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Evaluating A Multiple Criteria Decision Support Tool For Assessing Sustainability Implications Of Engineering Projects

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EVALUATING A MULTIPLE CRITERIA DECISION SUPPORT TOOL FOR ASSESSING SUSTAINABILITY IMPLICATIONS OF ENGINEERING PROJECTS

by

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EVALUATING A MULTIPLE CRITERIA DECISION SUPPORT TOOL FOR ASSESSING SUSTAINABILITY IMPLICATIONS OF ENGINEERING PROJECTS

Master of Applied Science – 2013

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ABSTRACT

This Professional Research Project evaluates GoldSET*, a sustainability decision support tool developed by Golder Associates Ltd., and its use in the decision making process for assessing the sustainability implications of engineering projects. A qualitative evaluation of the effectiveness of the decision support tool was carried out including the development of recommendations. Establishing sustainability practices within corporate operations and engineering projects is an important nonmarket factor for the global business community. Corporations need to present themselves as environmentally conscientious as well as being socially and financially stable to unlock market opportunities. Corporate Social Responsibility (CSR) plays a role in creating and maintaining sustainability practices through measurement, reporting and evaluation processes. Firms are continuously faced with engineering project decision opportunities and there is a need for viable decision support tools, such as GoldSET, to assist in achieving corporate sustainability objectives and goals.

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DEDICATION

To Nicole, Kai and Knox, you are my everything.

Hold on, to me as we go
As we roll down this unfamiliar road
And although this wave is stringing us along
Just know you're not alone
Cause I'm going to make this place your home

Settle down, it'll all be clear
Don't pay no mind to the demons
They fill you with fear
The trouble it might drag you down
If you get lost, you can always be found

Just know you're not alone
Cause I'm going to make this place your home

Settle down, it'll all be clear
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Just know you're not alone
Cause I'm going to make this place your home

(Home by Phillip Phillips)

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CHAPTER 1 Introduction

Corporations need assistance in making decisions concerning sustainability and in particular how to embed sustainable practices within their operations and engineering projects. Engineering projects are limitless in scope and size, as they can vary from construction of a large hydro-power dam to manufacturing of recyclable water bottles to a logistic company's vehicle purchase. There are vast possibilities in types of engineering projects which lead to a dilemma for engineers, scientists and project managers that a one-size-fits-all solution to sustainability is not possible. As decisions need to be made on how corporations will achieve their sustainability goals (either as a company or project specific) there is a need for viable tools to assist in the decision making process. This Professional Research Project (Research Project) examines a sustainability decision support tool developed by Golder Associates Ltd. known as GoldSET (Golder Sustainability Evaluation Tool)[1].

GoldSET is a multi-criteria analytical tool which looks at the strengths and weaknesses of engineering projects in the context of the triple-bottom-line (i.e., environmental, social and economic). The GoldSET tool compares a project's different options in a systematic and comprehensive manner with the aim of developing an optimal solution. The tool was designed to assist corporations and organizations, such as CN Railway, Metro Vancouver, the Canadian Federal Government, the City of Hamilton and Xstrata Nickel, in incorporating sustainability practices within their operations and engineering projects. These corporations are faced with

multifaceted problems and require assistance in structuring the decision making process to deal with complex issues.

This Research Project involves an assessment of the theoretical and conceptual basis of GoldSET based on a literature review, decision support tool reviews and a case study. Utilizing these resources with a focus on the application of GoldSET, a qualitative evaluation of the effectiveness of the decision making tool was carried out as well as the development of recommendations for possible improvement with the software.

This Research Project consists of the following: (1) a literature review, (2) review of decision making tools; (3) a detailed case study and (3) a set of recommendations for the GoldSET software. The literature review includes an overview of sustainability, its history and how it can be measured; and decision making processes and how they play a role in defining sustainability in terms of engineering projects. The detailed case study is based on a metal plating corporation which requires support in determining which wastewater treatment option would best help it address its environmental, social and economic responsibilities. Using the GoldSET software, an analysis of the case study is carried out and the results are used in the evaluation of the software. The literature review and case study findings are used as the basis for the development of recommendations for software and procedural improvements, and / or alternatives.

1.1 Objectives of Research

Sustainability is a buzz word which has spread across the globe. Business worldwide is growing especially cognizant of sustainability and continues to decide how to best incorporate

sustainable development practices within their operations / engineering projects. The ultimate goal is to increase their standing within the marketplace at the same time as being environmentally and socially responsible. This Research Project focuses on corporations embedding sustainability within engineering projects, particularly with the aid of the GoldSET decision making tool. The objective of the research is to evaluate the GoldSET software in terms of its performance to provide sensible and applicable results; and provide practical and constructive feedback to the software developers.

1.2 Research Method

This Research Project consists of a detailed case study and a discussion of possible advantages and disadvantages of the GoldSET software. The detailed case study is based on the experiences of the GoldSET team and is the method applied to a hypothetical metal plating corporation which requires assistance in determining which wastewater treatment option would best help it address its environmental, social and economic requirements (Golder Associates Ltd., 2010). Using a hypothetical corporation, PNKK Corporation (PNKK Corp.), allowed for the use of inputs not necessarily present at other similar locations, essentially creating a well-represented operational scenario. Designing and assessing a well-represented scenario has the potential to show GoldSET as a robust and capable decision making software.

A thorough iterative decision making process was carried out to determine a decision about which option is the most optimal for PNKK Corp. in terms of the triple bottom line. The decision as supported by GoldSET findings and the in-depth literature review is the basis on which GoldSET is to be assessed. A qualitative analysis of the software includes a review of the

GoldSET structure, approaches and methods compared to literature and industrial / international standards and policies. The knowledge established by carrying out the detailed case study is used to develop ideas for recommendations / alternatives for the software.

1.3 Organization of this Report

The first chapter introduces the topic of the research, objectives and research method. The second chapter provides background information on sustainability, Corporate Social Responsibility (CSR), and decision making methods. The third chapter reviews other decision support tools. The fourth chapter will provide information on the GoldSET software and its principles. The fifth chapter will provide an overview of the case study used to assess the GoldSET software review and the evaluation process. The sixth chapter provides the advantages and recommendations as opined by the author through the literature review, case study and the use of the GoldSET software. This document will provide an overview of sustainability, decision making, use of decision support tools and recommendations for the GoldSET software.

CHAPTER 2 A Literature Review on Sustainability and Decision Making

2.1 Sustainability

Sustainability has been in the human conscience probably since the existence of humanity. The sustainable development definition as per the report of the World Commission on Environment and Development (1987), Our Common Future, states "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition is the most widely used in the literature; however, others have ideas and concepts of the definition of sustainability. For example as stated by Balkema et al. (2002), the fundamental principle is that all human beings whether living today or in the future have the same equal rights to meet their own needs (access to food, water, resources, clean environment, etc.), whereas Mitcham (1995) critiques, sustainability could almost mean anything due to different people having different interpretations of its meaning.

GoldSET developers used a reference from The Great Law of the Iroquois to provide the focus of the software on sustainability within engineering projects. The Great Law states "In every deliberation, we must consider the impact on the seventh generation … even if it requires having skin as thick as the bark of a pine" (The Constitution of the Iroquois Nations, 2012). The concept of this law is to think seven generations in the future (a couple of hundred years) and determine if the decisions that are made today would benefit their children seven generations into the future.

According to World Bank Economist Herman Daly (Meadows, 1992; Meadows et al., 1992) there are three rules to define sustainability: (1) a sustainable world would not use renewable

resources (i.e., forests, soils, waters, fish and game) faster than they are replenished; (2) it would not use nonrenewable resources (i.e., fossil fuels, mineral ores) faster than renewable substitutes can be found for them; and (3) it would not release pollutants faster than the earth can process them to make them harmless. Meadows (1992) believes based on Daly's definition of a sustainable world, there is no economy on earth that is sustainable and with society far from meeting the needs of the present as it has borrowed greatly from the future, through increase debt and use of resources.

According to Simonovic et al. (1997), there is no consensus on sustainability's meaning or how to measure it. There have been attempts towards defining sustainability and there are now guidelines to assist organizing decision maker's thoughts; these guidelines include Global Reporting Initiative (GRI) and International Organization for Standardization (ISO); and will be discussed further on in the report. In 2011, GRI and ISO signed a Memorandum of Understanding to increase their cooperation with one another with the hope of increasing the awareness for sustainability practices (GRI & ISO, 2011).

Some would argue the World Commission on Environment and Development report's definition is a guide for the implementation of the criteria for sustainability decision making – "Clear vision of sustainable development and goals that define that vision and links vision and goals to indicators and assessment criteria" (Hardi & Zdan, 1997; Davidson & Venning, 2011). Castro (2004) agrees as he felt the definition is criticized because it fails to define the needs or identify ways to achieve a sustainable society. As such, society continues to look for the operationalization of the sustainability concept (Davidson & Venning, 2011).

For example, as Simonovic et al. (1997) state, economic terms are better defined, understood and applied than intergenerational equity and environmental integrity as the latter two items have greater difficulty in defining operational terms. It is the perception of sustainability that will determine the scope of the subject to be included in the assessment framework (Davidson & Venning, 2011). As such, defining sustainability may be a moving target as the decision opportunities continue to develop increasing complexity and the concept ever evolves. As well, as the public gain knowledge of the area corporations will have an educated client base and will need to meet their needs.

2.2 History of the Sustainability Concept

Sustainability has been connected to humankind throughout our existence; however the beginnings of modern sustainability are found in the 1960s and early 1970s (Ricketts, 2010). It was during this time as Ricketts (2010) states "… when middle-class reform mingled with upper middle-class radicalism." Various situations during the period occurred that began to shape the environmental movement, such as the civil rights movement, environmentalism, anti-Vietnam War movement and other student movements. Many credit Rachel Carson's book *Silent Spring*, published in 1962 (Carson, 1962), with bringing the environment movement into American mainstream.

Ms. Carson, a marine biologist with the United States (US) Fish and Wildlife Service, had concerns about synthetic pesticides and their effects on ecosystems and wrote the book which, in its title refers to areas without birds due to environmental chemicals and has become a metaphor for the impact of the human species on the world (Ricketts, 2010). Ms. Carson

exposed the American public to concepts of environmentalism, industrial pollution and ecosystem destruction. This was accomplished by bringing attention to issues including industrial pollution and the growing imbalance between human activity and the natural world. The North American community began to be curious about these types of problems, and started to probe. There was a sense that people needed to gain an understanding of the processes that underlie environmental problems, so that solutions can be implemented one day (McCarthy, 2009).

The release of Carson's book, interest of the public and the national media coupled with various ecological incidents in the world lead to the sustainability movement gaining momentum. The incidents included the following:

- Major oils spills – Great Britain in 1967 and Santa Barbara, California in 1969;
- Mercury poisoning of fishing waters – Minamata, Japan between 1932 to 1968;
- Toxic waste dumping – Niagara Falls, New York (Love Canal) in late 1970s; and
- Nuclear Power plant incident – Three Mile Island in 1979 (Ricketts, 2010).

As Ricketts (2010) states, "The 'fear factor', spurred by the mainstream reformist environmental movement, accelerated to the point of panic by 1970, when the first nationwide Earth Day was observed, with broad bipartisan political endorsement." It is from this point forward Ricketts (2010) believes environmentalism became part of American values; however, in the context of the sustainability movement, it would only begin in 1987 with the release of the World Commission on Environment and Development report (Ricketts, 2010). As stated in

the World Commission on Environment and Development report:

> *Until recently, the planet was a large world in which human activities and their effects were neatly compartmentalized within nations, within sectors (energy, agriculture, trade), and within broad areas of concern (environmental, economic, social). These compartments have begun to dissolve. This applies in particular to the various global 'crises' that have seized public concern, especially over the past decade. These are not separate crises: an environmental crisis, a developmental crisis, an energy crisis. They are all one. (World Commission on Environment and Development, 1987)*

From this point forward sustainability has been gaining momentum as can be seen in how corporations look at the implementation and reporting of sustainability practices, referred to as Corporate Social Responsibility (CSR); municipalities striving to provide residents with sustainability driven practices related to water, wastewater and transportation activities; automobile manufacturers providing greater fuel efficient or hybrid options and the development and implementation of alternative energy sources (wind, solar, biomass etc.).

2.3 Corporate Social Responsibility

2.3.1 Corporate Social Responsibility Overview

Sustainability has been part of the human consciousness, and now it has become a buzz word used within the corporate world as the business community across the globe is reviewing the need to incorporate sustainability / sustainable development practices within their operations. The concept of sustainability is based on the understanding that the economy, environment

and society are interrelated. This, from a corporation perspective, is the concept of a corporate "triple bottom line" which looks at achieving a balance between profit, people and the planet (Figure 2.1).

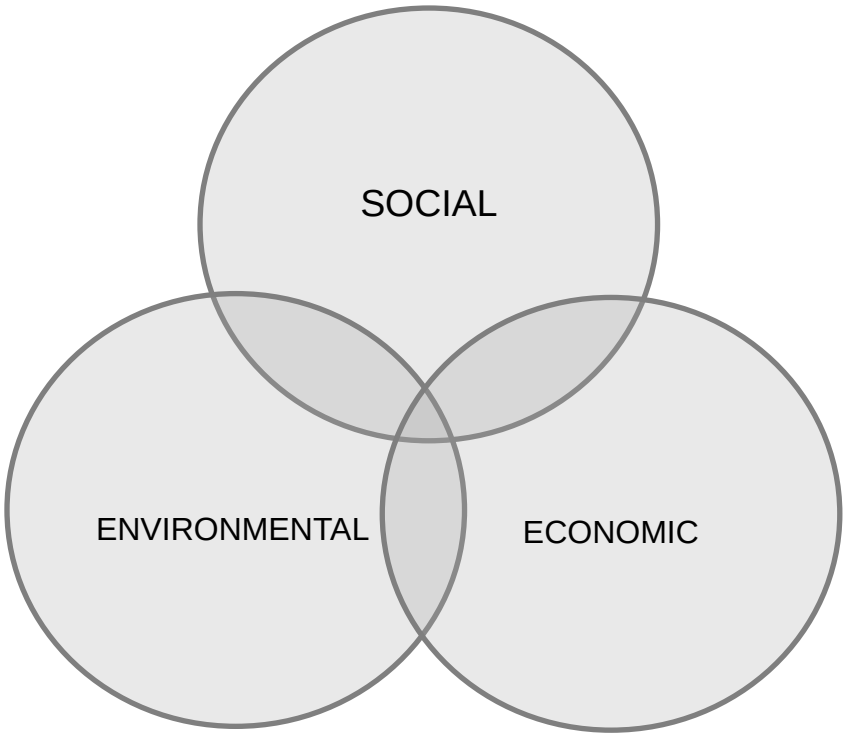


Figure 2.1: Sustainability – the "triple bottom line"

In the previous section the definition of sustainability was described as complex and constantly evolving, and as part of the evolution there are different metrics on how it is measured. As Tanzil and Beloff (2006) state, the old business adage of "only what gets measured gets managed" is important for sustainability goals to be met. Through indicators and metrics, the ideas within sustainability are captured and then converted into a quantitative measure that is useful for communication and decision making (Tanzil & Beloff, 2006). There are many

indicators available; such include Gross Domestic Product (GDP) per capita, literacy and poverty rates, and ambient concentrations of urban air pollutants (Tanzil & Beloff, 2006).

From a corporation perspective, CSR plays a role in the measurement and reporting of sustainability practices. There are various integrated frameworks to assess sustainability; these include GRI, United Nations Commission on Sustainable Development Framework, Sustainability Metrics of the Institution of Chemical Engineers and Wuppertal Sustainability Indicators.

Corporations' goals are to improve their performance over both the short and long-term (Overcash & Twomey, 2011). Overcash and Twomey (2011) have determined that over the fifteen years preceding 2008 there had been growth of about 25% in Fortune 1000 firms in corporate or industrial sustainability programmes. CSR is a growing trend for companies as they strive to minimize negative externalities in their operating activities and maximize beneficial impacts on society (Jamali, 2008). Decision making is vital within CSR programmes to provide guidance and direction. As sustainability is a complex objective, the decision making process needs to be robust to guide the process towards sustainable outcomes (Davidson & Venning, 2011).

CSR is known by a variety of different terms; a few of these are corporate responsibility, corporate accountability, corporate ethics, corporate citizenship or stewardship and the "triple bottom line" (Hohnen, 2007). The terms vary as does the definition of CSR, similar to sustainability. As stated by Turker (2009), the literature on the subject has provided a clearer understanding; however, it is difficult to find a commonly accepted definition. Organizations

have their own thoughts on the subject and therefore there is no consistency as they develop and build on these thoughts (Industry Canada, 2012). Some authors believe there should not be a common definition (Runhaar & Lafferty, 2009) as indicated in the earlier section.

As mentioned by Orlitzky et al. (2011), the Stern Review of Economics of Climate Change (Stern, 2007) and philosopher Joseph DesJardins (2007), believe ecological sustainability could be the main social responsibility challenge for business. Orlitzky et al. (2011) believe it is managers who have the ability to determine how their companies can be socially responsible, environmentally sustainable and economically competitive. Thus, it is the responsibility of business executives to tie their market and nonmarket operations / strategies together (Baron, 2001; Orlitzky et al., 2011). Orlitzky et al. (2011) posed two research questions one of which is of interest to this paper – How can social and environmental responsibilities be implemented more effectively through integrated market and nonmarket strategies? By integrating market and nonmarket strategies within a company's business strategy it positions the company to maximize performance and identify opportunities to sustain a competitive advantage to pursue those opportunities (market strategy) at the same time as maximize profits through the participation in the public processes (nonmarket factor) (Baron, 1998). As Baron (1998) states "nonmarket strategies can unlock market opportunities" which makes it important for having a strategy related to sustainability (an external nonmarket factor) tied to company market factors. As can be seen in today's marketplace, sustainability is used as a tool for tapping into the nonmarket economic factors. GoldSET and other decision support tools could help companies take a step towards possibly integrating market and non-market strategies.

Labuschagne et al. (2005) define business sustainability as "adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future." This definition incorporates a business spin on the World Commission on Environment and Development report definition of sustainable development.

Responsible business is good business (Hohnen, 2007). As organizations have begun to understand and accept this simple statement, CSR is becoming the requirement for operating in the global marketplace. It has become a strategic choice to incorporate different facets of CSR into an organization's daily operations and decision making through the engagement of employees and customers / clients. Organizations are at a time in economic and environmental history in which their decisions on corporate responsibility may potentially affect many generations to come. According to an article in The Economist (2008) "Climate change is probably the biggest single driver of the growth in the CSR industry of late. The great green awakening is making company after company take a serious look at its own impact on the environment." This aligns with DesJardins (2007), Stern (2007) and Orlitzky et al. (2011). Climate change, water resources, civil unrest, child labour and the list goes on, are issues corporations need to monitor and manage.

ISO 26000 Social Responsibility has been introduced to provide guidance on how to operate in a socially responsible manner, and may even provide a working definition of CSR (ISO, 2010). Social responsibility and sustainability are intertwined, in that a sustainable business should not only be satisfying customers / clients but doing so without harm to the environment and in a

socially responsible manner (ISO, 2010). Thus this guidance covers the three pillars of sustainability. ISO 26000 provides "harmonized, globally relevant guidance".

The current working definition of CSR (or Social Responsibility (SR) as it is referred to in the standard) is:

> *Social responsibility (is the) responsibility of an organization for the impacts of its decisions and activities on society and the environment through the transparent and ethical development that is consistent with sustainable development and the welfare of society; takes into account that expectations of stakeholders; is in compliance with applicable law and consistent with international norms of behaviour; and is integrated throughout the organization (ISO, 2010).*

The ISO 26000 working group decided to broaden the term CSR to include governments and other organizations and refers to this practice as SR. According to ISO (2010), CSR is important as with the onset of globalization in the world has consumers placing a greater importance on wanting to understand how the products they buy are produced. Consumers are becoming more cognizant of products that are environmentally harmful; produced by child labour, in dangerous working conditions and inhumane conditions. ISO (2010) believes if a company has the vision to achieve long-term profitability and credibility, they need to realize that they need to act within acceptable business practices. These practices essentially mean "doing the right thing".

With the evolution of CSR, there has been a push for tools, standards and regulations to be implemented so that organizations can use them to report their sustainable practices. It is

believed that a standard method of reporting is required so that reports can be compared to one another. Sustainability Reporting (SRG) is a necessary requirement of CSR to continue its acceptance and provide value in the business and governmental arenas. The instrument that has been identified on corporate websites and in the literature most often is GRI Sustainability Reporting Guidelines (Coca Cola, 2013; PPG, 2013). GRI has been able to harness the participation of people around the world in business, accountancy, investment, environmental, human rights, research and labour organizations to develop the reporting guidelines (Hohnen, 2007). The GRI is an official collaborating centre of the United Nations Environment Programme (UNEP).

GRI's framework sets out the principles and indicators (Figure 2.2) that organizations are to use to measure and report their environmental, social and economic performance (GRI, 2009). The GRI guidelines were developed with the intent to facilitate transparency and accountability by organizations when reporting their sustainable practices. The guidelines are applicable to organizations of any size or type or from any sector or geographical area (GRI, 2009).

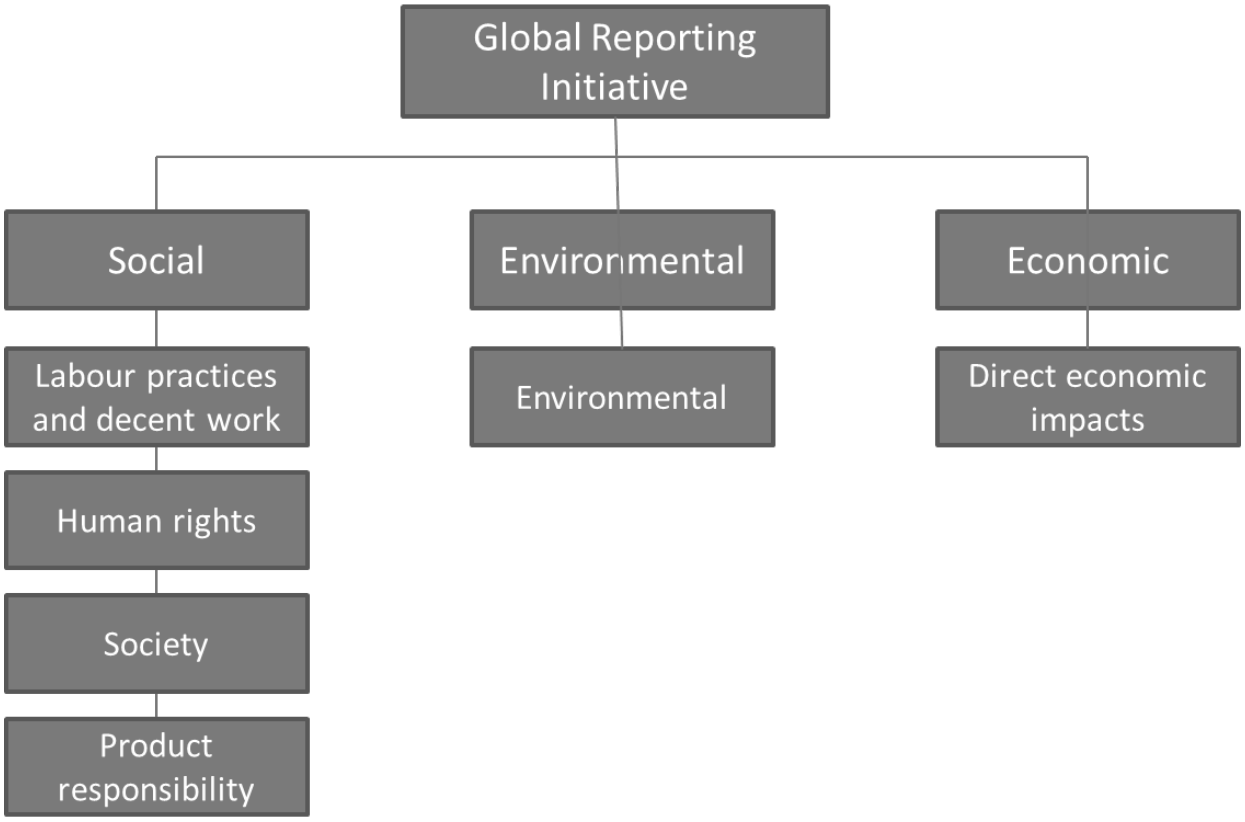


Figure 2.2: The hierarchical structure of the Global Reporting Initiative (GRI) framework (GRI, 2009)

As shown in Table 2.1, during 2011 greater than 1800 companies reported using the GRI sustainability reporting guidelines and publish CSR reports, with the US making up 11% of the reports being submitted (GRI, 2011). Whereas Canada submitted 3% of all reports; however when compared to the number of Global 500 companies who have headquarters in the country, Canada is "above average" in reporting. Contrarily, the US, with the highest number of reports submitted, is considered "below average" as it hosts 27% of the Global 500 companies' headquarters, although the US has shown steady growth in the number of reports submitted. The 1800 companies may not be a large number when compared to the numerous companies

worldwide; however there are promising signs of an increase in the number of submissions year to year. Figure 2.3 presents data showing the increasing number of submissions by year.

Table 2.1: Top 10 Reporting Countries 2011 (GRI, 2011)

Country	% of registered 2011 GRI reports	% Global 500 HQs*	GDP (IMF data in US$ billions)**
United States of America	11%	27%	15,094.025
Spain	8%	2%	1,493.513
Sweden	6%	1%	538.237
Brazil	6%	1%	2,492.908
China	5%	12%	7,298.147
Netherlands	4%	2%	840.433
Germany	4%	7%	3,577.031
Australia	4%	2%	1,488.221
Switzerland	3%	3%	636.059
Canada	3%	2%	1,736.869

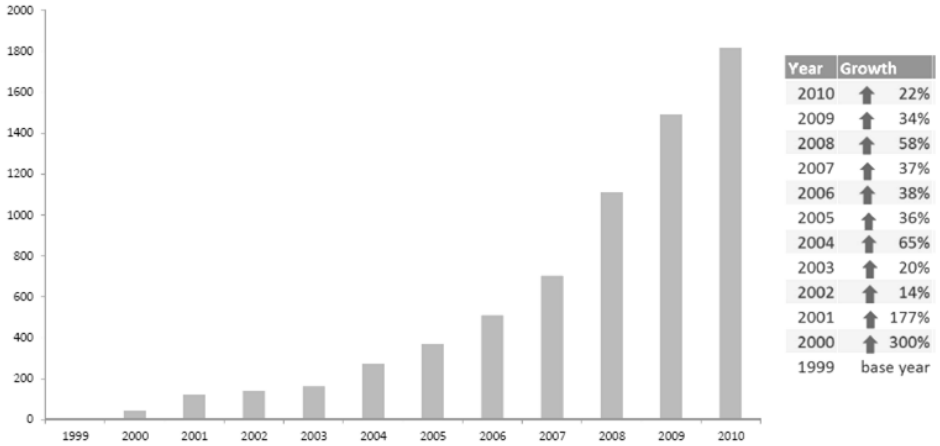


Figure 2.3: GRI Reports 1999-2010 (GRI, 2011)

The list of GRI reporting companies includes a variety of organizations from various sectors such as automotive, communications, food, pharmaceutical, energy, transportation and manufacturing. It appears sectors have realized the importance of CSR and SRG, Figure 2.4 presents GRI reporting by sector, with the financial services sector responsible for submitting the most reports in 2011 (14% of all reports), followed by the Energy and Energy Utilities sectors (GRI, 2012). Based on review of 2010 to 2011 statistics there was an increase in the number of reports submitted during these two years in the Chemicals and Real Estate sectors.

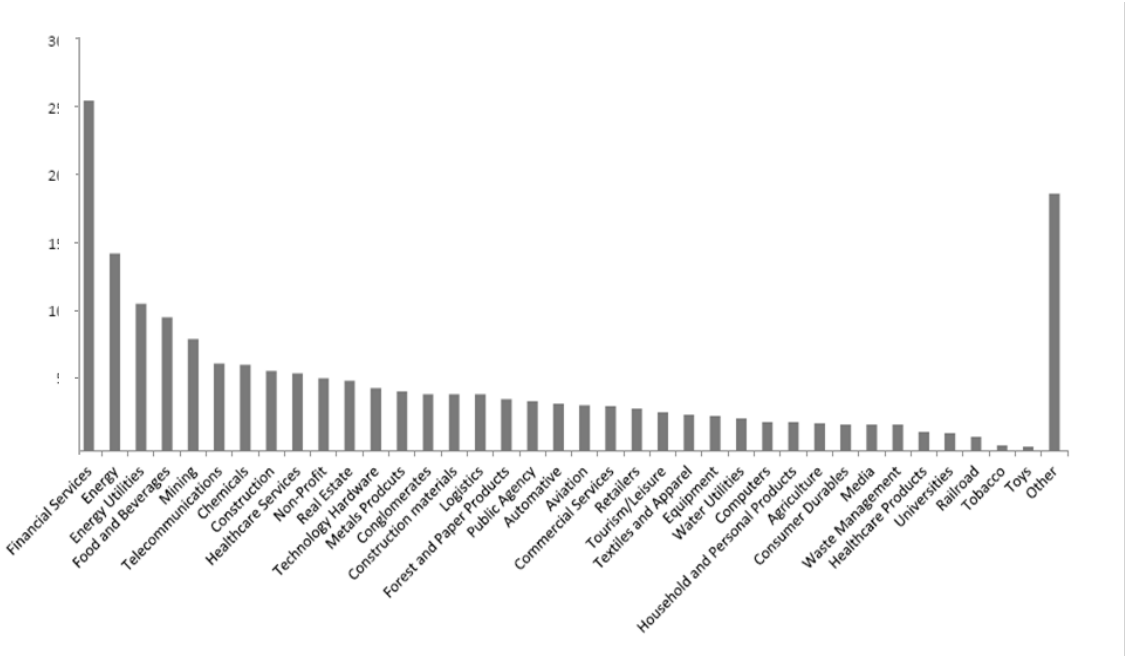


Figure 2.4: 2011 GRI Reports by Sector (GRI, 2012)

Governments tend to play a role in presenting CSR as a viable option for companies. Industry Canada (2012) states that it:

> *Promotes CSR principles and practices to Canadian businesses because it makes companies more innovative, productive and competitive. CSR helps make Canadian business more competitive by supporting operational efficiency gains; improved risk management; favourable relations with investment community; and improved access to capital; enhanced employee relations; stronger relationships with communities and an enhanced licence to operate; and improved reputation and branding (Industry Canada, 2012).*

A Government of Canada's Sustainable Development and International Affairs Department Study (Industry Canada, 2012) on CSR was carried out to document the experience of companies who had developed CSR programs and to review lessons learned from the process. The study was part of a larger federal Policy Research Initiative on Sustainable Development and was looking at the key policy issues facing Canada. The study concluded that CSR approaches, ideas and tools are important to companies who want to build on their competiveness in a globalized economy. The study also concluded that even the leading edge companies can benefit from the implementation of CSR.

Although the Canadian government has aided CSR implementation, ISO (2010) states a voluntary standardization reporting program is the way to proceed as it works from bottom-up which is dynamic and simplifies development, whereas legislation and regulation can be static and come from the top-down, resulting in a sense of obligation to complete the reporting

rather that creating an open and non-restrictive reporting environment (ISO, 2010). Whether or not social responsibility should be regulated by governments is an interesting topic of research and requires further development.

2.3.2 Implementation of Corporate Social Responsibility

When implementing a new strategy or idea, private industry commits appropriate resources to the preparation of a business plan to outline how the idea will be carried out. CSR is no different from any other strategy or idea; a business case for implementing CSR is necessary and will be different for every business. As mentioned in the International Institute for Sustainable Development (IISD) Report (Hohnen, 2007) factors such as the organization's size, products, activities, location, suppliers, leadership and reputation all play a part in the development of a CSR strategy. As well, the approach of implementing and incorporating CSR into the fabric of the organization will vary from strategic and incremental to being a mission-oriented CSR leader (Hohnen, 2007).

There are benefits for companies to implement CSR into their business strategy. According to Hohnen (2007) they can include:

- Better risk management and ability to anticipate risk;
- Developing a better reputation;
- Enhanced employee retention and development;
- Improved innovation and competitiveness;
- Increase operation efficiencies and reduce costs; and
- Better relationship with regulators / governmental agencies.

These are all worthwhile benefits for a company as they allow a company to fulfill the triple bottom line. The term triple bottom line refers to an accounting approach which takes into account the environmental and social performance as well as the economic performance of an organization. The approach focuses on the organization being responsible to its stakeholders rather than just its shareholders. It is very different approach to business as a stakeholder is anyone or thing that can be influenced directly or indirectly by the organization (Adams & Frost, 2008). Therefore a stakeholder does not require an economical involvement in the organization.

The business case is built upon how well the organization engages its stakeholders. CSR is a concept that an organization is accountable to relevant stakeholders. A company's strategy for incorporating CSR should be based on an integrated and balanced approach to environmental, social and economic factors. By not engaging them properly, the organization may hamper its ability to generate revenue and profit at the same time as increasing its legal risks. Implementing CSR as a method of monitoring this engagement and risk management should result over the long-term in increase value of the organization (Turker, 2009). Brammer and Millington (2008) concluded that the literature to date did not identify a clear pattern between CSR and financial performance. As well, Brammer and Millington (2008) suggest it takes a longer time for CSR performance to translate into financial performance. As the CSR definition is not definitive so is the measurement system (Turker, 2009). Turker (2009) argues that a new measurement system is necessary in order to better understand and measure how CSR relates to stakeholders and compare different organizations. Turker's (2009) study attempted to develop a scale for measuring CSR.

Every organization will have a different method of achieving CSR as organizations have different resources available (i.e., economics, staffing, desire). It is essential that any organization looking at implementing a CSR strategy needs to have it as a fundamental role in their decision making strategy, management processes and activities (Hohnen, 2007). As well it needs to start within upper management so that it can then be spread to the rest of the company with a consistent message. In doing so, employees at all levels will follow CSR practices and this will also spill into the public realm.

With CSR gaining momentum, there has been an increase in acceptance of how it affects the financial standing of a company. Jean Frilns, Chief Investment Officer of Stichting Pensioenfonds ABP at the time, stated "There is a growing body of evidence that companies which manage environmental, social and governance risks most effectively tend to deliver better risk-adjusted financial performance than their industry peers" (Hohnen, 2007). A study completed by the World Business Council for Sustainable Development shows benefits of CSR, for example "A coherent CSR strategy, based on integrity, sound values and a long-term approach, offers clear business benefits to companies and helps a firm make a positive contribution to society" (Hohnen, 2007).

The old saying "if you don't know where you are going, there is little chance you're ever going to get there" (Hohnen, 2007). With CSR and other business ideas this is true. This is why strategy is important to ensure a company moves forward in implementing and providing the framework for a strategy that the company management, employees and stakeholders find is

worthwhile. To accomplish the implementation of a corporation's strategy will require a solid foundation and tools to produce good decision making.

2.4 Engineering Projects

An engineering project can involve construction of a large hydro-power dam or a Leadership in Energy and Environmental Design (LEED) certified office building or the manufacturing of solar panels or the vehicle purchase of a logistic company's fleet. Engineering projects can be limitless in their scope, size and complexity. Engineers, scientists and project managers involved in engineering projects face the dilemma that a one size fits all solution to sustainability is not possible. With the numerous combinations of resources involved in many projects it is difficult to make decisions on how to incorporate sustainable practices. Therefore it is important a project be planned from the beginning to maximize resources, minimize the consumption of non-renewable resources and mitigate environmental impact (DEC Engineering, 2013).

In the 21st century, as natural resources and land area continue to be in decline as the hunger in developed and developing countries around the globe continues to grow, it is the world's corporations that will need to review or evaluate sustainability options for engineering projects. It is becoming less and less likely that governments have the necessary resources to guide sustainability practices as effectively as the private sector. As such, the private sector, through the vast numbers and types of its projects, can influence the inclusion of sustainable thinking within day to day operations / planning. Byrne et al. (2010) discuss a definition of sustainable engineering that includes an eco-efficiency focus as "practices that promote environmental,

social and economic sustainability through greater resource efficiency, reduced pollution and consideration of the wider social impacts of new technologies, processes and practices."

Education of engineers / scientists in sustainable development may be the necessary step to the fundamental change incorporating sustainability into the planning of project and ultimately the decision making process. The United Nations defines Education for Sustainable Development (ESD) as education that encourages "changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations" (Byrne et al., 2010). If the curriculum for engineers / scientists includes sustainable development it will aid in the integration of sustainable practices within engineering projects.

2.5 Decision Making

Decision making is inherent in our daily lives. We make decisions every day from which job to take, what movie to watch, to what car to buy, and many more. Psychological studies have shown people have a difficult time comparing more than seven objects, plus or minus two (Miller, 1956; Triantaphyllou & Mann, 1995), which can be of concern when faced with complex decision making problems involving many inputs and stakeholders. As Clemen (1996) states human beings are imperfect information processors. Decision making can involve making trade-offs between possibly conflicting / competing objectives. These trade-offs need to be understood and compared so as to come to a final decision. The problem with decision making has been how to evaluate the decision based on its benefits, costs, opportunities and risks and comprehend the interactions between the various criteria so that every aspect is included in

the final decision. This is not an easy task and thus the reason for the field of studying decision analysis.

Decisions can be difficult because of their complexity, the inherent uncertainty, requirement of tradeoffs and multiple decision makers (Clemen, 1996). Decisions can be instantaneous (e.g., where to buy a coffee) or long-term (e.g., resource allocation), personal (e.g., where to buy a house) or business (e.g., significant group decision). It is the long-term business type of decision which relates to GoldSET and decision making which leads to sustainable practices being embedded within projects. It is these types of problems for which no single discipline, profession or interest group has the knowledge to determine the best option (Simonovic et al., 1997). As with complex decision opportunities, trade-offs need to be scrutinized by all interest groups, and stakeholders should be included from the beginning of the process. Decisions need to be based on the values of the stakeholders as this will lead to the development of alternatives, assessment criteria, scoring and weighting and the decision analysis. As Searcy et al. (2007) state, to assess performance and measure progress in a practical, cost-effective way requires positioning the sustainable development concept into an operational phase.

2.5.1 Decision Making Methods – Value-focused thinking

Decisions can be made in many different ways. As Clemen (1996) states, a person's values are the reason for making decisions in the first place. Most people approach decision making by focusing on generating and evaluating alternatives. This approach is known as alternative-focused thinking and is a reactive approach. This approach is often viewed as backwards; it

puts the cart of identifying alternatives before the horse of articulating values (Keeney, 1994). Alternatives are relevant only as a means to achieve values. Values should be the primary focus of decision making.

Value-focused thinking is an approach that defines and structures a decision maker's fundamental values in terms of objectives and uses these objectives to guide and integrate decision making (Keeney, 1994). Keeney's value-focused thinking is strongly top-down orientation (Keeney, 1992). Values can be defined as something the decision maker cares about in a decision situation. They can be used to evaluate the desirability of any possible alternatives or consequences. This is why they should be the driving force behind any decision making.

Value-focused thinking requires hard thinking. It is through this hard thinking that a better set of alternatives are developed which can lead to better decisions and identification of better decision opportunities.

2.5.1.1 What is value-focused thinking?

Value-focused thinking is an approach that makes the decision maker focus on the activities that must occur before a solution is conceptualized. The central role of thinking about values is shown in Figure 2.5. The greatest benefit to using value-focused thinking is to be able to generate better alternatives for a decision and identify more appealing situations (Keeney, 1994). For this Research Project, value-focused thinking may provide an alternative to guide strategic thinking, identify decision opportunities, improve communication and uncover hidden objectives that has otherwise not been implemented.

Figure 2.5: Overview of value-focused thinking (Keeney, 1994)

Value-focused thinking is a philosophy to guide decision makers. It has three major ideas:

- Start with values – instead of starting with alternatives, start with the decision maker and stakeholders' objectives;
- Generate better alternatives – use values to generate better alternatives; and
- Use values to evaluate alternatives – use values to evaluate alternatives (Loerch & Rainey, 2004).

Strategic objectives of an organization are the foundation for which members can base their decisions and identify future decision opportunities. As Keeney (1994) mentions some organization mission and vision statements are very vague. For example, "improve productivity" or "provide quality service". These types of statements are guidelines to be used

for organizational behaviour and decision making however they cannot be used to make important decisions. Keeney (1994) argues that they need to be more explicit and there needs to be a better process for identifying objectives. This is where Keeney's value-focused thinking comes into use. Value-focused thinking includes a process of identifying objectives and using various techniques to develop a list of objectives.

2.5.1.2 Identifying objectives

As stated by Keeney and Raiffa (1993), an objective is the direction in which one would strive to do better. Keeney and Raiffa (1993) also state that is likely that objectives will conflict with one another, as to achieve an improvement in one objective may come at the expense of another. This can be seen in a typical business problem of minimizing cost versus optimizing the quality of service (Keeney & Raiffa, 1993) as quality of service can often come at a cost and thus the objectives conflict.

The need to clarify objectives has long been understood as being a key step in making informed decisions. Identifying and organizing objectives is sometimes considered an art which Keeney (1999) believes can be practiced systematically by following the five steps listed below:

- Step 1: Write down all the concerns you want to address through your decision;
- Step 2: Convert your general concerns into succinct objectives;
- Step 3: Separate ends from means to establish your fundamental objectives;
- Step 4: Clarify what you mean by each objective; and
- Step 5: Test your objectives to see if they capture your values.

As previously discussed, values are the foundation of the decision situation. As values are made explicit through the identification of objectives, the process of identifying the objectives is critical to defining values (Robin et al., 2001). Unambiguous and complete statements of strategic objectives and means objectives can be a guide to identifying decision opportunities and creating alternatives that enhance both the likelihood of achieving those objectives and the degree to which the objectives are achieved (Keeney, 1992).

When identifying objectives, it is best to not only list objectives but relate them to each other in the decision context (Step 3). This can be accomplished by using the definitions of fundamental and means objectives with the "Why Is That Important" (WITI) test. As well the objectives can be shown in an objectives network diagram. By relating the strategic objectives to other objectives, the objectives network will show how the achievement of certain objectives influenced the achievement of others (Keeney, 1992). Keep in mind, that the end result is the strategic objectives which are to be used to provide guidance on all decisions that are made within an organization and form the basis of greater detailed fundamental objectives for decisions (Keeney, 1994).

Strategic objectives of an organization are the foundation on which members can base their decisions and identify future decision opportunities. It is interesting to note that not many organizations take the time to identify their objectives and values (Keeney, 1994). As Keeney (1994) states the greatest benefits of value-focused thinking are being able to generate better alternatives for any decision problem and being able to identify decision situations that are more appealing than the decision problems that currently confront you.

2.5.2 Multi-Criteria Decision Analysis

Multi-criteria decision analysis (MCDA) is a field of study of decision making involving two or more conflicting objectives (Tecle & Duckstein, 1994; Pietersen, 2006). MCDA is used to provide the decision maker(s) with a method that assists them in choosing the 'best' alternative. Real life decisions including personal and business decisions typically compare different options in terms of a set of conflicting criteria. As stated by Dorini et al. (2011), there is usually no best overall option in these situations as moving from one option to the another simply results in an improvement in one set of criteria versus a decline in another set. It is MCDA which provides a method to reduce this difficulty within decisions. Often several parties are involved in a decision having conflicting criteria. As trade-offs are part of the decision making process, the final chosen alternative may not necessarily be considered the 'best' by all parties involved for their individual criteria.

Kim et al. (2003) state the key benefits of MCDA are its emphasis on the importance of the values of decision makers and stakeholders while establishing criteria, incorporation of these values into the decision making process and the ability to evaluate the values and criteria through a form of sensitivity analysis. According to Wang et al. (2009), MCDA is an operational and decision support approach that is suitable for looking at complex problems with high uncertainty, conflicting objectives, different forms of data and information, multiple interests and perspectives and accounting for the complex and evolving biophysical and socio-economical systems. MCDA methods can provide solutions to a variety of problems such as energy management, facility siting and capital expenditures. MCDA allows decision makers a

method for ranking or prioritizing alternatives that are being assessed. However, decision makers have to be careful in the use of MCDA as to avoid double normalization of quantitative indicators (Golder Associates Ltd., 2011). A project should be represented in its entirety by one indicator per dimension (environmental, social, economic) especially quantitative indicators. (Golder Associates Ltd., 2011). The result of not accounting for possible 'double accounting" may result in MCDA interpretations being biased (i.e., if two indicators are related to a similar issue representing the same idea / units). Some argue this is a fundamental flaw with MCDA, in that it breaches the principle of dimensionality (i.e., MCDA tries to compare incompatible indicators – add apples to oranges) (Dobes & Bennett, 2009).

MCDA determines the preference order of the alternatives that are presented in a decision problem. There are numerous MCDA methods. According to Wang et al. (2009) the most common approach is the weighted sum method. The score of an alternative is calculated and the resulting score for each alternative can be used to rank, screen or choose the alternative.

2.5.2.1 Weighting Methods

A weighting structure can also be developed for making a decision. The weighting reflects the degree of importance or value assigned to each criterion in the set of decision criteria. As Suedel et al. (2009) state weights represent the rate at which people are willing to trade off portions of criteria range between the objectives. Weighting presumes a decision maker's preference can be represented as a weighted additive sum of various criteria scores (Morton & Fasolo, 2009). It is the setting of weighting criteria which, for most decision makers, is the most cognitively demanding of the MCDA processes (Morton & Fasolo, 2009).

If the decision maker is consistent with his / her weighting, the weights elicited using various methods are expected to be the same. Behavioural research has shown that different methods may give diverging results (Mustajoki et al., 2005).

There are several methods of acquiring a weight judgement which include ratio-scale weights, rank-sum weights, rank-order-centroid weights and equal weights. All methods of weight elicitation result in a ratio scale. The weight assessment methods differ in the kind of information they preserve from a decision maker's judgements (Jia et al., 1998). Methods of developing weights include the swing method and Analytic Hierarchy Process (AHP).

Swing Weighting

The swing method is a method which represents the gain in overall value in going from the worst value to the best value in each criterion (Tholkala, 2011). According to Clemen (1996), the swing weighting method can be used in almost any weight-assessment situation. Using this method requires the decision maker to compare individual attributes directly by imagining hypothetical outcomes (Clemen, 1996). Swing weights have the advantage that they are sensitive to the range of values of an attribute (Diakoulaki & Grafakos, 2004). The swing weighting method has been shown in research to be useful in most situations as it is simple, transparent, consistent, adaptable to the number of criteria and sensitive to impact range (Diakoulaki & Grafakos, 2004).

Elicitation of swing weights can be used for developing weights in multi-criteria decision analysis problems. The goal of elicitation of the weights is to determine the relative importance of the indicators. The following example about the purchase of a bicycle is provided for an

understanding of how the swing weighting method works. The illustration is based on an example presented in Robert T. Clemen's textbook, *Making Hard Decisions: An Introduction to Decision Analysis* (Clemen, 1996).

Bicycle Purchase Example – Swing Weighting Method

A decision maker is interested in purchasing a bicycle. There are three indicators, Life span, Cost and Colour, which the decision maker is considering in the decision. Table 2.2 describes three bicycle alternatives. The decision maker needs to determine the relative weights associated with the indicators and has selected the swing weight method. The decision maker has already developed the utility function to be used to calculate the weighted score of the various cases. The first step in the process is for the decision maker to create a table (Table 2.3) which includes hypothetical best cases for each of the indicators and a benchmark case (worst level of each indicator).

Table 2.2: Bicycle purchase alternatives (example based on Clemen (1996))

Indicators	**Bicycle A**	**Bicycle B**	**Bicycle C**
Life span	4 years	1 year	3 years
Cost	$2300	$1000	$2000
Colour	Yellow	Blue	Red

Table 2.3: Swing-weight assessment table – Bicycle purchase example (example based on Clemen (1996))

Indicator Swung from Worst to Best	Consequence to Compare	Rank	Rate	Weight
(Benchmark)	1 year, $2300, red	4		
Life span	4 years, $2300, red			
Cost	1 year, $1000, red			
Colour	1 year, $2300, blue			

For this example the bicycle worst case would be a bicycle that lasts 1 year, costs $2300 and is red. The subsequent rows would then have the best of each indicator in the first column and the worst for the other two indicators. For example, for the Colour indicator the bicycle has the worst on life span and cost, and the best for colour (i.e., favourite colour is blue). The next step is to rank the cases, as has been done with the Benchmark case being given a rank of 4 as it is assumed to be considered the worst case.

The decision maker then needs to decide on how they view Life span, Cost and Colour by comparing to one another. This has been completed in Table 2.4. Following the ranking of the cases, the decision maker then assigns points to the highest swing and a percentage of point to the other indicators. The rate column then needs to be completed with the Benchmark and Cost cases rating. The worst case receives a rating of 0 and the top ranked a rating of 100, respectively. The decision maker then needs to think about how much less satisfaction they get by swinging certain indicators (e.g., Life span from 1 to 4 years as compared to Cost from $2300

to $1000). This satisfaction can be looked upon in percentage terms, such as the Cost is 100% and the others can be considered a percentage of this case.

Table 2.4: Swing-weight assessment table – Bicycle purchase example – Ranks assessed (example based on Clemen (1996))

Indicator Swung from Worst to Best	Consequence to Compare	Rank	Rate	Weight
(Benchmark)	1 year, $2300, red	4	0	
Life span	4 years, $2300, red	2		
Cost	1 year, $1000, red	1	100	
Colour	1 year, $2300, blue	3		

After the decision maker has given thought to the rankings, it was decided that Life Span would receive 80 points and Colour would receive 20 points. Therefore this means that improving Life Span from worst to best is worth 80% of the value you get from improving Cost. Once the rank and rate are determined the weight (or ratio) can be determined by dividing the points assigned by the total points (i.e., normalization – total of weights equals 1). The calculation is presented in Table 2.5. The weight can then be used with the utility function to determine the overall score for the option and provide the decision maker information on how the options rate against one another.

Table 2.5: Swing-weight assessment table – Bicycle purchased example – Complete assessment (example based on Clemen (1996))

Indicator Swung from Worst to Best	Consequence to Compare	Rank	Rate	Weight
(Benchmark)	1 year, $2300, red	4	0	
Life span	4 years, $2300, red	2	80	0.400 (=80/200)
Cost	1 year, $1000, red	1	100	0.500 (=100/200)
Colour	1 year, $2300, blue	3	20	0.100 (=20/200)
		Total	200	1.000

As Clemen (1996) states if a decision maker has a difficult time thinking about the worst conceivable case, they could reverse the process and look for the best conceivable case (best of all attributes). The decision maker would then consider swinging indicators from best to worst.

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) method was developed in the 1970's by Dr. Thomas Saaty, and was intended to mimic human thinking (Saaty, 1980). The method allows users to assess the relative weight of multiple criteria or multiple options against given criteria. Saaty developed a consistent method of converting pairwise comparisons into a set of numbers which represent the relative priority of each of the criteria.

The steps of AHP include:

- Structure a decision problem and selection of criteria;
- Priority setting of criteria by pairwise comparison (weighting);

- Pairwise comparison of options on each criterion (scoring); and
- Obtaining an overall relative score for each option.

2.5.2.2 Indicators Development

Indicators can be quantitative or qualitative, that can be measured or described and show trends (Simonovic et al., 1997). As Simonovic et al. (1997) describe, an indicator's major role is providing analytical, communication, warning and mobilization and coordination functions. Making decisions without a reliable set of indicators is like driving without road signs. The indicators for sustainability need to adequately look at environmental, social and economic dimensions. The indicators main feature is to summarize, focus and condense the complex problem into a manageable amount of meaningful information (Singh et al., 2009).

CHAPTER 3 A Review of Decision Support Tools

Decision support tools can aid decision makers in organizing and analyzing data as these can be tedious and complex tasks. There are many web-based decision making tools available in the marketplace, including GoldSET, that can help support the decision making process. This chapter provides a summary of a review of four other decision support tools which have been chosen based on a review of the literature and internet sources, and their relevance to this Research Project. These decision support tools include the following:

- United States Environmental Protection Agency (USEPA) Decision Analysis for a Sustainable Environment, Economy & Society (DASEES);
- HIPRE 3+ (HIerarchical PREference analysis) (or Web-HIPRE);
- SiteWise™; and
- Sustainable Remediation Tool™ (SRT™).

The qualitative review of these models provided an understanding of other available decision analysis techniques, modelling strategies, weighing methods and organization theories which helped in the critical review of the GoldSET model.

3.1 Decision Analysis for a Sustainable Environment, Economy & Society (DASEES)

Decision Analysis for a Sustainable Environment, Economy and Society (DASEES) is a web-based decision tool developed by a team of the USEPA, university and private company researchers for which the primary focus is sustainable systems and communities. The USEPA Science Advisory Board had recommended the USEPA develop a decision-making framework to address

complex multi-faceted problems. As described, the framework should assess cumulative risk, evaluate competing management options, and clarify tradeoffs (USEPA, 2012a).

According to DASEES developers the software is "flexible but rigorous, transparent and auditable, and adapts to new information" (USEPA, 2012a). As with other software, DASEES looks at the triple bottom line through a MCDA, and it is inclusive and incorporates stakeholder input. The framework of the software is based on the same common sense decision-making principles that are used in everyday life. It applies these principles to the more complex environmental issues.

DASEES is organized as a five step model:

- Understand context;
- Define objectives;
- Develop options;
- Evaluate options; and
- Take action.

The web application framework was designed using Open Source Software (OSS) and this provides an advantage in terms of software licensing and cost (USEPA, 2012a). The software allows users to create a user-specific model using interactive tools that allow input of data and generation of graphs, charts and statistical analyses. It is the use of these tools with which users will be able to quantify and evaluate their different decision options.

Bayesian probabilistic modelling and statistical analysis of data are carried out by the software. An influence diagram interface will allow the user to build, specify and simulate Bayesian models which connect the various options and measures used in the problem (USEPA, 2012a).

The following are reasons why the USEPA believes DASEES should be used:

- Addresses complex management decisions involving multiple stakeholders, objectives, and / or management options;
- Facilitates buy-in from stakeholders on action selection and implementation planning;
- Enhances stakeholder understanding on uncertainty in the effectiveness of options in achieving objectives;
- Explicitly incorporates uncertainty;
- Leads to scientifically defensible actions;
- Clearly connects objectives and the means for achieving the objectives;
- Provides approaches for tracking achievement of objectives following action implementation;
- Leads to efficient allocation of resources across private and government organizations; and
- Allows visualization of spatial aspects of the management options (USEPA, 2012a).

Developers believe the DASEES framework allows communities to determine their values and what decisions help to reach those values.

3.2 HIPRE 3+ (or Web-HIPRE)

Web-HIPRE (HIerarchical PREference analysis) is free web-based MCDA software which uses the Simple Multi-attribute Rating Technique (SMART) and AHP (Saaty, 1980; Hämäläinen & Salo, 1997). Web-HIPRE was developed by Raimo Hämäläinen and programed by Jyri Mustajoki (French & Xu, 2005). It is claimed to be the first interactive MCDA software on the internet. The software is designed to be powerful and simple to use. Web-HIPRE requires only a Java-enabled browser and is not required to be installed on local computers (Web-HIPRE, 2012). The web-based software provides the problem structured as a value tree with the problem objectives and stakeholder preferences being structured in a hierarchical manner (Figure 3.1).

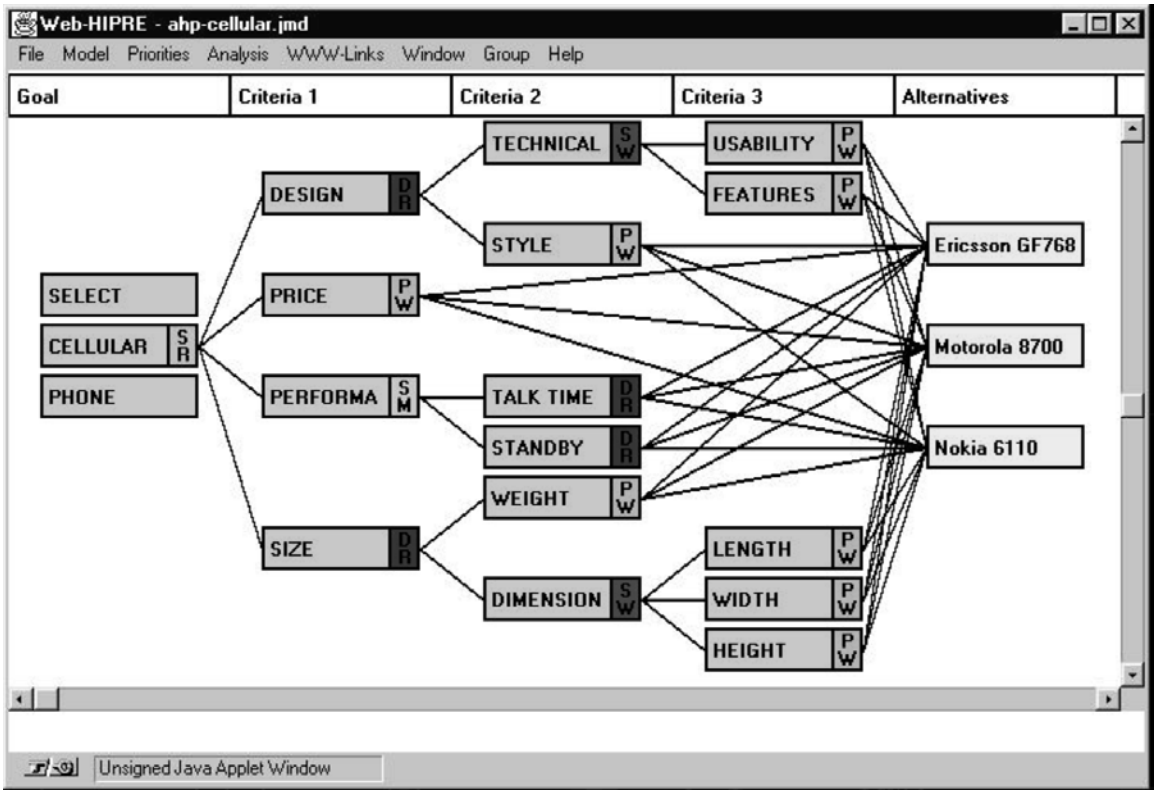


Figure 3.1: Web-HIPRE value tree structure (Mustajoki & Hämäläinen, 1999)

The goal is to help experts plan more appropriately and to create innovative alternatives or expand alternatives. Web-HIPRE allows the user the option of using different weighting methods, such as Swing, Pairwise comparisons (AHP), SMART, Direct, SMARTER and value functions. Direct weighting allows the user to directly provide the weights for the criteria as well as import values from other value functions (Web-HIPRE, 2012). The SMARTER weighting method is similar to the swing weighting technique in ranking the indicator in order of importance for the change from worst to best (Web-HIPRE, 2012). Combinations of methods are supported in the software.

Raimo Hämäläinen in development of the system allowed for a mix of AHP and multi-attribute value theory (MAVT) methodologies as he felt the two have more in common than others may believe (Hämäläinen & Salo, 1997). The output of the decision is shown as composite priorities or sensitivity analysis. The software has the ability to be organized in group decisions and provides sensitivity analysis based on the relative importance of each decision maker (Web-HIPRE, 2012). An advantage of Web-HIPRE is that it can be used via the internet; however it is recommended to buy the program for use in consulting and decision conferencing because it is easier to run the program with local files (French & Xu, 2005). Currently there is no reporting feature with Web-HIPRE (French & Xu, 2005).

3.3 SiteWise™

SiteWise™ is a stand-alone tool that assesses the environmental footprint of a remedial alternative / technology in terms of a consistent set of metrics, including: (1) greenhouse gas emissions; (2) energy use; (3) air emissions of criteria pollutants including oxides of nitrogen,

sulfur oxides, and particulate matter; (4) water consumption; and (5) worker safety (Battelle et al., 2011).

SiteWise™ is designed to calculate the environmental footprint of remedial alternatives through Excel spreadsheets. The tool is applied at various stages of the remediation process such as selection, design or implementation. The tool focuses remedial activities and is composed of various Excel spreadsheets (Battelle et al., 2011). SiteWise™ conducts a comparative analysis of several different remedial alternatives, making it well suited for use during the remedy selection phase. In addition, SiteWise™ can be applied to any part of a remedy as a way to aid in decision making (Battelle et al., 2011).

The objectives of using SiteWise™ are to allow Green and Sustainable Remediation (GSR) metrics to be considered during remedy selection and to identify the aspects of a particular remedy that cause the greatest footprint for each metric (Battelle et al., 2011). Remediation professionals are able to focus footprint reduction methods on those aspects of the remedy with the greatest impact. SiteWise™ is based on the 2007 Microsoft® Excel platform. The tool includes seven different Excel files as shown the user guide, including input, calculation, summary and final summary sheets (Battelle et al., 2011).

The remedy footprint is calculated by multiplying the impact factors (emissions per usage rate) with the material, electricity or fuel consumption while carrying out the remediation activity. The basis of the SiteWise™ calculations are emission factors from government and non-government sources. The user is provided with an output file. The software provides summary documents and compares the different remedial alternatives on a set of consistent metrics.

The tool would allow sensitivity analysis to be carried out. There is a warning for the user to be cautious in not opening or keeping calculation sheets open during a calculation process (Battelle et al., 2011).

3.4 Sustainable Remediation Tool™ (SRT™)

Sustainable Remediation Tool (SRT™) helps incorporate sustainability concepts into decision making about the implementation of future remedies and optimization of existing remedies (AFCEC, 2012). The tool currently estimates sustainability metrics for eight technologies: excavation, soil vapor extraction, pump and treat, enhanced in situ bioremediation, thermal treatment, in situ chemical oxidation, permeable reactive barrier, and long-term monitoring of monitored natural attenuation (AFCEC, 2012). The tool is a Microsoft Excel-based software. It consists of two tiers – Tier 1 rule of thumb calculations and Tier 2 more detailed calculations.

The software consists of the following sections: User Input, Design and Materials, and Consumables and Sustainability Metrics Output. The output section provides the carbon dioxide emissions, energy use, economic cost, safety / accident risk and change in resource service for the land and groundwater for each technology. The output is presented in two formats – natural units specific to each metric (i.e., CO_2 emissions in tonnes) and dollars. The goal of the software is to combine sustainability metrics with the traditional selection criteria in an easy-to-use tool. This allows the user to review the technologies holistically to maximize the net environmental benefit of remedial activities (AFCEC, 2012).

CHAPTER 4 GoldSET Decision Support Tool

4.1 GoldSET Decision Support Tool Overview

The GoldSET decision support tool was developed by Golder Associates Ltd. for assisting with decision making on engineering projects. GoldSET refers to Golder Associates Ltd. Sustainability Evaluation Tool. Examples of projects that have used the software include site remediation, wastewater treatment, tailing ponds and road pavement. In these examples GoldSET was used to help structure the decision and develop options for the projects which included the best design for a tailing pond, most economical and environmental remediation of contaminated soil site, wastewater treatment capital expenditures and choice of road pavement options (Golder Associates Ltd., 2011).

The tool is a multi-criteria decision making tool presented as web-based customizable software where users provide inputs related to the environmental, social and economic aspects of a project (Figure 4.1). The objective of using the software is to help decision makers with incorporating sustainability into engineering projects. It was the GoldSET developer's vision for the software to be used as a way for engineers, scientists and project managers in industry and government to implement Sustainable Development at the ground level of a project. GoldSET was seen as a way to influence the project setup, design and management towards more sustainable outcomes by providing the means to achieve triple bottom line benefits and a way to better manage the impacts and performances during a project life cycle (Golder Associates Ltd., 2011).

Figure 4.1: GoldSET interactive webpage (Golder Associates Ltd., 2013)

According to the Golder Associates Ltd. software developers, the software provides the following benefits to project owners, managers and technical staff (Golder Associates Ltd., 2011):

- Simplify the decision-making process;
- Reduce risks and increase opportunities;
- Allow stakeholders to better understand impacts and benefits;
- Provide intuitive visual representation;
- Evaluate alternatives and trade-offs;
- Increase sustainable actions / practices within engineering projects; and
- Improve corporate image.

The intention of the GoldSET design was to improve a decision process which involves complex issues, facilitate trade-offs between conflicting priorities within a project and provide a framework for managing the risks associated with a project. The goal of GoldSET is software that provides a transparent decision support tool which can be used in proactive stakeholder engagement and lead to optimized alternatives and better operational practices (Golder Associates Ltd., 2011).

4.2 GoldSET Design, Technical Principles and Process

This section will describe the GoldSET design, technical principles and five step evaluation process. The evaluation process includes the following steps and is shown in Figure 4.2:

- Step 1 – Project Description;
- Step 2 – Options Description;
- Step 3 – Indicators Selection;
- Step 4 – Scoring and Ranking; and
- Step 5 – Interpretation and Decision Making.

The GoldSET methodology is to take a complicated problem and structure it in a manner for the data to provide guidance on the best approach / option to implement. The five step process is used as a guide to help the user progress through the software. Each of the steps is outlined in an easy to understand format within the software, as well as described in the GoldSET user manual (Golder Associates Ltd., 2011).

Figure 4.2: GoldSET five step evaluation process (Golder Associates Ltd., 2011)

4.2.1 Step 1: Developing a Project Description

The initial step in the GoldSET process is the Project Description component where the user provides the situation for which the analysis is to be concentrated. Items included in this section include site conditions, problems, identifying internal / external stakeholders, identifying project objectives and key issues, and description / background of project and applicable regulations. This step is carried out to ensure the consistency with the objectives of the project. Objectives of the project can be specified at this stage and can be tailored to a specific type of activity (e.g., remediation, wastewater treatment). The step is an administrative step which is important for organizing the decision process (Golder Associates Ltd., 2011).

As mentioned the decision maker can begin the process of identifying key stakeholders in the decision process. Figure 4.3 illustrates a method for determining the key players in decision making process (Golder Associates Ltd., 2012). The decision maker needs to determine where and how a potential stakeholder is involved within the project based on the level of interest and influence a stakeholder may have with the project. This is an important step in the process

as decision makers do not want to overlook or seclude stakeholders as this may result in problems during the project implementation stage.

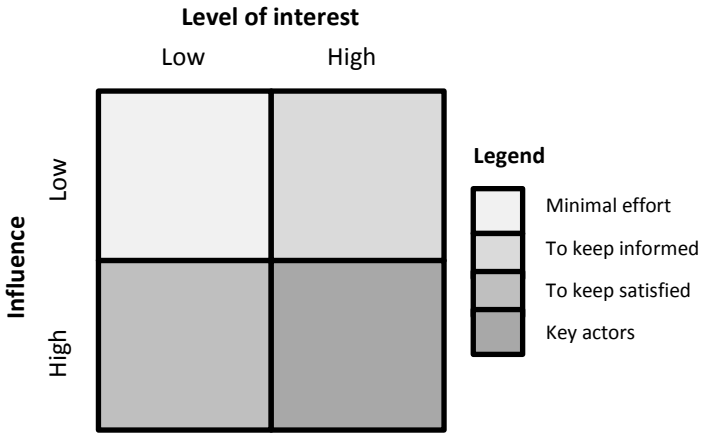


Figure 4.3: Stakeholder influence and interest (Golder Associates Ltd., 2012)

4.2.2 Step 2: Developing Options

The user is required to develop the options which may be used as a solution to the problem. This involves listing of all possible scenarios that could be used, generating ideas for possible solutions and pre-screening to retain a subset of the most plausible options. This step is necessary to outline the direction of the decision making process. It may be prudent to include a baseline (or operations as usual) option to provide a reference point for comparison of options (i.e., possible improvement). Options are developed by the decision maker and may include discussions with the project design team and stakeholders (Golder Associates Ltd., 2011). Research needs to be carried out to determine the viable and accepted options for the proposed project.

4.2.3 Step 3: Selecting Indicators

Following the option development, users then choose which indicators are to be used in the assessment. Selecting indicators is an important step in the decision making process as they are used to determine the validity and judgment of the various options / solutions. GoldSET allows for the selection from a standard set of indicators specific to the activity or can be developed for the specific case. It also has the ability to add and remove indicators according to client and project requirements, for example, Environmental – air and noise emissions, water quality, Social – public image, health and safety, Economic – capital cost, potential for fines (Golder Associates Ltd., 2011).

GoldSET has a number of modules with developed indicators which can be modified and expanded depending on the requirement. The GoldSET manual (Golder Associates Ltd., 2011) states that to perform the initial indicator selection the starting point should be the selection of the appropriate GoldSET module. The indicators then need to be reviewed and selected, and if necessary the list of indicators may need to be expanded possibly through a literature review and stakeholder workshops (Golder Associates Ltd., 2011). Before proceeding with the decision process a consensus should be reached on the list of final indicators.

Indicators can be quantitative or qualitative, that can be measured or described and show trends (Simonovic et al., 1997). As Simonovic et al. (1997) describe, an indicator's major role is providing analytical, communication, warning and mobilization and coordination functions.

GoldSET provides modules specific to certain applications or project types. These include site remediation, mining waste, road construction and rehabilitation, and wastewater treatment.

The user can select one of these modules to assist in the process of defining the decision opportunity. The indicators within each module have been selected / developed keeping in mind the environmental, social, economic and technical concerns of a project. These indicators have been based on international, national, industry-specific standards and legal requirements (Golder Associates Ltd., 2011).

Table 4.1 outlines examples of indicators included in GoldSET and used in the case study assessment. Examples of quantitative indicators used in the assessment included energy consumption/generation and Net Present Value (NPV); whereas qualitative indicators included community attitudes and management practices. The indicators are grouped within dimensions, Environmental, Social and Economic. GoldSET also has a 4th dimension, Technical, to include indicators associated with the technical aspects of a project (e.g., design complexity, durability, reliability). For the purposes of this Research Project, carrying out a review of an engineering project to meet sustainability goals, the technical dimension was chosen not to be included. Further research into the technical dimension could occur.

Table 4.1: GoldSET general indicators (Golder Associates Ltd., 2011)

Dimension	Indicator
Environmental	• Water use • Energy consumption / generation • Input materials used • Quality and quantity of solid waste • Quality and quantity of liquid waste discharge • Air quality
Social	• Public health and safety • Workers health and safety • Local sourcing (contractors and suppliers) • Local job creation & diversity • Community attitudes • Management practices
Economic	• Net present value (total project costs) • Financial recoveries • Logistics • Ease of obtaining necessary permits • Interference with activities on site • Potential fines, penalties and surcharges

Indicators are important components of the decision making process as they are tied into the quality of the evaluation. GoldSET has a four criteria procedure for choosing indicators for a decision opportunity. The following procedure has been adapted from the 2007 version of the

Global Environmental Management Initiative (GEMI) (Golder Associates Ltd., 2011):

- Aligns with the success of the project;
- Indicator exhibits impact of project activities;
- Incorporates stakeholder needs; and
- Project has a tangible effect on indicator.

Based on these principles, the user chooses the most applicable indicator to include in the decision process. As indicators help to shape the decision problem, an in depth indicator selection process is necessary for setting up the software to aid the decision maker and stakeholders. The process should have thorough input from the stakeholders. Defining the decision problem with indicators that accurately and realistically reflect the decision maker / stakeholders' inputs for the problem / opportunity will lead to a better decision process.

4.2.4 Step 4: Scoring and Ranking

Scoring and ranking is carried out using multi-criteria framework to provide ranking of options. GoldSET has produced a scoring scheme for both qualitative and quantitative indicators. Typically a qualitative indicator can use a four-point scale ('a forced choice method'). GoldSET allows users to structure the scoring scheme using a three, four or five scale system depending on the user's needs. Scoring scales can range from 0 to 100. These values can be interpolated for quantitative indicators and refined into various levels for qualitative indicators. A weight is then assigned to each of the indicators by comparing the relative importance of the indicator with respect to other indicators in the same dimension. With the Golder model, the indicators

are weighted using two criteria, Relevance to organization and Level of concern to stakeholders. As the GoldSET manual (2011) states, users need to "minimize the subjectivity within an evaluation is that the scoring and weighing schemes must be agreed upon and be maintained unchanged during the evaluation." Once scoring and weighing are agreed upon, the MCDA calculations are carried out in the background in GoldSET and the user does not interface with the calculations.

Weighting is an important aspect of the MCDA process. The user is required to assign a weight to each of the indictors. The weighting process should involve the project proponent and other stakeholders. The weight is a means of comparing the importance of an indicator to other indicators. Weighting is based on the interest and influence of the different stakeholders (developed during the initial Project Description step). Figure 4.4 presents the GoldSET weight matrix. The two criteria, Relevance to organization and Level of concern to stakeholders, are used to develop the weight for each indicator. Each criterion weight is assessed using a scale of low, medium and high priority. The individual weights of the criteria are then combined within a matrix to provide the decision maker with the indicator's overall weight. GoldSET also includes an option to weight 'themes', these are groups of indicators under a dimension which can be given an individual weight. The MCDA calculations for the dimensions would incorporate the indicators and themes. For this Research Project, themes were not used in the analysis as they were developed later in the research process.

GoldSET has recently introduced a method for changing the weighing scales to be based on the user's input. For this Research Project, the different weighing scales were not reviewed in detail and analysis was carried out using the basic scale of 1 to 3.

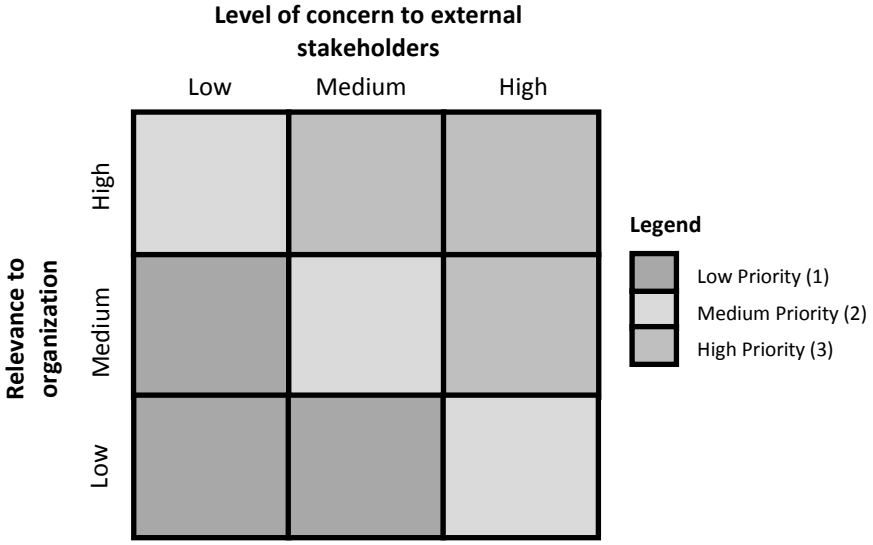


Figure 4.4: Weight matrix (Golder Associates Ltd., 2012)

Following the agreement on scoring schemes and assignment of weights, the decision maker can now proceed with the calculation of the appropriate scores for each indicator and subsequent dimension. The GoldSET software automatically calculates the aggregate score for each dimension (Golder Associates Ltd., 2011). The calculation used is based on the additive sum of the individual indicators and results in the percentage for each dimension. The results and their presentation are presented in the Step 5.

4.2.5 Step 5: Interpreting and Decision Making

Upon completion of Steps 1-4 the user can then initiate the interpretation and reporting step. This step provides the user with the results of the analysis and a report outlining the various steps during the process. The GoldSET process is iterative, therefore the decision can be refined and the decision is not necessarily defined by what is illustrated in the graphical format provided in the interpretation section (Figure 4.5).

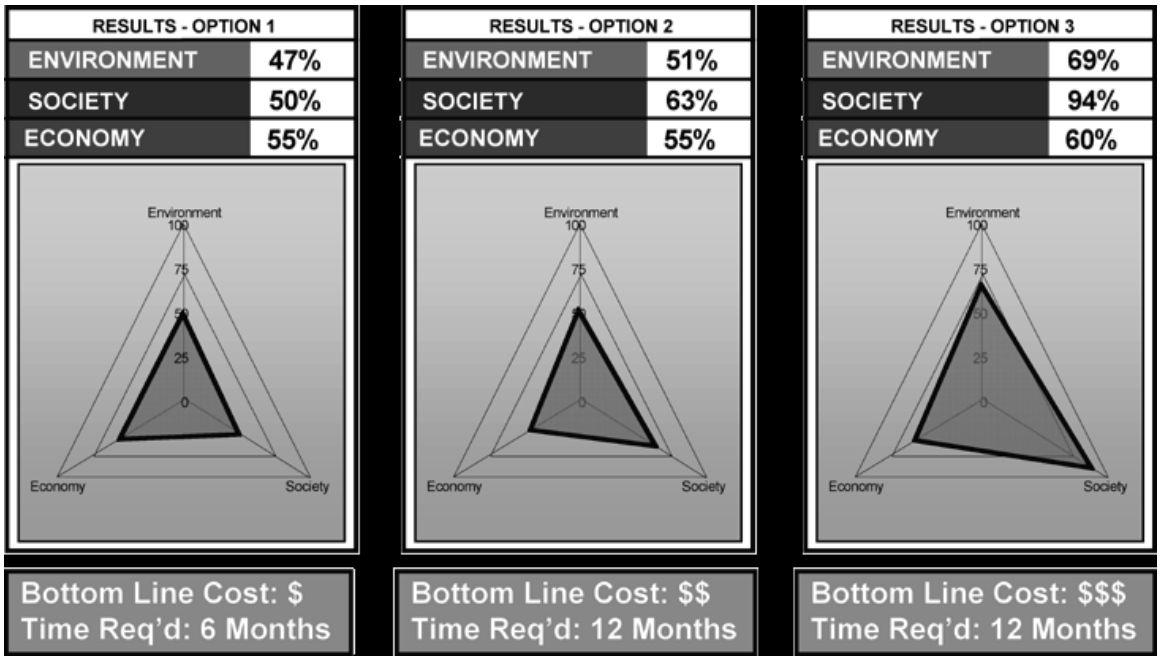


Figure 4.5: GoldSET graphical output (Golder Associates Ltd., 2011)

GoldSET only facilitates the decision making process by providing structure and the decision maker needs to carry out an analysis of the results to determine if they are sensible and applicable. Results are summarized in a diagram that illustrates the strength and weaknesses of each option. This allows the user visualize the decision. The best approach from a

sustainability perspective is based on the largest most balanced triangle, highest performance in each dimension, balanced performances between all dimensions and the specifics (i.e., location, economics) for each problem must be considered when selecting the option. The decision makers base their decision on the results; however, interpretation can be subjective. Based on the results above, Option 3 may be the chosen option as the three dimension scores are all higher than the other options.

Step 5 includes reviewing the results, performing sensitivity analysis, reviewing assumptions (weights, scores, etc.) and reviewing a plan for the next step (Golder Associates Ltd., 2011). An example of a next step would be carrying out an iterative process for refining the number of options. An example could be that there are five options and after the first iteration (Project description to Interpretation steps completed) it shows three options outperform the other two options. By removing two of the options and with some refinement to the indicators, scoring and weighting, one or more of the remaining options may display the optimal solution. The iterations do not have to end at this point; further refinement can still be carried out by the decision maker. The GoldSET software is set up to allow for the iterative process to occur seamlessly and easily, allowing the user to refine a decision and present results quickly.

CHAPTER 5 Application and Evaluation of GoldSET

The application and evaluation of GoldSET involved an assessment of the theoretical and conceptual basis of GoldSET based on the literature review, decision support tool review and a wastewater treatment case study. Utilizing the detailed case study, an evaluation of the effectiveness of the decision making tool was carried out as well as the development of recommendations for the decision support tool. The wastewater treatment case study uses a hypothetical corporation and scenario for the purposes of the review. The reason for using a hypothetical case is that it creates a well-represented scenario that includes inputs which may not be present at other similar locations. The following sections provide an overview of the case study and the results of the decision process using the GoldSET software.

5.1 Wastewater Treatment Case Study – PNKK Corporation

The detailed case study has PNKK Corporation (PNKK Corp.), which is a well-known metal plating company, currently treating its wastewater via limited settlement (in a containment tank not designed for balancing just holding) and dilution using fresh main potable water. The company is consistently exceeding the metal and Total Suspended Solids (TSS) permit limits. The local authority frequently visits the site and the community has the site high on its radar as neighbours have complained about odour, noise from truck traffic and visual impacts (trucks at night, unattractive building, etc.) from the site. PNKK Corp. has plans to increase production and its shareholders are a mix of reactive (nervous) and proactive (want to do the best) members who have different opinions on the site's impacts on the surrounding community and operation personnel. The workers at the site are generally positive but are concerned about

the impacts of increased work requirements / obligations especially because of anticipated increased production levels. The Environment, Health and Safety (EHS) staff consists of one person who is stretched to meet the compliance and reporting demands.

A detailed case study description has been included in the Appendix. Overall PNKK Corp. wants to improve on its current social and environmental standing by meeting the following objectives at the same time as being fiscally responsible:

- Minimize water use;
- Minimize neighbours concerns;
- Minimize solid waste produced;
- Minimize material usage;
- Achieve permit standards; and
- Keep their workforce happy and safe.

In an effort to meet the above criteria the facility has four options which the facility personnel need to decide of which would best help them meet their objectives. Each option has various costs, duration, risks and benefits associated with it. The four options include the following and are described in further detail in the Appendix:

- Option 1: Perform wastewater treatment;
- Option 2: Perform wastewater treatment and implement a chemical management system;

- Option 3: Perform wastewater treatment, chemical management system and metal recovery; and
- Option 4: Redesign metal application process.

PNKK Corp. using GoldSET would like to decide which option is the best choice to treat the wastewater at the same time as meeting other requirements. If suboptimal decisions are made by PNKK Corp. they can lead to approaches that are financially costly, environmentally ineffective and negatively affect relationships with the key stakeholders (public, regulators, employees, etc.). PNKK Corp. wishes to use the GoldSET Wastewater Treatment module (Version 1) to assist it in navigating the decision opportunity to optimize design of the wastewater treatment solution and avoid / minimize pitfalls throughout the process. The multi-criteria analysis framework is expected to help PNKK Corp. evaluate alternatives in terms of the triple bottom line and provide analysis on issues such as lifecycle cost, regulatory costs, energy and greenhouse gas emissions, reuse opportunities and social acceptability.

5.2 Case Study Analysis

The case study analysis included the review of the software decision process (i.e., project description, alternatives, indicators and selection process, weighting process and decision making / interpretation) and the practical use of the software in developing a decision. The outcome of the analysis was to identify advantages and recommendations for opportunities for improvement within the GoldSET software.

Various steps were taken to carry out the analysis and review of the software, these included:

- Review GoldSET information (user manual, software, etc.);
- Learning of GoldSET software;
- Review detailed case study;
- Input and organization of case study information within software;
- Review indicators and weights;
- Review results – which option chosen;
- Sensitivity analysis (indicator; option selection); and
- Development of advantages and recommendations.

The case study information was entered into the GoldSET software following the GoldSET five step evaluation process. Considerable learning of the software was carried out including review of the user manual, understanding the case study inputs, understanding how each step of the process is related to one another, a review of the outcome including the summary documents and sensitivity analysis. As mentioned previously, the inputs into the software are extremely important in developing a strong, reliable and representative decision model. Following the input of the case study information the case study was carried through to the point of a decision. For this Research Project, a brief sensitivity analysis was carried out; however, in a real life decision it is recommended that a detailed sensitivity analysis would be carried out to truly understand the intricacies of the decision problem. The sensitivity analysis would need to involve a review of all significant indicators and weights; and may also include a

comparison of the results to another decision support tool. The following section provides a summary of the outcome of the case study.

5.3 GoldSET Results

The results from the wastewater treatment evaluation are shown in Figure 5.1 and with an example of detailed results for the economic dimension in Figure 5.2.

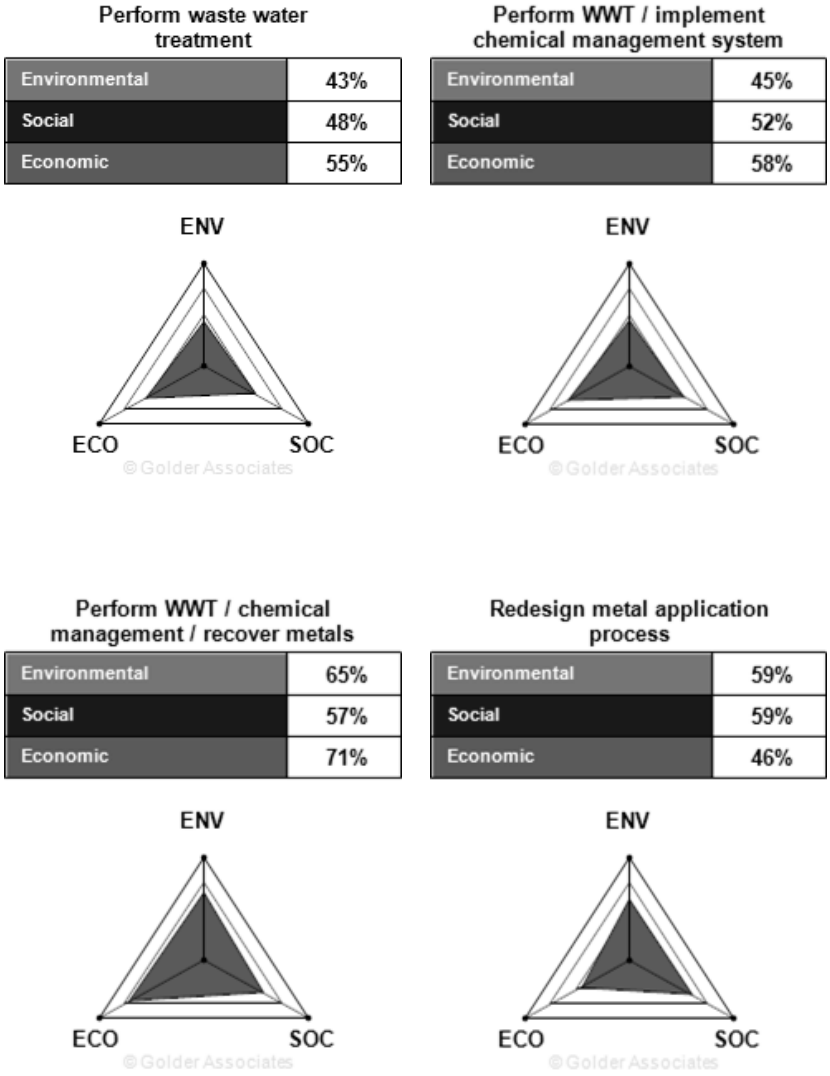


Figure 5.1: GoldSET – Wastewater treatment case study results

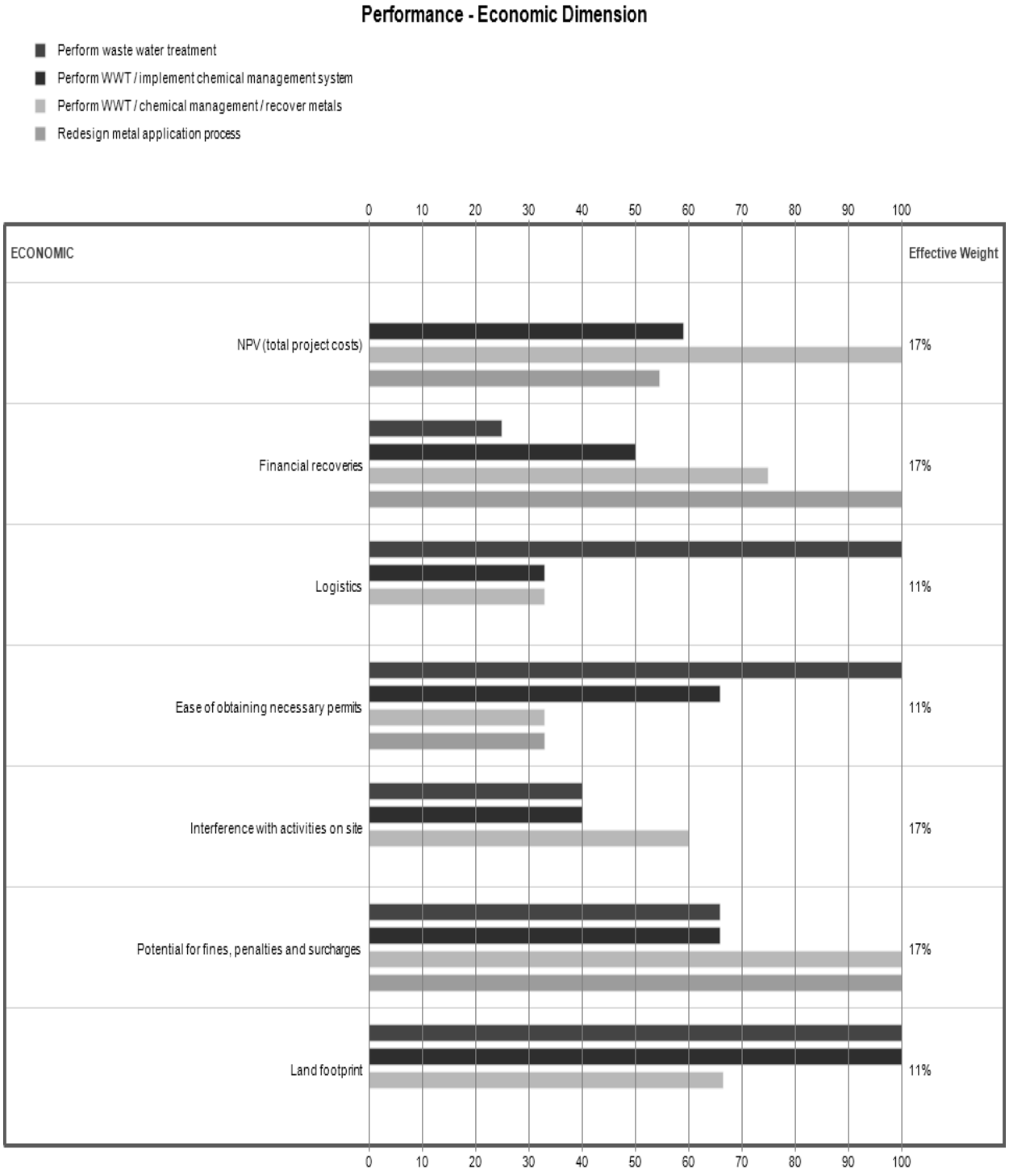


Figure 5.2: GoldSET – Economic dimension – Wastewater treatment case study results

Based on the case study inputs, Option 3 was shown to be the optimal option. This was determined using an iterative approach of only selecting the top options for subsequent rounds of analysis. Examples included Option 1 being removed following the first round of analysis and Option 2 not being selected for the third round of analysis. The final assessment was completed reviewing Options 3 and 4; with Option 3 being selected as the optimum solution based on the resulting environmental and economic scorings. A discussion on this selection process is included in Section 6 Recommendations.

During the iterative approach the user has the ability to modify the decision set-up including indicators and weights. As with any decision that is not clear cut, the decision maker's views of the inputs can change during the process as there is greater insight about the decision problem developed and new information or ideas may become available. One item to note during this process is the decision maker should take time to review the process and outputs to make sure data has been entered correctly and accurately as well as provide a period of time for the decision maker to take time to contemplate the inputs and decision. By taking the time to 'think' about the decision process there may be room for improvements in the setup and inputs.

Overall the economic score for Option 3 was significantly better than Option 4 which in large part was due to the Net Present Value (i.e., includes overall capital and maintenance costs, and duration of project). The detailed results in Figure 5.2 showed the Net Present Value (NPV) had an effective weight of 17% and the next closest option had a NPV that was nearly double in monetary terms to Option 3. Therefore with the large weight placed on NPV and the significant

difference in the monetary terms affected the overall economic dimension. The environmental and social dimensions were comparable between the two options.

The results of the decision determined that Option 3: Perform wastewater treatment, chemical management system and metal recovery was preferred based on the data entered. The end decision of this process is not necessarily important to this Research Project as much as the process of learning the software and working through the case study to meet the goal of determining the advantages and recommendations of the software. The final decision (as presented by the GoldSET software) is subjective to the decision makers' (and stakeholders') understanding of the problem and the software technical elements. The result is only as good or reliable to the user as the inputs entered. Therefore some scrutiny on the quality of the data being used as well as the source of the data is needed. If transparency is a requisite of the decision making process then one must be aware of origin of the data and that all stakeholder data is represented fairly and accurately.

The following are the details behind the case study decision process, with some insight into the technical aspects. Other software packages were not used for this assessment as a technical comparison to GoldSET.

Through the development of the decision problem within GoldSET the following positive items / advantages were noted:

- Sensitivity analysis is quick and easy to use. The user can modify the weighting or other parameters quite easily and then at a click of the mouse a new report can be created.

- Reporting – GoldSET offers a reporting feature which helps to summarize the inputted data and subsequent results. This feature is easy to use and is not provided in this manner for other software reviewed for this Research Project.
- File storage / organization – GoldSET storage and organization are very intuitive. Other software reviewed were not as straight forward to follow and required multiple files for storage and manipulation of data.
- Weighing – Set up is easy to understand and use, and developers are continually trying to refine the weighting system used in GoldSET.
- Data organization – GoldSET provides users with the ability to organize and input the level of detail they require to prepare and structure their decision making process. With the user manual users can learn the software relatively easily.

The ability of GoldSET to provide a step-by-step approach to the decision process is different from the Web-HIPRE method (i.e., value trees). GoldSET is a less interactive as a tool in the visual development of the decision problem whereas Web-HIPRE provides a visualization of the problem in steps. GoldSET excels with the visual display of the final decision (Figure 5.1) with the three pillar triangle and percentage summary. The visual display is informative and provides clients with results in an easy to understand format. Through the presentation of this display users are able to visually show others responsible for decisions to make decisions quicker, and intelligibly review and process the information. The result is an informed decision maker who can make the decision to go forward with a certain process or determine that additional information is required.

CHAPTER 6 Recommendations

The theoretical and conceptual basis of GoldSET was assessed through a literature review, other marketplace software review and a detailed case study. It was this evaluation of the GoldSET software program that has led to the following recommendations.

Overall the software is an effective decision making tool and meets the goals of the developers as being simple and flexible. The software is user friendly and intuitively easy to navigate. From alternative and indicator selection to scoring / weighting criteria, using the software requires thought and input by the decision maker throughout the process. This aligns with the software developers' vision that the software does not make the choice for the decision maker with the final decision being the decision maker's; developers of other software also state this point (e.g., Web-HIPRE). The data input, organization and storage are all carried out in the GoldSET software and allow for the decision maker to spend more time focused on the important decision indicators and alternatives. Another strength of the GoldSET software is the ability for it to allow for a sensitivity analysis of indicators (i.e., scores, weights, structure) to be carried out with relative ease and the report provided by GoldSET is updated quickly for review by the decision maker. Review of uncertainties in a MCDA model is typically handled through sensitivity analysis. Therefore one item which could be reviewed for GoldSET is the sensitivity analysis to allow for a different MCDA method (i.e., linear additive model, AHP and outranking methods) (Brinkhoff, 2011).

Decision support tools are not magical solutions for making decisions; their purpose is to aid a decision maker faced with complex decision situations. As mentioned in the literature review,

MCDA is a very useful tool for organizing, structuring and presenting decision problems. Therefore the use of MCDA within the GoldSET model is appropriate for the situations / project types the developers were targeting. By using the MCDA, decisions involving aspects of the triple bottom line can be framed properly and understood by all the stakeholders. According to Brinkhoff (2011), there are important aspects to highlight when developing an MCDA model, which include:

- Being based on a MCDA method (compensatory, non-compensatory or outranking method, or a combination thereof) which is suited for the problem;
- Structure criteria in a manner that reflects the overall objective in a way to allow for elicitation of scores and weights; and
- Review the uncertainties in the model – from hierarchical construction to performance evaluation (Brinkhoff, 2011).

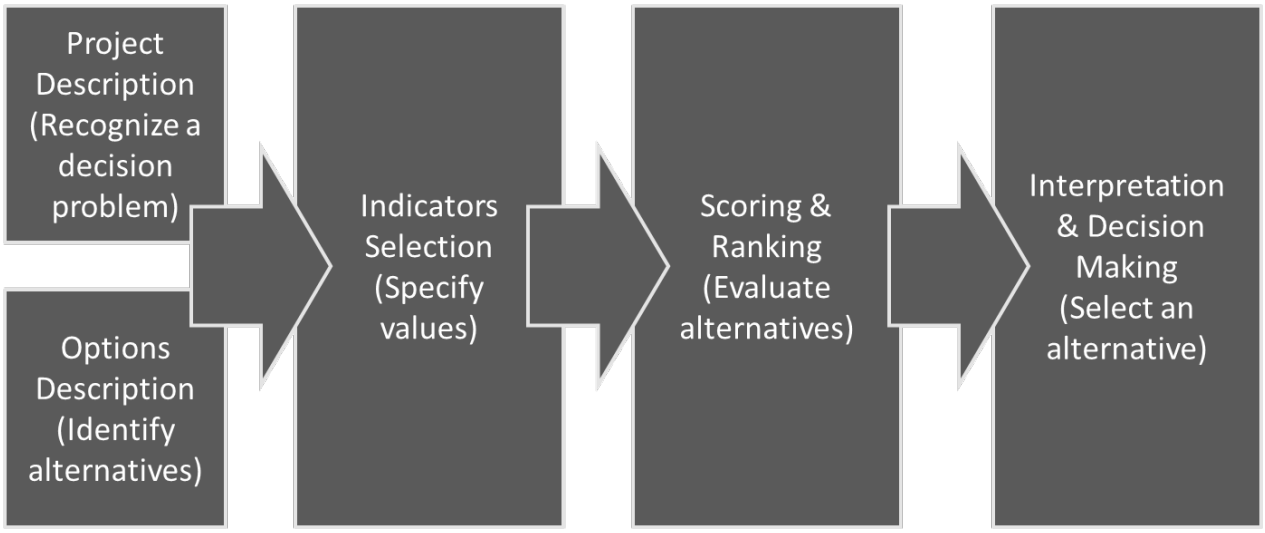
Literature has indicated it may be appropriate to develop values prior to developing the options to be used to solve the problem (Keeney, 1992; 1994). It may be possible by rearranging the structure of the decision making process more alternatives / options become apparent. This is important as decision makers may limit their decision outcomes to a small group of possible alternatives. The elicitation of weights involves assigning various weights to different indicators to specify their relative importance to the decision and thus influencing the decision results of the alternatives / options that are being assessed (Hämäläinen & Alaja, 2008; Wang et al., 2009). Therefore as the weighting method is important in the decision process, other weighting method options may provide an alternative to the current GoldSET system.

The following four recommendations are the result of a review of the literature, other decision support software and the wastewater treatment case study.

6.1 Recommendation 1 – Revising evaluation process

From the literature review, Keeney (1992) suggest decisions be based on the values of the decision makers, known as value-focused thinking. Values will drive the development of the alternatives in an unconstrained setting. Currently the GoldSET model is structured in the alternative-focused thinking approach without any guidance on the development of alternatives. Therefore it is proposed the sequence of activities within the decision process used by GoldSET be altered to follow the value-focused thinking approach. Value-focused thinking would help to recognize and identify decision opportunities; to create better alternatives for decision problems; and develop a set of guiding principles for the company. The modification is illustrated in Figure 6.1, which outlines both the current GoldSET sequence and the suggested modified sequence.

(A)



(B)

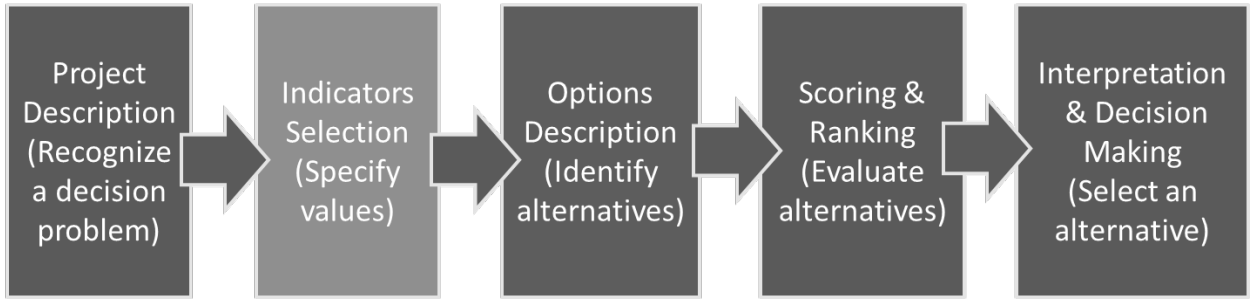


Figure 6.1: (A) GoldSET evaluation process – Structure based on alternative focused thinking; (B) Proposed value focused thinking structure (based on Keeney, 1992)

As inputs used in GoldSET are sensitive to the user of the program, there needs to be a review of the inclusion of the data, especially data such as the alternatives. Alternatives are a significant part of the decision problem structure and require effort and thought into their development. GoldSET currently does not have a process for developing the alternatives to be used by engineering projects. Alternatives are developed by the engineering team or user and

may be biased to one outcome. Therefore it is imperative for the decision maker when using decision support software to focus on the task and review why this is important. A decision support tool is used only to help the decision maker.

The value-focused thinking approach structure specifies values before alternatives development / identification. Keeney (1992) indicates it is necessary to qualitatively review and if possible quantify values. The qualified and quantified values are then used to develop alternatives. The purpose of restructuring this decision process is to increase the range of alternatives by removing any rooted (identified) alternatives. Once alternatives are developed then the evaluation and interpretation occur in a similar manner as the alternative-focused thinking approach.

As mentioned the overall goal of modifying the GoldSET framework is to increase the possible alternatives and not stifle the creativity used in alternative development. Such a shift may allow stakeholders to revise the alternatives.

An example within the case study would have been to develop the indicators, what stakeholders' value in the decision process, and prior to the development of the alternatives. The case study presented the alternatives based on the available processes and then defined these processes in terms of indicators. This is opposite to the proposed approach; where the indicators (values) would be required up front and then the corresponding alternatives would be developed afterwards.

Adelman et al. (1986) believe that there may be some differences in the value trees between top-down and bottom-up approaches. The top-down structure of value-focused thinking may

produce criteria that are general, which may be difficult to relate to particular options, whereas the bottom-up structure (alternative focused thinking) is focused on developing criteria relevant to the current problem however cannot be transferred to other decision problems (Morton & Fasolo, 2009).

6.2 Recommendation 2 – Computing an overall value for each option

GoldSET does not specifically determine the final decision outcome as this is the ultimate responsibility of the decision maker. However, how does the software aid the decision maker in removing options from consideration? There is a lack of description on the process. Currently, GoldSET decision makers are to carry out a sensitivity analysis of the weights, scores and indicators. The decision maker can then remove the suboptimal options from the decision process (i.e., unselect the option in the Project Description section) and reevaluate the options. This iterative approach can occur until the final outcome is agreeable between all parties.

A recommendation would be to create an overall parameter which would permit the comparison of options to one another. This overall decision parameter would be calculated from the three dimensions (environmental, social and economic) which would be weighted in a similar manner to the indicators and themes. The overall decision parameter would provide the decision maker another parameter to consider when for example Option A outscores Option B in one category while Option B outscores Option A in another category.

GoldSET displays the results showing the area on a triangle and a percentage attributed to each dimension for each alternative being considered. In review of the case study results, Option 3 outscored Option 4 in two of the three categories (i.e., environmental and economic).

Depending on the organization and stakeholders the social dimension may be higher priority. As such the social dimension may not have received the appropriate weighing level. A sensitivity analysis and iterative approach should be carried out to gain an understanding of the decision process; however an overall decision parameter could be helpful to the decision maker and provide another resource to assess the decision.

Another recommendation which may be of aid to the overall decision is to include a value path analysis – either running in the background or show visually to the decision maker. The value path visualization would aid decision makers by illustrating the higher level criteria (i.e., environmental, social and economic dimensions) and how they are related to one another. The percentages are similar to this aspect however by using value path visualization a decision maker can clearly see which of the dimensions is stronger than the other.

6.3 Recommendation 3 – Adding alternative weighting methods

As discussed in the literature review, weights are used within the MCDA process to represent the decision maker's preference. GoldSET uses a weighted additive sum of the individual criteria scores to rank decision options for each dimension. The current weighting system is very simplistic which ties into the overall strategy of GoldSET. GoldSET assigns weights based on a matrix of the Relevance to business and Level of concern to stakeholders. Each ranks criteria based on a low, medium and high scale. Using the matrix and weights assigned to both business and stakeholder involvement, the overall weigh of the indicator is a combination of both. GoldSET during the development of this report has updated the software to include a theme strategy which groups certain indicators together and allows different weights to be

assigned. This can be a very useful strategy for assisting decision makers in developing a greater sense of organization and stakeholder concerns.

A recommendation for the weighting method would be to include the swing weighting method as an alternative option to the current weighting system. The swing method represents the gain in overall value in going from the worst value to the best value in each criterion (Tholkala, 2011). According to Clemen (1996), the swing weighting method can be used in almost any weight-assessment situation. Using this method requires the decision maker to compare individual attributes directly by imagining hypothetical outcomes (Clemen, 1996). Swing weights have an advantage in that they are sensitive to the range of values of an attribute (Diakoulaki & Grafakos, 2004). The swing weighting method has been shown in research to be useful in most situations as it is simple, transparent, consistent, adaptable to the number of criteria and sensitive to impact range (Diakoulaki & Grafakos, 2004). Further assessment of the use of the swing weighting could be carried out to determine its effect on decisions as compared to the current weighting system.

Following up on the previous weighting recommendation, another recommendation is for GoldSET to provide alternative methods for developing the weights. This would provide another parameter to carry out a sensitivity analysis. This can be done by using the current method, and incorporating other methods such as the swing, trade off and AHP methods. As described in the literature review, the weighting methods have various strengths and weaknesses. It is understood that GoldSET strives to be simple and flexible; however allowing for other options in the weighting system increases the flexibility of the tool. Decision makers

would use alternative weighting systems to further provide themselves with greater confidence in the GoldSET decision output.

6.4 Recommendation 4 – Expanding the database of indicators selection / development

According to USEPA report (2012b), "… a sustainability indicator can be defined as a measurable aspect of environmental, economic or social systems that is useful for monitoring changes in system characteristics relevant to the continuation of human and environmental well-being." Indicator development is an important part of the decision making process and requires a great deal of effort to develop and refine so as to ensure that all aspects of the problem are captured. GoldSET modules provide a database of indicators decision makers are able to access and customize decisions. GoldSET users are also able to update the list with indicators derived from other resources. Besides GoldSET providing all of the indicators it is beneficial for the user to carry out additional research on indicators and other jurisdictions as to provide them with a sense of comfort in the indicators. The list of indicators is the foundation of the decision process and presents the ideas / thoughts of the stakeholders'.

Indicators can be project by project specific and it is important for stakeholder groups to discuss the significant (at least perceived) indicators for inclusion in the decision making process. The GoldSET software continues to develop the indicator selection and this is a significant step in keeping the software current. Guidance on the use of the indicators may be a next step for the developers, especially the development of a project specific indicator. Interestingly, USEPA (2012b) is working on an indicator database which will be developed as a web-based discovery tool. The tool will be used to allow users to create a customized list of

indicators using the data available, which is similar to GoldSET providing users to access indicators from other projects and create a project specific list.

Meadows (1998) states an environmental indicator becomes a sustainability indicator with the addition of time, limit or target. Building on Meadows statement, an indicator needs to have relevance to the decision and be able to separate between two project options. Indicators with the same resulting scoring / weighting need to be considered and possibly removed. One reason to keep such indicators in the decision process is for completeness and transparency as this allows stakeholders to observe their concerns within the process. This may be another area for GoldSET developers to consider as the software could identify these indicators and provide feedback to the user.

CHAPTER 7 Conclusions

Even though there is not a single accepted framework on how to incorporate the assessment / evaluation of sustainability in engineering projects (Brinkhoff, 2011), GoldSET provides corporations with a decision support tool that is simple and flexible based on a compensatory method to aid them with the goal of embedding sustainability within their engineering projects. Based on the literature, other decision support tools and case study, this Research Project shows the effectiveness of GoldSET in achieving its intended purpose; however the research process has allowed for recommendations on the structure and operations within GoldSET.

The GoldSET developers (as well as other MCDA software developers) have the difficult task of balancing between refining decision support tools for the goal of improving decision making with over complication of the decision making process. By increasing the level of complexity within the process a decision maker is not going to receive the help he / she desires; in fact the opposite is more likely true – confusion. Keeping an MCDA model efficient yet transparent and easily organized are the keys to aiding decision makers and stakeholders (even those against a possible decision). With the GoldSET model the modular set-up allows for the user to create a very basic model for a complex decision project. The purpose of MCDA is not to show the correct decision; however to improve decision makers understanding of risk, multiple criteria and conflicting interests (Linkov et al., 2004).

As mentioned in this Research Project, MCDA methods can be used in the decision support tools however they are not best used to derive the correct answer. Triantaphyllou and Mann (1995) state the search for finding the best MCDA method will always continue as

software is developed, and the continued MCDA research is a valuable to scientific and engineering applications. As has been seen in decision making research using MCDA methods can be very useful for decision makers and the development of GoldSET will be ever evolving as developers are in search of the decision support tool to provide insight into every decision and outcome.

APPENDIX – CASE STUDY

APPENDIX

Case Study Description

The detailed case study has PNKK Corporation (PNKK Corp.), which is a well-known metal plating company, currently treating its wastewater via limited settlement (in a containment tank not designed for balancing just holding) and dilution using fresh main potable water. The company is consistently exceeding the metal and Total Suspended Solids (TSS) permit limits. The local authority frequently visits the site and the community has the site high on their radar as neighbours have complained about odour, noise from truck traffic and visual impacts (trucks at night, unattractive building, etc.) from the site. PNKK Corp. has plans to increase production and its shareholders are a mix of reactive (nervous) and proactive (want to do the best) members who have different opinions on the site's impacts on the surrounding community and operation personnel. The workers at the site are generally positive but are concerned about the impacts of increased work requirements / obligations especially because of anticipated increased production levels. The Environment, Health and Safety (EHS) staff consists of one person who is stretched to meet the compliance and reporting demands.

Existing costs associated with operations and monitoring of the site are outlined in Table A.1.

Table A.1: Existing costs

Operations & Monitoring Costs	• Additional EHS staff – $60,000 / year • Water purchase costs – $30 000 / year • Waste Water Disposal Costs – $40,000 / year • Permit breaches – $100,000 / year • Chemical use in plant – $600,000 / year

Overall the site wants to improve on its current environmental standing by meeting the following objectives at the same time as being fiscally responsible:

- Minimize water use
- Minimize neighbours concerns
- Minimize solid waste produced
- Minimize material usage
- Achieve permit standards
- Keep their workforce happy and safe

In an effort to meet the above criteria the Facility has four options which the Facility personnel need to decide of which would best help them meet their objectives. Each option has various costs, duration, risks and benefits associated with it. The four options include the following:

Option 1 – Perform wastewater treatment

Focus is solely on minimizing regulatory problems (breaches of permit). Involves implementing a simple precipitation and settlement system so breaches should be limited to <20%. Alkali (NaOH) addition is to be used to precipitate out metals. The flocculant addition will allow the precipitate to be pressed. The press is to be used to remove water with the resulting solids disposed of at a landfill site. Costs associated with this option are outlined in Table A.2.

Table A.2: Option 1 Project Specifics

Project duration (before replacement)	• 20 years
Construction costs	• $300,000
Operations & Monitoring costs	• $2,000 / year for chemicals • Existing staff will need training to operate plant and uplift in salary for additional expertise – $10 000 / year • Water purchase costs – $30 000 / year • Waste Water Disposal Costs – $40,000 / year • Disposal Costs – $50,000 / year • Permit breaches – $5,000 / year • Chemical use in plant – $600,000 / year • Chemical use in WWTP – $50,000 / year

Risks

- Produce a hazardous solid waste which needs disposal (cost and risk)
- May be affected by either increase or decrease in production rates or poor monitoring / maintenance

- Requires building of a large Wastewater Treatment Plant (WWTP) which upsets local people and workforce as have to walk further (parking lot removed)
- Increases use of chemicals (for WWTP at this point)
- Does not minimize chemical use
- Does not really educate workforce on waste minimization / environmental issues
- Does not reduce water costs

Benefits

- Reduces pollutants in water leaving site and thus external environmental impacts (water quality, sludge production and disposal at receiving treatment works)
- Employ's one additional staff member from local community (hopefully)
- Makes local community aware that site is trying to improve environmental impacts

Option 2 – Perform wastewater treatment and implement a chemical management system

Implement a chemical management system to ensure appropriate use of plating process chemicals. Better chemical management should result in a reduced treatment requirement (process water should be within permit limits >90% of the time). Treatment of any out of specification water will be completed by precipitation, flocculation and pressing. Chemical automatic monitoring and dosing systems are to be implemented. Automatic rinse water recycling systems are to be implemented. Costs associated with this option are outlined in Table A.3.

Table A.3: Option 2 Project Specifics

Project duration	• 20 years
Construction costs	• $100,000 for dosing and rinsate return system • $150,000 for WWTP (smaller and more automation as better chemical management should reduce the need for significant treatment)
Operations & Monitoring costs	• Additional staff time to manage WWTP – $0 / year • Additional staff time for O&M staff – $5,000 / year – salary uplift • Additional O&M costs for dosing equipment – $3,000 • Water purchase costs – $10,000 / year • Waste Water Disposal Costs – $20,000 / year • Disposal Costs – $30 000 / year • Permit breaches – $100 / year • Chemical use in plant – $400,000 / year • Chemical use in WWTP – $10,000 / year

Risks

- Heavy reliance on dosing and monitoring systems means there is a need for significant staff responsibility for operational maintenance
- Additional cost for staff for O&M (Operations and Maintenance) of extra equipment
- Additional O&M costs for equipment
- Produce a hazardous solid waste which needs disposal (cost and risk)
- Some use of chemicals (for WWTP)

Benefits

- Minimizes chemical use
- High level of education of workforce on waste minimization / environmental issues
- Some reduction of water use and discharge costs
- Requires building of a smaller WWTP which will upset fewer local people and means parking lot is less affected, therefore fewer workforce having to walk further (still will require some additional parking off-site)
- Reduces pollutants in water leaving site and thus external environmental impacts (water quality, sludge production and disposal at receiving treatment works)
- Uplifts staff standing within local community (hopefully)
- Makes local community aware that site is trying to improve environmental impacts
- Less chemical use means less delivery truck movement

Option 3 – Perform wastewater treatment, chemical management system and metal recovery

Implement a chemical management system and a WWT system for out of specification water which incorporates a metal recovery system for significant metal wastes generated. Dosing systems for chemicals are to be used. WWTP incorporating separation of waters into single metal bearing wastewater streams. Recovery of metals to be completed using Reverse Osmosis (RO). Return of concentrated metals to production for reuse. Costs associated with this option are outlined in Table A.4.

Table A.4: Option 3 Project Specifics

Project duration	• 20 years
Construction costs	• $50,000 for dosing and rinsate return system • $300,000 for RO system
Operations & Monitoring costs	• Additional staff time to manage WWTP – $0 / year • Additional staff time for O&M staff – $5,000 / year – salary uplift • Additional O&M costs for dosing equipment – $7000 • Water purchase costs – $5,000 / year • Waste Water Disposal Costs – $10,000 / year • Disposal Costs – $20,000 / year • Permit breaches – $0 / year • Chemical se in plant – $200,000 / year • Chemical use in WWTP – $10,000 / year

Risks

- Heavy reliance on dosing and monitoring systems means there is a need for significant staff responsibility for operational maintenance
- Additional cost for staff for O&M of extra equipment

- Additional O&M costs for equipment as RO systems required a higher level of maintenance and parts replacement
- Some use of chemicals (for WWTP)

Benefits

- Produces a solid material which can be used / sold as a resource – recycling of the contained metal. Some impact on environment from the recycling of metal "waste" but much lower than discharge / disposal impacts
- Minimizes chemical use
- High level of education of workforce on waste minimization / environmental issues
- Some reduction of water use and discharge costs
- Requires building of a smaller WWTP which will upset fewer local people and means parking lot is less affected, therefore fewer workforce having to walk further (still will require some additional parking off-site)
- Less chemical use means less delivery truck movement
- Reduces pollutants in water leaving site and thus external environmental impacts (water quality, sludge production and disposal at receiving treatment works)
- Uplifts staff standing within local community (hopefully)
- Makes local community aware that site is trying to improve environmental impacts
- Less chemical use means less delivery truck movement so less neighbour impacts

Option 4 – Redesign metal application process

Complete redesigning of the plating process to eliminate water treatment needs and manage chemical applications better. Dry application of metals following a solvent (100% recyclable) and dry (sonic) cleaning process. Air emissions are to be minimized by using a fully enclosed application process. Costs associated with this option are outlined in Table A.5.

Table A.5: Option 4 Project Specifics

Project duration	• 40 years
Construction costs	• $1 million
Operations & Monitoring costs	• Additional staff time for O&M staff – $5,000 / year – salary uplift • Water purchase costs – $3,000 / year • Disposal Costs – $10,000 / year • Permit breaches – $0 / year • Chemical Use in plant – $200,000 / year

Risks

- Customers may have to be educated that this process produces goods of the same quality than using the traditional wet application method
- Staff will have to be trained in new application method may reduce production capacity
- Additional cost for staff for O&M of extra equipment
- Education of neighbours so they understand dry application will not cause air pollution and thus other impacts

Benefits

- Minimizes chemical use
- Materials recovered from dry booths can be recycled – some impact on environment from recycling activity but much lower than discharge / disposal impacts and recycling of metal "wastes"
- High level of education of workforce on waste minimization / environmental issues
- Significant reduction in water use and elimination of discharge costs
- Does not require building of a WWTP so neighbours are happier and parking lot is not affected so staff are happier
- Eliminates pollutants in water leaving site and thus external environmental impacts (water quality, sludge production and disposal at receiving treatment works)
- Uplifts staff standing within local community (hopefully)
- Makes local community aware that site is improving environmental impacts

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GLOSSARY

AFCEC	United States of America Air Force Engineer Centre
AHP	Analytic Hierarchy Process
CN Rail	Canadian National Railway
CO_2	Carbon dioxide
CSR	Corporate Social Responsibility
DASEES	Decision Analysis for a Sustainable Environment, Economy & Society
EHS	Environment, Health and Safety
ESD	Education for Sustainable Development
GDP	Gross Domestic Product
GEMI	Global Environmental Management Initiative
GoldSET	Golder Sustainability Evaluation Tool
GRI	Global Reporting Initiative
GSR	Green and Sustainable Remediation
HIPRE	HIerarchical PREference analysis
IISD	International Institute for Sustainable Development
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
MAVT	Multi-attribute Value Theory
MCDA	Multi-criteria Decision Analysis

NaOH	Sodium hydroxide
NPV	Net Present Value
OSS	Open Source Software
O&M	Operations and Maintenance
PNKK Corporation	Paul, Nicole, Kai and Knox Corporation
RO	Reverse Osmosis
SMART	Simple Multi-attribute Rating Technique
SMARTER	Simple Multi-attribute Rating Technique Exploiting Ranks
SR	Social Responsibility
SRG	Sustainability Reporting
SRT™	Sustainable Remediation Tool™
TSS	Total Suspended Solids
UNEP	United Nations Environment Programme
US	United States
USEPA	United States Environmental Protection Agency
WITI	“Why Is That Important”
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant