against each other, allowing the user to determine which TBL elements are most important to the user.

This work also provides an easy to use tool that utilizes commonly available software, Microsoft Excel. The Microsoft Excel Tool allows for the metrics to be prioritized against each other per the objectives of the entity making the sourcing decision.

CHAPTER THREE

Methodology

The major steps followed in developing the proposed supplier selection model are shown in Figure 3 and described in detail in the following sections.

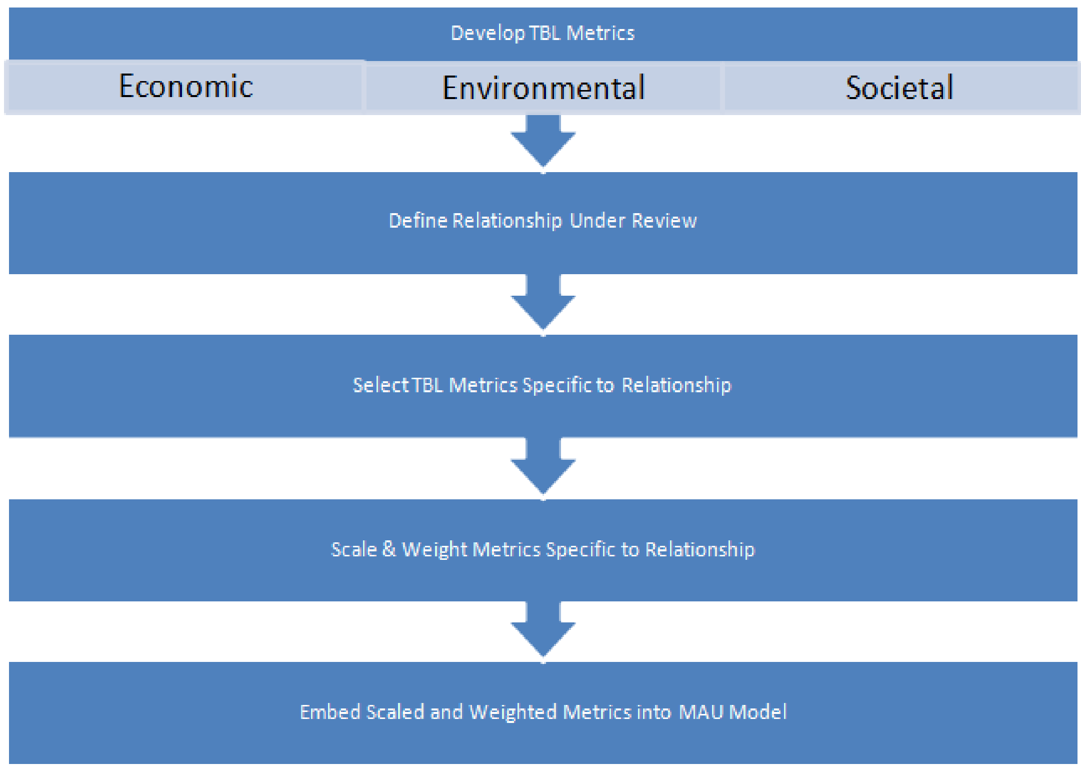

Figure 3 Steps in Supplier Selection Model

Significant thought was placed on selecting metrics to yield a representative result, because "metrics should always be tied to strategic goals" (Marshall, 2007). The Brundtland Report published by the United Nations describes the framework for metrics to be used in reviewing and evaluating sustainability in general. This report makes the case for sustainability by stating “economics and ecology bind us {the world} in ever-tightening networks.” These networks are loosely defined as our economic {trade and production}, our environmental {the resources needed to sustain life} and our society {poverty and equality}. These basic tenants can be extrapolated into metrics such as a company's profitability, a company's resource usage, and a company's treatment of and concern for its employees (Brundtland, 1987). The 2002 United Nations Johannesburg Summit yielded specific metrics. Specifically significant to this work was the emphasis this report placed on energy consumption and water usage (Summit, 2002).

Much of the academic literature concerned with metrics tends to be established at the product level. One such work considered six metrics: material consumption, energy consumption, emissions, liquid waste and solid waste (Jiang et al., 2012), but as is the case with most literature this work considered only the environmental aspect and to a lesser extent the economic elements or the TBL. Another significant work in this area proposes a methodology for establishing a product sustainability index for manufactured parts (Zhang et al., 2012). This does combine all of the TBL elements into an aggregate score for a given product, but the evaluation is performed at the product level and not the supplier level. This difference causes many of the metrics to be considered to be significantly different.

3.1 Importance of Defining Relationship Under Review

Defining the relationship to be evaluated is important because the particular metrics that must be chosen for TBL evaluation depends on the type of supply chain relationship to be evaluated. For example, if an original equipment manufacturer (OEM)–contract manufacturer relationship is being evaluated, the product/component designs are provided by the OEM with the materials and processes mostly defined. The metrics used to evaluate TBL performance for such a relationship must then take into account these factors. On the other hand, if a retailer was evaluating suppliers providing the merchandise sold by the retailer, then the factors to be considered and the metrics could be different. Therefore, it is important to define the nature of the relationship to be evaluated. Developing a tool to evaluate any generic supplier-manufacturer/retailer relationship will require including an extensive number of metrics some of which may be redundant in evaluating certain relationships.

3.2 General Parameters for Metric Selection

A variety of metrics are used by companies to assess supplier performance. In selecting a representative sample of metrics for supplier sustainable performance assessment, a number of factors must be considered: relevance in the context of supplier's business (industry and size of business); availability of data required or ease of computing from information provided; limited number of metrics for practicality of use. The metrics presented in the following sections were selected with these factors in mind.

It is important to understand the context of the supplier's business, because different industries have different challenges and goals. For example, due to regulations and other factors such as public opinion, automotive companies have a need to monitor carbon dioxide emissions. While an injection molding company would be more concerned with what percentage of its incoming raw plastic ends up being discarded to a landfill during the manufacturing process.

The ease of obtaining the data is significant as the ideal situation would be for the supplier evaluation process to generate as little disruption as possible to the parties involved with the evaluation and to not create additional effort.

Limiting the number of metrics serves several purposes. First, it causes the entity using the tool to carefully consider the metrics which are most important for their evaluation. Limiting the metrics also provides for a clearer differentiation in the weighting of the metrics. The limiting of the metrics has the added benefit of not overwhelming either entity in the evaluation.

3.2.1 Economic Metric Selection

The primary drivers in selecting the economic metrics were to gain insight into (1) the current financial strength of the company being reviewed and (2) on the potential for future growth and success. Metrics selected to evaluate economic performance in the context of the relationship of focus. The economic metrics used and the formulas to derive each of them are outlined in Figure 3.2.1 below.

Metric	Weight	Formula / Explanation	Scale	
Acid Test Ratio	0.2	(current assets - inventories) / current liabilities	100	Above 1.76
			75	1.51 - 1.75
			50	1.26 - 1.50
			25	1 - 1.25
			0	Less than 1
First Pass Yield Rate - Quality Metric	0.2	units the require no rework upon the completion of the fabrication process	100	98% - 100%
			75	96% - 97%
			50	95% - 96%
			25	94% - 95%
			0	93 % and lower
Inventory Turnover Ratio	0.2	sales / inventory	100	Above 2
			75	1.76 - 2.0
			50	1.51 - 1.75
			25	1.25 - 1.5
			0	Less than 1.25
Annual Sales Increase	0.2	pecentage increase in USD	100	Above 15%
			75	15% - 19%
			50	10% - 14%
			25	5%-9%
			0	Less than 5%
Return on Total Assets	0.2	net profit / total asets	100	Above 20%
			75	10% - 14%
			50	6% -9%
			25	0%-5%
			0	Negative

Figure 3.2.1 Economic Metrics

3.2.2 Environmental Metric Selection

The environmental metrics were selected to gain an insight into the current environmental impact of a given supplier, while attempting to ascertain if the company under review is attempting to improve their impact on the environment. The environmental metrics were also selected so that they would be quantifiable and not binary in nature, and the data required was either already available or relatively easy to obtain. The environmental metrics chosen and the formula to derive each of them is outlined in Figure 3.2.2.

Metric	Weight	Formula / Explanation	Scale	
Water usage per unit produced	0.2	Liter / unit produced	100	Less than 1
			75	1 -1.5
			50	1.51-2
			25	2.01-2.5
			0	greater than 2.5
Energy used per unit produced	0.2	Kilojoule / uniits produced	100	less than 2
			75	2.1-4
			50	4.1-6
			25	6.1-8
			0	8.1-9.9
Percentage of incoming material (cafeteria, manufacturing, etc…) sent to land fill	0.2	total weight of material sent to landfill / total material received	100	0%
			75	1%
			50	2%
			25	3%
			0	above 3%
Scrap Rate	0.2	Units Discarded / Units Produced	100	0% - 2%
			75	3% - 5%
			50	6% - 9%
			25	10% - 12%
			0	Above 13%
Emissions Rate	0.2	Metric Tons	100	Less then .79
			75	.80 -.89
			50	.90 -.99
			25	1.0 - 1.08
			0	Greater than 1.09

Figure 3.2.2 Environmental Metrics

3.2.3 Societal Metric Selection and Process for Selection

The societal metrics were defined to characterize how the company behaves with respect to the treatment of their employees and community in which they are located. It is also significant to note that societal evaluations tend to be challenging in nature, as companies tend to be either reluctant to provide sensitive information or fail to track the information being reviewed. The metrics chosen for this work are listed in Figure 3.2.3.

Metric	Weight	Formula / Explanation	Scale	
Percentage of employees participating in health and wellness programs	0.2	Employees Participating / Total number of Employees	100	95% - 100%
			75	90% - 94%
			50	85% - 89%
			25	80% - 84%
			0	79% or lower
Number of Equal Opportunity Employment violations in previous 12 months	0.2	Number of Equal Opportunity Employment violations in previous 12 months	100	0
			75	1
			50	2
			25	3
			0	4
Accident Rate	0.2	(# of non fatal injuries / total employee hours worked) * 200,000	100	0
			75	Less than 10
			50	Less than 50
			25	less than 100
			0	100 or higher
Training Hours Ratio	0.2	Employee hours spent in Training / Empolyee hours spent working	100	10% or higher
			75	8% - 9.9%
			50	6% - 7.9%
			25	4% - 5.9%
			0	3.9% or Lower
Percentage of executives (2 levels from CEO) that are female or minorities	0.2	number of female or minority Employees 2 levels from CEO / Total number of Employees 2 levels from CEO	100	40% or above
			75	35% - 39%
			50	30% - 34%
			25	25% - 29%
			0	Less than 25%

Figure 3.2.3 Societal Metrics

3.3 Weighting and Scaling of Metrics

Each metric is assigned a weight by the user of the tool. The weight for each set of metrics (Environmental, Economic, and Societal) must sum to one. The totaling of the weights to a total of one is a conventional needed for the MAU Model which is explained in section 3.5 of this paper. The weighting is significant as it allows the user to rank order the importance of each metric being reviewed relative to the other metrics in the same TBL element and due to the nature of the MAU Model effect the Overall Score of a company being reviewed. The weighting of the metrics also allows for the tool to have additional flexibility for use in different industries, as the relative importance of metrics may vary widely depending on the particular industry or supplier under review.

In addition to assigning a weight to the metrics, each metric must also be scaled or have a range established by which the entity or entities under review can be evaluated. Scaling of the metrics can be very difficult, as the entity being evaluated might be measured with different scales. An example of this would be that there would be different scales for carbon dioxide emissions if two power plants were being scored versus scoring two plastic part suppliers. The scales must be adjusted to show significant differentiation between the two entities being scored. In addition, for the purposes of the model being used, a multi attribute utility model, the utility score for each metric derived from the scaling needs to either be 0, 25, 50, 75, or 100.

3.4 Quality Function Deployment (QFD)

The initial model used was a QFD. The figure below provides a view of the model that was attempted using a QFD. Ultimately, the QFD method was abandoned. Although it could accomplish the desired output, the requirements placed on the user of the Microsoft Excel Tool was too cumbersome. It required the same data to be entered in several different places, which in addition to being cumbersome also introduced more opportunity for error during the data entry. In addition, output was unclear – requiring too much subjective interpretation by the end-user.

QFD was considered due to the models ability to weight various items against each other. QFD also lends itself to being utilized as a Microsoft Tool, although the tool turned out to be cumbersome for the reason outlined in the previous paragraph.

Strength of Relationship between Company Goals and Metrics	
4	Strong relationship
3	Moderate relationship
2	Weak Relationship
1	No relationship

	Metric	Formula / Explanation	Scale		Score (1-5)	Company Performance Goals: Cost	Quality	Innovation	Supplier Development	Customer Satisfaction	Energy Reduction	Residue Reduction	Resource Use Reduction	Employee development	Ethics Compliance	Community Development	
ECONOMIC	Revenue per Unit Produced	(current assets - inventories) / current liabilities	5	Above 1.76													Metric Score
			4	1.51 - 1.75													
			3	1.26 - 1.50													
			2	1 - 1.25													
			1	Less than 1													
	Cost per Unit Sold	units the require no rework upon the completion of the fabrication process	5	98% - 100%													Metric Score
			4	96% - 97%													
			3	95% - 96%													
			2	94% - 95%													
			1	93 % and lower													
	Return on Equity	sales / inventory	5	Above 2													Metric Score
			4	1.76 - 2.0													
			3	1.51 - 1.75													
			2	1.25 - 1.5													
			1	Less than 1.25													
	% change in net cash provided by Operating Activities	pecentage increase in USD	5	Above 15%													Metric Score
			4	15% - 19%													
			3	10% - 14%													
			2	5%-9%													
			1	Less than 5%													
	% of net revenue spent on R&D Expenses	net profit / total asets	5	Above 20%													Metric Score
			4	10% - 14%													
			3	6% -9%													
			2	0%-5%													
			1	Negative													
ENVIROMENTAL	Water usage per unit produced	KG/unit	5	Less than 1													Metric Score
			4	1 -1.5													
			3	1.51-2													
			2	2.01-2.5													
			1	greater than 2.5													
	Energy used per unit produced	MMBTU/unit	5														Metric Score
			4														
			3														
			2														
			1														
	Carbon Dioxide per unit produced	Metric Ton / unit	5	0%													Metric Score
			4	1%													
			3	2%													
			2	3%													
			1	above 3%													
	Nonsaleable waste per vehicle	kg / unit	5	0% - 2%													Metric Score
			4	3% - 5%													
			3	6% - 9%													
			2	10% - 12%													
			1	Above 13%													
	Remanufactured Parts Introduced per year	Number of Parts	5														Metric Score
			4														
			3														
			2														
			1														
SOCIETAL	Percentage of Female Employees		5	95% - 100%													Metric Score
			4	90% - 94%													
			3	85% - 89%													
			2	80% - 84%													
			1	79% or lower													
	Industrial Accident Frequency	Frequency Rate of Lost Workdays	5	0													Metric Score
			4	1													
			3	2													
			2	3													
			1	4													
	BMI of Employees	Body Mass Index of Employees	5	0													Metric Score
			4	<.5													
			3	<.75													
			2	,1													
			1	1 or greater													
	Smoking Rate	Percentage of employees that smoke	5	10% or higher													Metric Score
			4	8% - 9.9%													
			3	6% - 7.9%													
			2	4% - 5.9%													
			1	3.9% or Lower													
	Percentage of employees with Disablilites		5	40% or above													Metric Score
			4	35% - 39%													
			3	30% - 34%													
			2	25% - 29%													
			1	Less than 25%													

Figure 3.4.1 QFD Model for Sustainable Supplier Selection

3.5 Multi Attribute Utility (MAU) Model

Several mathematical methods and models were reviewed as noted in section 2.7 of this paper. After the attempt to use QFD detailed in section 3.5 of this work, the method chosen was a MAU Model. The MAU Model was selected due to three major factors: (1) the MAU allows for weighting and scaling of metrics, (2) it provides a score for each TBL element, and (3) it allows for a MAU to be embedded in a MAU, so that not only can the individual metrics being weighted against each other within a given TBL element, the TBL elements can be weighed against each other when the Supplier Sustainability Rating is calculated.

The MAU is constructed so that once the scaling and scoring of the individual metrics is complete, as explained in section 3.4, the metrics are then placed into a multi attribute utility model for a given TBL element. Each metric has two values assigned the weight $\{W_1,\dots W_5\}$ and the utility score $\{US_1,\dots US_5\}$. Each metrics' weight and utility score are multiplied together and then added to the other metrics' weight and utility score multiplication within a TBL element to generate the Category Utility Score. The weight of each element reflects its relative importance and is dependent on the priorities of the organization comparing the suppliers. The weight is distributed among the five metrics but must sum to one. For example, metric 1 and 2 can have weights of .2, metrics 3 and 4 can have weights of .1, requiring metric 5 to have a weight of .4.

For each TBL element a "Category Utility Score" is by combining the two values for each metric within the TBL element with the equation $\sum_1^5 (W_x*U_x)$. This calculation and generic format is illustrated in Figure 3.5.1below.

Metric	Weight	Formula / Explanation	Scale	Utility (0-100)	Category Utility Score	Overall Weight		Supplier Sustainability Rating
M1	W1	NA	100 NA 75 NA 50 NA 25 NA 0 NA	U1				
M2	W2	NA	100 NA 75 NA 50 NA 25 NA 0 NA	U2				
M3	W3	NA	100 NA 75 NA 50 NA 25 NA 0 NA	U3	CUS = $\sum^{5}_{1}(W_x*U_x)$	OW1		
M4	W4	NA	100 NA 75 NA 50 NA 25 NA 0 NA	U4				
M5	W5	NA	100 NA 75 NA 50 NA 25 NA 0 NA	U5				

Figure 3.5.1 Category Utility Score

The “Category Utility Score” for each TBL element then acts as the Utility Score for the multi attribute utility model that determines the overall utility score for the supplier being evaluated. The TBL element is then weighted with an overall element weight. In this work, it has been determined that the economic element is weighted at .6, the environmental element is weighted at .25 and the societal element is weighted at .15. These numbers are then combined as they were to determine the individual element score to determine the Supplier Sustainability Rating (SSR).

The generic MAU model created for this research is depicted in the Figure 3.5.2.

Category	Metric	weight	Formula / Explanation	Scale		Utility (0-100)	Category Utility Score	Overall Weight
ECONOMIC	Acid Test Ratio	0.2	(current assets - inventories) / current liabilities	100 75 50 25 0	Above 1.76 1.51 - 1.75 1.26 - 1.50 1 - 1.25 Less than 1	25		
	First Pass Yield Rate - Quality Metric	0.2	units the require no rework upon the completion of the fabrication process	100 75 50 25 0	98% - 100% 96% - 97% 95% - 96% 94% - 95% 93 % and lower	50		
	Inventory Turnover Ratio	0.2	sales / inventory	100 75 50 25 0	Above 2 1.76 - 2.0 1.51 - 1.75 1.25 - 1.5 Less than 1.25	25	*40*	0.6
	Annual Sales Increase	0.2	pecentage increase in USD	100 75 50 25 0	Above 15% 15% - 19% 10% - 14% 5%-9% Less than 5%	75		
	Return on Total Assets	0.2	net profit / total asets	100 75 50 25 0	Above 20% 10% - 14% 6% -9% 0%-5% Negative	25		
ENVIRONMENTAL	Water usage per unit produced	0.2	Liter / unit produced	100 75 50 25 0	Less than 1 1 -1.5 1.51-2 2.01-2.5 greater than 2.5	25		
	Energy used per unit produced	0.2	Kilojoule / uniits produced	100 75 50 25 0	less than 2 2.1-4 4.1-6 6.1-8 8.1-9.9	75		
	Percentage of incoming material (cafeteria, manufacturing, etc…) sent to land fill	0.2	total weight of material sent to landfill / total material received	100 75 50 25 0	0% 1% 2% 3% above 3%	75	*50*	0.25
	Scrap Rate	0.2	Units Discarded / Units Produced	100 75 50 25 0	0% - 2% 3% - 5% 6% - 9% 10% - 12% Above 13%	50		
	Emissions Rate	0.2	Metric Tons	100 75 50 25 0	Less then .79 .80 -.89 .90 -.99 1.0 - 1.08 Greater than 1.09	25		
SOCIETAL	Percentage of employees participating in health and wellness programs	0.2	Employees Participating / Total number of Employees	100 75 50 25 0	95% - 100% 90% - 94% 85% - 89% 80% - 84% 79% or lower	75		
	Number of Equal Opportunity Employment violations in previous 12 months	0.2	Number of Equal Opportunity Employment violations in previous 12 months	100 75 50 25 0	0 1 2 3 4	75		
	Accident Rate	0.2	(# of non fatal injuries / total employee hours worked) * 200,000	100 75 50 25 0	0 Less than 10 Less than 50 less than 100 100 or higher	75	*60*	0.15
	Training Hours Ratio	0.2	Employee hours spent in Training / Empolyee hours spent working	100 75 50 25 0	10% or higher 8% - 9.9% 6% - 7.9% 4% - 5.9% 3.9% or Lower	50		
	Percentage of executives (2 levels from CEO) that are female or minorities	0.2	number of female or minority Employees 2 levels from CEO / Total number of Employees 2 levels from CEO	100 75 50 25 0	40% or above 35% - 39% 30% - 34% 25% - 29% Less than 25%	25		

Supplier Sustainability Rating
SSR = $\sum^{3}_{1}$ (CUSx*OWX)
45.5

Figure 3.5.2 Multi Attribute Utility Model

CHAPTER FOUR

Case Study

The methodology detailed above was utilized to conduct a review of Toyota Motor Company by comparing Toyota's performance against itself on year to year basis for the fiscal years of 2010 and 2011 utilizing data obtained from Toyota's Annual Report, Environmental Report, and the Relations with Employees Website.

Comparing a company's performance against itself is not the intended use of the methodology and tool developed in the work. The case study was performed in this manner primarily due to the difficulty in obtaining the data required for two separate entities by an impartial observer. This difficulty can be overcome if a customer was trying to obtain this information from potential suppliers, as the suppliers under consideration would be motivated to provide the information requested by a potential customer.

Although it is not the intention of this work, comparing Toyota to itself on a year on year basis validates this work as it allows two entities, "2010 Toyota" versus "2011 Toyota" to be compared for the three TBL elements using the same metrics.

4.1 Determining Metrics Used for Case Study

The metrics justified in the methodology section were not available in the sources used to obtain data for this case study. Thus, following the main criteria discussed for selecting metrics detailed in Section 3.3 of this work a slightly different set of metrics were chosen for this study. However the metrics conform to the criteria outlined in the methodology. One of those criteria being the data should be readily available.

In addition to conforming to the criteria outlined above, choosing metrics from the various reports published by Toyota Annual Report (Toyota website), Environmental Report, and the Relations with Employees Website, provided insight into what is important to Toyota as an organization.

It is important to note that there are metrics that are specifically derived from Toyota's North American Operations, while other metrics use data from Toyota as an entire corporation. The financial metrics are based on the entire corporation as the entire corporation's financial health is an important factor in determining whether or not to have or continue with Toyota as a supplier. The environmental and societal aspects of the TBL are more regionalized as they are, by their nature, governed by local legal and cultural norms.

Based on the criteria outlined in section 3.3 of this work, the metrics selected for comparing Toyota's 2010 performance against Toyota's 2011 performance are illustrated in the Figures 4.1.1, 4.1.2, & 4.1.3.

Metric	Weight	Formula / Explanation	Scale	
Net Revenue per Vechile	0.3	(Revenue gererated from Automotive Business segment) / Number of Vechiles Sold	100	2.6 or higher
			75	2.5 - 2.59
			50	2.4 - 2.49
			25	2.3 - 2.39
			0	2.29 or lower
Return of Equity	0.2	Net Income / Shareholder's Equity	100	4% or higher
			75	3% - 3.9%
			50	2% -2.9%
			25	.1% - 1.9%
			0	Negative
Cost of Products Sold per vehicle	0.1	Cost of products / number of vehicles produced	100	2.19 or lower
			75	2.2 - 2.29
			50	2.3 - 2.39
			25	2.4 - 2.49
			0	Greater then 2.5
Net Cash provided by Operating Activities	0.3	Revenue - cost of operating activities	100	3,000,000 or above
			75	2,500,000 - 2,999,999
			50	2,000,000 - 2,499,999
			25	1,500,000 - 1,999,999
			0	Less than 1,499,999
Annual Sales Increase	0.1	pecentage increase in USD	100	Above 15%
			75	15% - 19%
			50	10% - 14%
			25	5%-9%
			0	Less than 5%

Figure 4.1.1 Economic Metrics for Toyota Evaluation

Metric	Weight	Formula / Explanation	Scale	
Energy Consumed per Vehicle Produced in North America	0.2	MMBTU/Vehicle	100	7.30 or lower
			75	7.31 - 7.40
			50	7.41 - 7.50
			25	7.51 - 7.60
			0	7.6 or higher
Carbon Dioxide Produced per vehicle produced in US	0.4	Metric Ton/ Vehicle	100	Less then .79
			75	.80 -.89
			50	.90 -.99
			25	1.0 - 1.08
			0	Greater than 1.09
Non saleable Waste per vehicle produced in North America	0.1	kg /vehicle	100	Less than 17
			75	17.1 - 18.0
			50	18.1 - 19
			25	19.1 - 20
			0	20.1 or greater
Number of Remanufactured Parts Released per Year	0.1	Number of Remamufactured Parts Released per Year	100	101 of Greater
			75	75-100
			50	51-75
			25	26-50
			0	0-25
Water Used per Vechile Produced in North America	0.2	kgal / vehicle	100	.69 or lower
			75	.70 - .79
			50	.80 - .89
			25	.90 - .99
			0	1.0 or highr

Figure 4.1.2 Environmental Metrics for Toyota Evaluation

Metric	Weight	Formula / Explanation	Scale	
Number of Employees Taking Child Care Leaves	0.1	Number of Employees Taking Child Care Leaves	100	600 or higher
			75	550 -599
			50	500 - 549
			25	450 - 499
			0	Less than 449
Number of Employees Utilizing Flex Time	0.1	Number of Employees Utilizing Flex Time	100	400 or higher
			75	350 - 399
			50	300 - 349
			25	250 - 299
			0	249 or Lower
Industrial Accident Frequency (frequncy Rate of lost workday cases)	0.4	Incidents / million hours worked	100	0
			75	.1 - .5
			50	.51 - 1.0
			25	1.1 - 1.5
			0	1.51 or higher
Employee Body Mass Index (BMI)	0.2	measure of body fat based on height and weight	100	18.5 -24.9
			75	16 - 18.49
			50	25 -29.99
			25	18.49 or lower
			0	30 or greater
Percentage of Employees who Smoke	0.2		100	25 % or lower
			75	25.1% - 30%
			50	30.1% - 35%
			25	35.1% - 40%
			0	Greater than 40%

Figure 4.1.3 Societal Metrics for Toyota Evaluation

4.2 Multi Attribute Utility Modeling for Toyota Case Study

The MAU model utilizes the framework outlined in the methodology section of this work, but uses the metrics described above to perform the sustainability evaluation of Toyota as a supplier.

4.2.1 Toyota MAU for 2010

The MAU for the evaluation of the 2010 performance of Toyota is in figure 4.2.1.

Category	Metric	weight	Formula / Explanation	Scale	Utility (0-100)	Category Utility Score	Overall Weight	Supplier Sustainability Rating
ECONOMIC	Net Revenue per Vechile	0.3	(Revenue gererated from Automotive Business segment) / Number of Vechiles Sold	100: 2.6 or higher 75: 2.5 - 2.59 50: 2.4 - 2.49 25: 2.3 - 2.39 0: 2.29 or lower	75			
	Return of Equity	0.2	Net Income / Shareholder's Equity	100: 4% or higher 75: 3% - 3.9% 50: 2% -2.9% 25: .1% - 1.9% 0: Negative	50			
	Cost of Products Sold per vehicle	0.1	Cost of products / number of vehicles produced	100: 2.19 or lower 75: 2.2 - 2.29 50: 2.3 - 2.39 25: 2.4 - 2.49 0: Greater then 2.5	50	62.5	0.6	
	Net Cash provided by Operating Activities	0.3	Revenue - cost of operating activities	100: 3,000,000 or above 75: 2,500,000 - 2,999,999 50: 2,000,000 - 2,499,999 25: 1,500,000 - 1,999,999 0: Less than 1,499,999	75			
	Annual Sales Increase	0.1	pecentage increase in USD	100: Above 15% 75: 15% - 19% 50: 10% - 14% 25: 5%-9% 0: Less than 5%	25			
ENVIROMENTAL	Energy Consumed per Vehicle Produced in North America	0.2	MMBTU/Vehicle	100: 7.30 or lower 75: 7.31 - 7.40 50: 7.41 - 7.50 25: 7.51 - 7.60 0: 7.6 or higher	25			
	Carbon Dioxide Produced per vehicle produced in US	0.4	Metric Ton/ Vehicle	100: Less then .79 75: .80 -.89 50: .90 -.99 25: 1.0 - 1.08 0: Greater than 1.09	25			
	Non saleable Waste per vehicle produced in North America	0.1	kg /vehicle	100: Less than 17 75: 17.1 - 18.0 50: 18.1 - 19 25: 19.1 - 20 0: 20.1 or greater	75	35	0.25	56.375
	Number of Remanufactured Parts Released per Year	0.1	Number of Remanufactured Parts Released per Year	100: 101 of Greater 75: 75-100 50: 51-75 25: 26-50 0: 0-25	25			
	Water Used per Vechile Produced in North America	0.2	kgal / vehicle	100: .69 or lower 75: .70 - .79 50: .80 - .89 25: .90 - .99 0: 1.0 or higher	50			
SOCIETAL	Number of Employees Taking Child Care Leaves	0.1	Number of Employees Taking Child Care Leaves	100: 600 or higher 75: 550 -599 50: 500 - 549 25: 450 - 499 0: Less than 449	50			
	Number of Employees Utilizing Flex Time	0.1	Number of Employees Utilizing Flex Time	100: 400 or higher 75: 350 - 399 50: 300 - 349 25: 250 - 299 0: 249 or Lower	75			
	Industrial Accident Frequency (frequncy Rate of lost workday cases)	0.4	Incidents / million hours worked	100: 0 75: .1 - .5 50: .51 - 1.0 25: 1.1 - 1.5 0: 1.51 or higher	75	67.5	0.15	
	Employee Body Mass Index (BMI)	0.2	measure of body fat based on height and weight	100: 18.5 -24.9 75: 16 - 18.49 50: 25 -29.99 25: 18.49 or lower 0: 30 or greater	100			
	Percentage of Employees who Smoke	0.2		100: 25 % or lower 75: 25.1% - 30% 50: 30.1% - 35% 25: 35.1% - 40% 0: Greater than 40%	25			

Figure 4.2.1 Toyota’s 2010 Multi Attribute Utility Model

4.2.2 Toyota MAU for 2011

The MAU model for the evaluation of 2011 performance of Toyota is in figure 4.2.2.

Category	Metric	weight	Formula / Explanation	Scale	Utility (0-100)	Category Utility Score	Overall Weight	Supplier Sustainability Rating
ECONOMIC	Net Revenue per Vehicle	0.3	(Revenue generated from Automotive Business segment) / Number of Vehicles Sold	100: 2.6 or higher 75: 2.5 - 2.59 50: 2.4 - 2.49 25: 2.3 - 2.39 0: 2.29 or lower	50	55	0.6	54
	Return of Equity	0.2	Net Income / Shareholder's Equity	100: 4% or higher 75: 3% - 3.9% 50: 2% -2.9% 25: .1% - 1.9% 0: Negative	75			
	Cost of Products Sold per vehicle	0.1	Cost of products / number of vehicles produced	100: 2.19 or lower 75: 2.2 - 2.29 50: 2.3 - 2.39 25: 2.4 - 2.49 0: Greater then 2.5	75			
	Net Cash provided by Operating Activities	0.3	Revenue - cost of operating activities	100: 3,000,000 or above 75: 2,500,000 - 2,999,999 50: 2,000,000 - 2,499,999 25: 1,500,000 - 1,999,999 0: Less than 1,499,999	50			
	Annual Sales Increase	0.1	percentage increase in USD	100: Above 15% 75: 15% - 19% 50: 10% - 14% 25: 5%-9% 0: Less than 5%	25			
ENVIRONMENTAL	Energy Consumed per Vehicle Produced in North America	0.2	MMBTU/Vehicle	100: 7.30 or lower 75: 7.31 - 7.40 50: 7.41 - 7.50 25: 7.51 - 7.60 0: 7.6 or higher	75	45	0.25	
	Carbon Dioxide Produced per vehicle produced in US	0.4	Metric Ton/ Vehicle	100: Less then .79 75: .80 -.89 50: .90 -.99 25: 1.0 - 1.08 0: Greater than 1.09	50			
	Non saleable Waste per vehicle produced in North America	0.1	kg /vehicle	100: Less than 17 75: 17.1 - 18.0 50: 18.1 - 19 25: 19.1 - 20 0: 20.1 or greater	50			
	Number of Remanufactured Parts Released per Year	0.1	Number of Remanufactured Parts Released per Year	100: 101 of Greater 75: 75-100 50: 51-75 25: 26-50 0: 0-25	0			
	Water Used per Vehicle Produced in North America	0.2	kgal / vehicle	100: .69 or lower 75: .70 - .79 50: .80 - .89 25: .90 - .99 0: 1.0 or higher	25			
SOCIETAL	Number of Employees Taking Child Care Leaves	0.1	Number of Employees Taking Child Care Leaves	100: 600 or higher 75: 550 -599 50: 500 - 549 25: 450 - 499 0: Less than 449	75	65	0.15	
	Number of Employees Utilizing Flex Time	0.1	Number of Employees Utilizing Flex Time	100: 400 or higher 75: 350 - 399 50: 300 - 349 25: 250 - 299 0: 249 or Lower	75			
	Industrial Accident Frequency (frequency Rate of lost workday cases)	0.4	Incidents / million hours worked	100: 0 75: .1 - .5 50: .51 - 1.0 25: 1.1 - 1.5 0: 1.51 or higher	75			
	Employee Body Mass Index (BMI)	0.2	measure of body fat based on height and weight	100: 18.5 -24.9 75: 16 - 18.49 50: 25 -29.99 25: 18.49 or lower 0: 30 or greater	50			
	Percentage of Employees who Smoke	0.2		100: 25 % or lower 75: 25.1% - 30% 50: 30.1% - 35% 25: 35.1% - 40% 0: Greater than 40%	50			

Figure 4.2.2 Toyota's 2011 Multi Attribute Utility Model

4.3 Review and Discussion of Toyota MAU Results

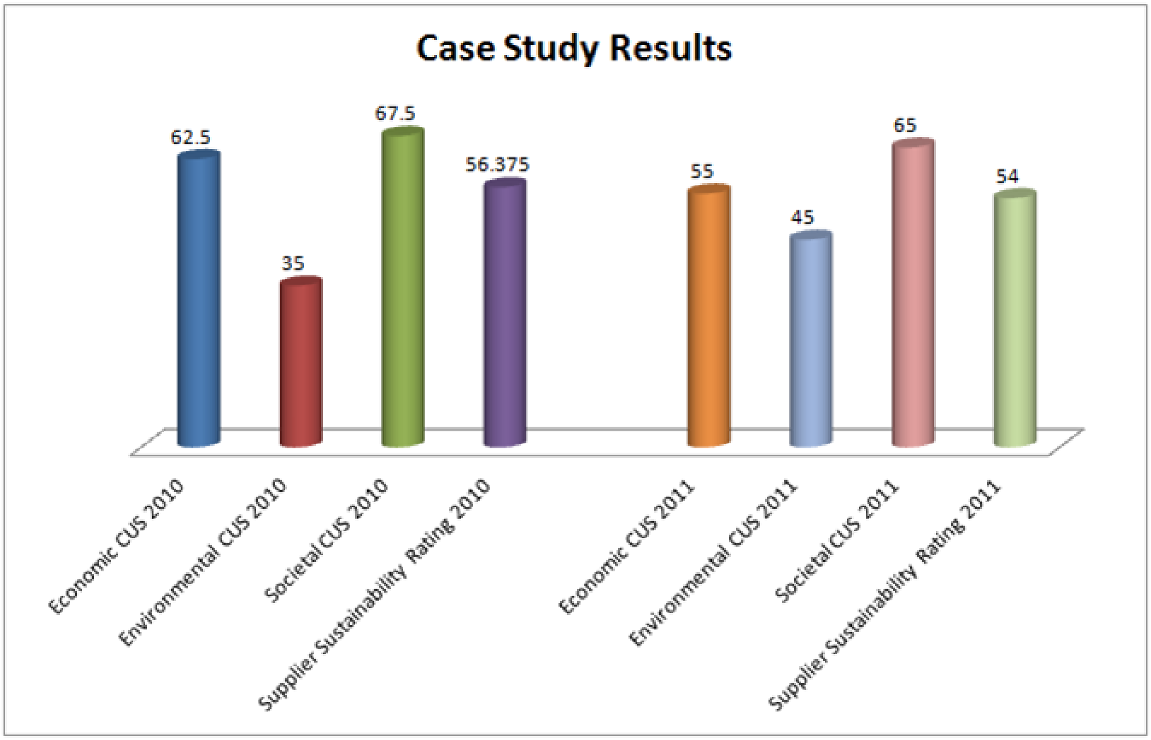

Figure 4.3.1 Summary of Toyota Case Studies

As can be observed from Figure 4.3.1 Toyota's Economic Category Utility Score was reduced from 62.5 in 2010 to 55 in 2011. As reported in Toyota's Annual Report, 2011 was indeed a challenging year for the company from a financial standpoint as production output was significantly affected by the "Great East Japan Earthquake". Therefore, it can be inferred that the financial portion of the model effectively represents reality. This finding is important as the financial performance is typically the easiest to evaluate, due to the nature of the metrics. Furthermore it adds validity to the evaluation of the environmental and societal TBL elements, as discussed below.

There was an improvement in the Environmental Category Utility Score for Toyota from 35 in 2010 to 45 in 2011, with the major contributor to the improvement being that less “carbon-dioxide was produced per vehicle produced”. Due to the weight of this metric, the overall environmental score improved despite two other environmental metrics reducing on a year to year comparison. This finding underscores the importance of the weighting assigned to a given metric.

Although the Societal Category Utility Score remained relatively flat – 67.5 in 2010 and 65 in 2011, several metrics scored differently. The total score remaining relatively unchanged was largely due to the most heavily weighted metric, Industrial Accident Frequency, remaining unchanged on a year to year basis.

As can be observed, even though the Environmental Category Utility Score was 10 points higher in 2011 and the Societal Category Utility Score changed by 2.5, the overall Utility Score was better in 2010. This finding is due to the Supplier Sustainability Rating of the Economic Category Utility Score being higher at .6, compared to the Environmental Category Utility Score being having a Supplier Sustainability Rating of .25 and the Societal Category Utility Score being having a Supplier Sustainability Rating of .15.

The methodology used was able to successfully evaluate the entities being reviewed, while the tool provided results that concur with Toyota’s own assessment of the two years in question. Per Toyota’s Annual report 2011 is recognized as a difficult year for the company.

A significant finding in performing the case study was the need to identify and highlight the Category Utility Score for each TBL element in addition to providing the Utility Score for the entity under evaluation. This finding is significant due to the fact that although the Category Utility Score can change significantly, the Utility Score may not change due to the weighting of each TBL element.

4.4 Toyota Results with Equal TBL Weighting

This section of the Case Study is a review of the data from the Case Studies that "idealizes" the weighting of the TBL Elements by assigning them equal weight.

Figure 4.4.1 shows the results when applying equal weight to the TBL to the Toyota 2010 results presented earlier in this section:

	Metric	weight	Formula / Explanation	Scale	Utility (0-100)	Category Utility Score	Overall Weight	Supplier Sustainability Rating
ECONOMIC	Net Revenue per Vehicle	0.3	(Revenue generated from Automotive Business segment) / Number of Vehicles Sold	100: 2.6 or higher 75: 2.5 - 2.59 50: 2.4 - 2.49 25: 2.3 - 2.39 0: 2.29 or lower	75			
	Return of Equity	0.2	Net Income / Shareholder's Equity	100: 4% or higher 75: 3% - 3.9% 50: 2% -2.9% 25: .1% - 1.9% 0: Negative	50			
	Cost of Products Sold per vehicle	0.1	Cost of products / number of vehicles produced	100: 2.19 or lower 75: 2.2 - 2.29 50: 2.3 - 2.39 25: 2.4 - 2.49 0: Greater then 2.5	50	62.5	0.33	
	Net Cash provided by Operating Activities	0.3	Revenue - cost of operating activities	100: 3,000,000 or above 75: 2,500,000 - 2,999,999 50: 2,000,000 - 2,499,999 25: 1,500,000 - 1,999,999 0: Less than 1,499,999	75			
	Annual Sales Increase	0.1	percentage increase in USD	100: Above 15% 75: 15% - 19% 50: 10% - 14% 25: 5%-9% 0: Less than 5%	25			
ENVIRONMENTAL	Energy Consumed per Vehicle Produced in North America	0.2	MMBTU/Vehicle	100: 7.30 or lower 75: 7.31 - 7.40 50: 7.41 - 7.50 25: 7.51 - 7.60 0: 7.6 or higher	25			
	Carbon Dioxide Produced per vehicle produced in US	0.4	Metric Ton/ Vehicle	100: Less then .79 75: .80 -.89 50: .90 -.99 25: 1.0 - 1.08 0: Greater than 1.09	25			
	Non saleable Waste per vehicle produced in North America	0.1	kg /vehicle	100: Less than 17 75: 17.1 - 18.0 50: 18.1 - 19 25: 19.1 - 20 0: 20.1 or greater	75	35	0.33	55
	Number of Remanufactured Parts Released per Year	0.1	Number of Remanufactured Parts Released per Year	100: 101 of Greater 75: 75-100 50: 51-75 25: 26-50 0: 0-25	25			
	Water Used per Vehicle Produced in North America	0.2	kgal / vehicle	100: .69 or lower 75: .70 - .79 50: .80 - .89 25: .90 - .99 0: 1.0 or higher	50			
SOCIETAL	Number of Employees Taking Child Care Leaves	0.1	Number of Employees Taking Child Care Leaves	100: 600 or higher 75: 550 -599 50: 500 - 549 25: 450 - 499 0: Less than 449	50			
	Number of Employees Utilizing Flex Time	0.1	Number of Employees Utilizing Flex Time	100: 400 or higher 75: 350 - 399 50: 300 - 349 25: 250 - 299 0: 249 or Lower	75			
	Industrial Accident Frequency (frequency Rate of lost workday cases)	0.4	Incidents / million hours worked	100: 0 75: .1 - .5 50: .51 - 1.0 25: 1.1 - 1.5 0: 1.51 or higher	75	67.5	0.33	
	Employee Body Mass Index (BMI)	0.2	measure of body fat based on height and weight	100: 18.5 -24.9 75: 16 - 18.49 50: 25 -29.99 25: 18.49 or lower 0: 30 or greater	100			
	Percentage of Employees who Smoke	0.2		100: 25 % or lower 75: 25.1% - 30% 50: 30.1% - 35% 25: 35.1% - 40% 0: Greater than 40%	25			

Figure 4.4.1 Idealized Model for Toyota's 2010 Results

Figure 4.4.2 shows the results when applying equal weight to the TBL to the Toyota 2010 results presented earlier in this section:

Category	Metric	weight	Formula / Explanation		Scale	Utility (0-100)	Category Utility Score	Overall Weight	Supplier Sustainability Rating
ECONOMIC	Net Revenue per Vehicle	0.3	(Revenue generated from Automotive Business segment) / Number of Vehicles Sold	##	2.6 or higher	50			
				75	2.5 - 2.59				
				50	2.4 - 2.49				
				25	2.3 - 2.39				
				0	2.29 or lower				
	Return of Equity	0.2	Net Income / Shareholder's Equity	##	4% or higher	75			
				75	3% - 3.9%				
				50	2% -2.9%				
				25	.1% - 1.9%				
				0	Negative				
	Cost of Products Sold per vehicle	0.1	Cost of products / number of vehicles produced	##	2.19 or lower	75	55	0.333	
				75	2.2 - 2.29				
				50	2.3 - 2.39				
				25	2.4 - 2.49				
				0	Greater then 2.5				
	Net Cash provided by Operating Activities	0.3	Revenue - cost of operating activities	##	3,000,000 or above	50			
				75	2,500,000 - 2,999,999				
				50	2,000,000 - 2,499,999				
				25	1,500,000 - 1,999,999				
				0	Less than 1,499,999				
	Annual Sales Increase	0.1	percentage increase in USD	##	Above 15%	25			
				75	15% - 19%				
				50	10% - 14%				
				25	5%-9%				
				0	Less than 5%				
ENVIROMENTAL	Energy Consumed per Vehicle Produced in North America	0.2	MMBTU/Vehicle	##	7.30 or lower	75			
				75	7.31 - 7.40				
				50	7.41 - 7.50				
				25	7.51 - 7.60				
				0	7.6 or higher				
	Carbon Dioxide Produced per vehicle produced in US	0.4	Metric Ton/ Vehicle	##	Less then .79	50			
				75	.80 -.89				
				50	.90 -.99				
				25	1.0 - 1.08				
				0	Greater than 1.09				
	Non saleable Waste per vehicle produced in North America	0.1	kg /vehicle	##	Less than 17	50	45	0.333	55
				75	17.1 - 18.0				
				50	18.1 - 19				
				25	19.1 - 20				
				0	20.1 or greater				
	Number of Remanufactured Parts Released per Year	0.1	Number of Remanufactured Parts Released per Year	##	101 of Greater	0			
				75	75-100				
				50	51-75				
				25	26-50				
				0	0-25				
	Water Used per Vehicle Produced in North America	0.2	kgal / vehicle	##	.69 or lower	25			
				75	.70 - .79				
				50	.80 - .89				
				25	.90 - .99				
				0	1.0 or higher				
SOCIETAL	Number of Employees Taking Child Care Leaves	0.1	Number of Employees Taking Child Care Leaves	##	600 or higher	75			
				75	550 -599				
				50	500 - 549				
				25	450 - 499				
				0	Less than 449				
	Number of Employees Utilizing Flex Time	0.1	Number of Employees Utilizing Flex Time	##	400 or higher	75			
				75	350 - 399				
				50	300 - 349				
				25	250 - 299				
				0	249 or Lower				
	Industrial Accident Frequency (frequency Rate of lost workday cases)	0.4	Incidents / million hours worked	##	0	75	65	0.333	
				75	.1 - .5				
				50	.51 - 1.0				
				25	1.1 - 1.5				
				0	1.51 or higher				
	Employee Body Mass Index (BMI)	0.2	measure of body fat based on height and weight	##	18.5 -24.9	50			
				75	16 - 18.49				
				50	25 -29.99				
				25	18.49 or lower				
				0	30 or greater				
	Percentage of Employees who Smoke	0.2		##	25 % or lower	50			
				75	25.1% - 30%				
				50	30.1% - 35%				
				25	35.1% - 40%				
				0	Greater than 40%				

Figure 4.4.2 Idealized Model for Toyota’s 2011 Results

Equalizing the weights yielded results that for the Supplier Sustainability Rating that the performance was the same. The non-idealized data showed that 2010 was a better performer than 2011. This was primarily due to a much better economic performance in 2010. When weighted equally, the environmental improvements in 2011 was able to off-set the financial issues seen by Toyota during 2011.

CHAPTER FIVE

Conclusions and Future Work

The methodology and case study were presented in the previous sections of this research. This section is intended to present conclusions and future research opportunities.

In this research, the issue of generating a method by which all aspects of a supplier's (or business entity in general) TBL can be evaluated concurrently and comprehensively was solved by a MAU model. In addition to providing metrics and scaling, a framework for altering both the metrics and scaling was explained.

The research was motivated by the lack of a comprehensive method for evaluating the TBL, as most methods address only one or two of the TBL elements. However the typical industry practice is for an entity to choose the supplier based on an economic relationship and after the relationship is solidified an inspection of the environmental and societal TBL elements is undertaken to ensure conformance.

Overall the research demonstrates a methodology and a tool by which entities can be compared to each other to create a rank order score.

Although the research presented here is intended to evaluate potential or current suppliers in similar, if not the same, industry relative to each other; the case study conducted compared Toyota's 2010 & 2011 performance. This case study was sufficient to prove out the tool and research, as it was able to compare two entities in similar if not the same industries and show differentiation between them. The ideal case study would have been to compare two suppliers in similar industries, but from an academic standpoint it is unrealistic to expect two entities to reveal the data required for an academic exercise. It is however, very realistic to expect suppliers to supply the data required to current or potential customers.

The largest hole that the Toyota study leaves versus a case study of two separate, but similar companies is that of vetting the metrics to be used. From an academic standpoint, it is assumed that if two companies would submit to taking part in the case study they would only be willingly to reveal public data and this data may be different between the two companies being reviewed. This would cause additional work in establishing the metrics.

The true purpose of a case would be for a company to use the tool created in this research to evaluate potential or current suppliers. Not having this company allowed for the metrics to be established via relativity arbitrary "values" of the author's research. An example of this would be if a company is a not for profit entity, it my look at its supplier's through a much different lens than a company that is for profit.

The overall Supplier Sustainability Rating given to each entity provides a relative score that can be used to compare similar entities. What is inferred by similar is that the entities being reviewed or compared are in similar, if not the same, industry. The metrics presented in the methodology section of this research were developed as idealized metrics conforming to the parameters for metric selection and scaling outlined there, while the metrics in the case study section of this research were altered to allow for the evaluation of Toyota. Future work can be conducted to develop metrics for specific industries or businesses.

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Year	**Degree**	**Institution**
1995	BS in Engineering	Case Western Reserve University

Professional Positions Held

Year	**Employer**	**Title**
2012	Lexmark International	Senior - Component Engineering Team Lead
2006	Lexmark International	Component Engineering Team Lead
2005	Lexmark International	Manufacturing Engineer
2004	Delphi - Packard Electric	Senior Plant Tool Engineer
2000	Delphi – Packard Electric	Plant Tool Engineer
1999	The Kirby Company	Tooling Engineer
1998	Eaton Corporation	Product Engineer I
1997	Eaton Corporation	Product Engineer II
1996	Rubbermaid Incorporated	Product Engineer
1996	Rubbermaid Incorporated	Associate Product Engineer
1995	Rubbermaid Incorporated	Design Engineer

Scholastic and professional honors

Year	**Honors**	**Institution**
2000	U.S Patent 6,142,654	Eaton Corporation

Scott E. Ladd
Signature