System Analysis Perspectives: Lead-Acid Battery Recycling in British Columbia, Canada

by

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Abstract

This dissertation aims to use a system thinking approach to describe and evaluate the Lead-Acid Battery Recycling Program in British Columbia, compare it with other provincial regulated recycling programs and identify strategies on how it can be improved. The research is presented in the manuscript based format, comprised of four interrelated chapters. Following the introduction, chapter 2 describes a multiple regression analysis to assess how various factors identified by informed stakeholders have contributed to recycling rate in 14 transportation zones from 1995 to 2005. This study demonstrates that the existing recycling scheme ineffectively promotes recycling as it has achieved an average of 75% over the past 13 years with large fluctuations among transportation zones. The regression also shows that recycling rate of transportation zones are not highly influenced by LME lead prices and Transportation Incentive (which can be explained by the strong market power of the recycling plants responsible for setting up the price of scrap lead to which the collectors respond).

Chapter 3 identifies key components that influence the performance of varied recycling systems based on a comparative analysis of provincial recycling systems informed by expert interviews. In chapter 4, comprehensive evaluation criteria for the lead-acid battery recycling program is developed based on objectives and performance measures elicited through an extensive stakeholder consultation process with various individuals and organizations. Fundamental objectives identified by stakeholders include: reduce environmental impacts, reduce occupational health impacts, reduce net costs, increase equity in resource consumption patterns and increase systematic learning. In chapter 5, we use multiple criteria decision analysis (MCDA) to design and assess effective recycling strategies to meet societal objectives previously identified in the chapter 4. Recycling strategies were compiled using the results of chapter 3. The results reveals that the optimal policy for the lead-acid battery recycling system combines a return to retailer program financed through an advanced disposal fee included in the battery price in combination with increased plant or recycling capacity domestically. This research also provides relevant contributions to the refining and application of value-focused thinking and decision analysis methodologies.

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List of Abbreviations

BC: British Columbia

BCUOMA: British Columbia Used Oil Association

EPR: extended producer responsibility

FIRST: Financial Incentives to Recycle Scrap Tires

Fuel: fuel costs

GVRD: Greater Vancouver Regional District

LCA: Life Cycle Analysis

LME: London Metal Exchange

MDR: manufacturers, distributors and retailers

MoE: Ministry of the Environment

MMWR: Morbidity and Mortality Weekly Report

MWLAP: Ministry of Water, Land and Air Protection

OHS: Occupational Health and Safety

PCPSA: Post-Consumer Pharmaceutical Stewardship Association

Rec: Recyclers

RR: Recycling rate

TIPs: Transportation Incentive Payments

Transp: transportation capacity

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Co-authorship Statement

The main body of this manuscript-based thesis consists of four draft manuscripts (Chapters 2, 3, 4, and 5), which were co-authored by my research supervisors, Dr. Timothy McDaniels and Dr. Marcello Veiga. My role in these joint publications was to develop the research design, conduct the literature review, carry out interviews and questionnaires, perform the analysis, compile the results into presentable table and figures, propose discussion and conclusions, and prepare/draft individual manuscripts for submission.

Chapter 1 Introduction

1.1 Problem statement: recycling, the future of mining

Historically, lead consumption has not been driven by price, as it has not been easily substitutable by cheaper alternatives (Henstock 1996). There have been, though, changes in lead consumption patterns including declined use of lead in paints, solders, motor fuel and water systems (Henstock 1996). These changes have been driven by increasing awareness of the environmental and health impacts of lead which has increased costs and caused some retrenchment in the primary and secondary lead industry in early 80s (Henstock 1996; Roberts 2003)

However, lead consumption increased substantially in the past decade with growing population and the expansion of private vehicle ownership with associated consumption of lead-acid batteries. Although western world lead consumption fell 1.5% in 2002 over 2001 due to a fall in industrial battery needs, the demand for lead will likely remain high with the increasing demand for automotive batteries (Teck Cominco Limited 2003) and standby power generation. The lower cost of lead-acid batteries compared with nickel/cadmium equivalents makes them the more popular choices for most standby-power duties, and with the advent of maintenance free design this competitive position has been enhanced and will likely find progressively broader applications (Pierson et al. 1997; Rand 1997; Trinidad et al. 2001; Trinidad et al. 2003; Prengaman 2005; Soria et al. 2005).

On the other hand, the level of primary lead production has been decreasing with old lead mines reaching the end of their life (Ahmed 1996; Roberts 2003; Tsoulfas et al. 2003) followed by primary smelter closures in Europe (Teck Cominco Limited 2003). As a result, lead concentrate has shifted to China to feed their refinery capacity and growing domestic consumption (Teck Cominco Limited 2003).

In the Western world, secondary lead production growth has compensated for the declines in primary lead production in the past 20 years (Teck Cominco Limited 2003). Additional growth in consumption in the Western World will likely depend on secondary lead production, world lead prices and the discovery of new deposits.

Battery manufacture is the largest single end user of lead worldwide, responsible for 85% of total lead consumption in USA and Canada (Figure 1-1). In many industrialized countries, recycling of lead-acid batteries is considered as an appropriate response to reducing the environmental effects associated with landfill disposal, while also realizing the economic potential that could be achieved through recycling (Bied-Charreton 1993; Bernardes et al. 2004). Since there is a growing world demand for lead, in particular in rapidly industrializing countries, it is expected that battery recycling be seen as an increasingly important component in the production of lead.

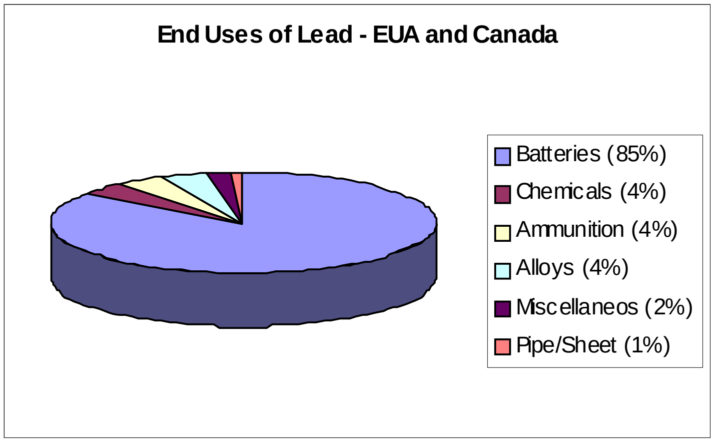

Figure 1-1: End uses of lead.
Source: (International Lead and Zinc Study Group 2004)

Economics aside, the recycling process itself also has the potential for creating environmental impacts and risks to human health and the natural environment (Robertson et al. 1997). The most notable environmental impacts include particulate and acid discharges into the atmosphere during the smelting and refining processes, discharge of contaminated industrial waste to water sources and the leakage of acidic electrolyte during battery storage (Dahodwalla and Herat 2000; Heino Vest 2002). The growing recognition of such impacts within communities, and by regulatory authorities, has been paralleled by the tightening of environmental protection standards and by higher environmental protection costs for recycling plants (Wilson 1993; Suttie 1995).

However, recycling scenarios gives overall environmentally better results regarding resources consumption, liquid effluent and solid waste than landfill disposal (Daniel et al. 2003). The United Nations Environment Programme (Technical Working Group of the Basel Convention 2002) confirms that an environmentally sound recycling system minimize overall environmental costs associated with lead exposures and potential landfill disposal.

In addition, established patterns of over consumption in industrialized countries, especially in Canada and the USA, have demonstrated to be among the most important threats to the natural environment and human health globally (McDonough and Braungart 2000). Every year 40,000 pounds of minerals must be provided for every person in North America to maintain our standard of living (U.S. Geological Survey 2002). The numbers above only include the refined final product and do not take into account the "ecological rucksack" of the metal, which measures how many kilograms of materials must be mined to produce one kilogram of waste product (Schmidt-Bleek 1994). For example, one kilogram of lead carries at least 15.6 kilograms of materials in its ecological rucksack. Given the current rate of consumption, many authors have begun to argue we are approaching the peak for metals (Bardi and Pagani 2007). According to Cohen (2007), copper has between 38 and 61 years left before depletion, indium (used in LCD monitors) has between 4 and 13 years, silver (used in catalytic converters and jewelry) has between 9 and 29 years, antimony (used in flame retardants and some drugs) has between 13 and 30 years, and lead has between 8 and 42 years.

Although many have questioned the imminent scarcity of metals (Radetzki 1975; Tilton and Lagos 2007), is the potential scarcity of resources the only issue? As populations continue to expand, more pressures are placed on natural resources (Ayres, 1997) and future shortages of non-renewable resources are not necessarily inevitable. In order to achieve sustainable development, we need to reduce our resource consumption and, at the same time, make sufficient environmental space available for the less industrialized countries when moving jointly toward ecological sustainability. Indeed, Wackernagel and Rees (1997) estimate that the ecological footprint of the average North American consumer is approximately 9.6 hectares per person - or five times the earth's biological capacity of 1.90 hectares per person. This is explained by the fact that 20% of the world's richest population is responsible for 86% of economic activities (Schmidt-Bleek 1994). Therefore, greater efficiencies in materials use, increased recycling, designing products for future recycling or reuse, and pollution prevention are important instruments for reducing the inequity in resource consumption patterns globally.

To attempt to turn this situation around, there has been increasing domestic and international pressure for extending life cycle management of products to consumers and producers (NRCAN 2000; OECD 2001) As a result, recycling programs have started to incorporate the principles of extended producer responsibility (EPR), which is the extension of the responsibility of producers and manufacturers for the environmental impacts of their products over the entire product life cycle – including take-back, recycling, and disposal. An effective recycling system is not only seen as an exercise of waste management but also an important element in materials efficiency (Subramanian 1997). However, in Canada, only 24% of the waste is recycled (NRCAN, 2004), although our per capita consumption rate is among the highest in the world (Friedland et al. 2003). Canada still lags behind Europe, United States and Japan in implementing national approaches for progressive life cycle management of products (Clapham 2004) and a national program recycling program for lead-acid batteries is yet to be implemented.

Many other countries have established national targets for the collection and recycling of scrap lead-acid batteries, ranging from 75% in Portugal to 100% in France (International Lead and Zinc Study Group 2001). Most countries estimate recycling rates at approximately 90% (Ahmed 1996; Subramanian 1997; Hagen 1999; Battery Council International 2005) but determination of precise rates is very difficult in practice. The conventional approach for calculating recycling rates implemented by some countries consists of dividing the number of batteries collected by the number of batteries sold (International Lead and Zinc Study Group 2001). This ignores the numbers of batteries imported or exported in vehicles and scrap, the numbers of batteries already in circulation and variations in battery life spans. In addition, performance evaluation is based exclusively on the percentage of battery collections, without taking into account the environmental, social and equity considerations. The challenge that lies ahead is to devise recycling policies and actions that will help society to optimize the efficient use of metal resources and stocks while at the same time reduce their environmental and social impacts. Lack of systematic data collection combined with the absence of adequate management tools make design and evaluation of these systems extremely difficult to accomplish. The objective of this dissertation is to address this gap using the context situation of lead-acid batteries in British Columbia, Canada.

1.2 Research aim and objectives

The aim of this study is to apply a systems thinking approach to evaluate and develop strategies for the lead-acid battery recycling system in British Columbia, Canada. In order to work towards this aim the following objectives have been set:

- To gain an understanding of the current lead-acid battery recycling, the performance of the system and the factors that contribute to the recycling rate

- To examine and compare key factors that influence the performance of government mandated recycling programs in British Columbia.

- To elicit a set of objectives that reflect the best recycling system for lead-acid batteries according to stakeholders' values and concerns

- To produce a list of performance measures to assess environmental, social and economic performance of lead-acid battery recycling systems

- To formulate and assess strategies to improve the lead-acid battery recycling scheme in British Columbia based on societal objectives.

- To understand the applicability of system analysis and decision analytical tools in evaluating recycling systems.

- To develop a decision model to identify better strategies for the lead-acid battery recycling in British Columbia.

- To widely disseminate the knowledge gained from this research, in order to assist in the development of effective future research, policy evaluation, practice guidelines, interventions and public policy for recycling systems.

1.3 Thesis overview

This manuscript-based thesis consists of four main chapters (Chapter 2, 3, 4 and 5) that are based on four manuscripts to be submitted to a refereed journal. The relationship among the chapters is illustrated in the figure below:

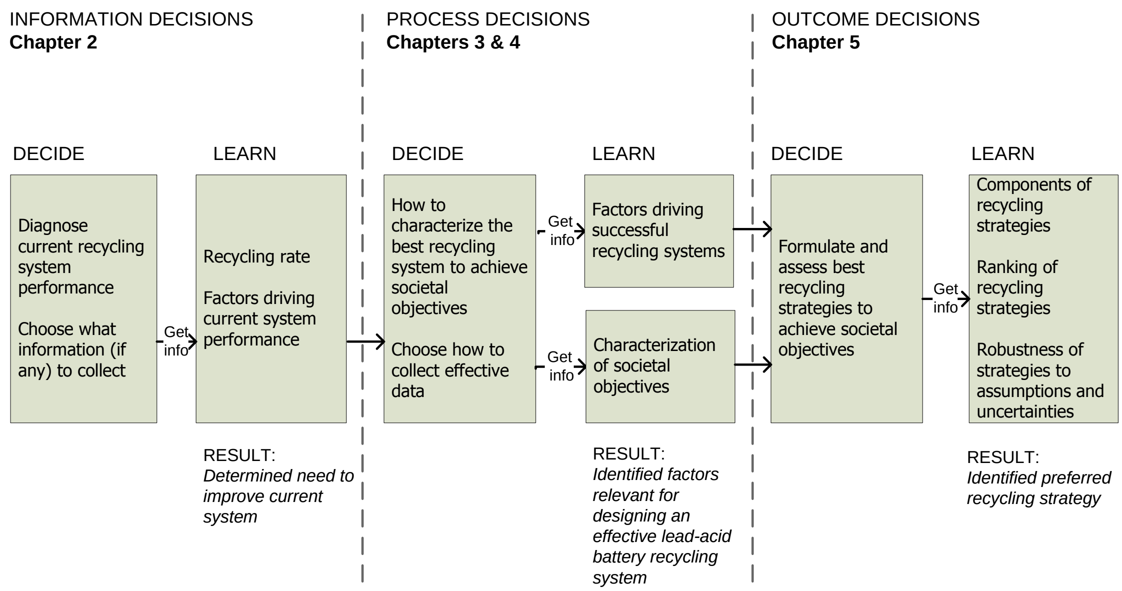

Figure 1-1: Relationship among chapters of this dissertation

Chapter 2: Information Decisions

Information decisions are pursued before making the outcome decision (Hammond et al. 2002). The first step for the decision maker is to understand the current context and choose what information (if any) to collect in order to characterize the problem and identify the decision situation (Clemen and Reilly 2002). With this concept in mind, the various influences within the lead-acid battery recycling system are first obtained from interviews and then used to guide the data collection to produce a multiple regression model of the recycling rate. The recycling performance of fourteen transportation zones in British Columbia, Canada is assessed from 1995 to 2005 based on a series of variables informed by stakeholders. These variables are then incorporated in a spatial econometrics analysis, which included several explanatory variables, including LME lead prices, fuel prices, and distance to the recycling plant, recycling plant capacity, presence of auto wreckers, scrap dealers and recycling depots (*recyclers*) and participation of manufacturers, distributors and retailers (MDR). The regression model investigated how these factors contributed to the collection and transportation of batteries in each of the transportation zones during the given period. The results reveal that despite recent increases in lead prices, the Lead Acid Battery Collection Program implemented by the Ministry of the Environment in 1992 has failed to sustain high recycling rates, with an average of 75%, with high fluctuations within zones located in remote areas and with low transportation capacity. General recommendations for improvement of the recycling system are discussed. These recommendations are then used as a basis for a policy analysis study presented in the subsequent chapters, aimed at developing performance indicators and investigating better alternatives to the provincial lead acid battery recycling system.

Chapter 3 & 4: Process Decisions

Process decisions are decisions concerning "how the decision is made rather than what decision is made" (Keeney 2004). This step in the decision analytical process focuses on *how* to identify relevant factors for designing and assessing an effective lead-acid battery recycling system. Getting a clear understanding of the objectives in a decision situation must be done before an outcome decision is formulated. Two approaches are used to address this question in the context of British Columbia: 1) identification of factors driving successful recycling systems in the province and 2) characterization of objectives that the public cares about in the particular situation of lead-acid battery recycling in British Columbia. Chapters 3 and 4 collectively address these two aspects. These chapters were produced concurrently over the course of this dissertation and the order presented in this manuscript does not necessarily reflect relative priority. The aim here is to collect effective data for later formulation and assessment of better strategies for the lead-acid battery recycling program.

In Chapter 3, a qualitative system analysis of all mandated recycling programs in British Columbia is presented. A literature review is then conducted based on publicly available literature followed by expert interviews with managers of the stewardship agencies. Influence diagrams were used to guide the interview process and collect information on various factors that affect the performance of recycling systems. The compiled results provide a conceptual framework that illustrates the general factors which play a role in all recycling systems (revenue direction, producer responsibility, transportation network, public awareness, consumer access, design for the environment, and operating practice of collection sites) and context specific factors that vary according to the type of product and its logistical network (ease of siting, capacity of processing plants, consumer incentive, transport incentive, environmental and health impacts). The lessons learned from existing provincial recycling systems in British Columbia provide useful information on the types of elements that shape the nature of complex systems as well as incentives and behaviours that are more likely to drive system performance.

Objectives should reflect what is important to those whose views must be considered in a decision situation (Keeney 1992). In chapter 4, objectives and performance measures for the current lead-acid battery recycling program in British Columbia are structured using value-focused thinking. Stakeholder objectives were elicited through interviews and site visits with manufacturers, recycling plants, auto wreckers, scrap dealers and retailers in 22 municipalities across the province. Multiple objectives that emerged during the interview process are organized into a means-end objectives network. This hierarchical framework is structured to represent stakeholders' values for better recycling strategies and to address occupational health and safety, economic costs, equity in resource consumption patterns, environmental and health impacts and continual learning. This chapter presents the use of value-focused thinking as an effective tool for evaluating recycling systems, which usually involve multiple stakeholders with a variety of potential conflicting objectives. Often, a careful examination of objectives can reveal alternatives that are not obvious at the onset. This methodological framework also provides an applied guide for creating objectives and performance measures for recycling systems in general taking into consideration societal objectives.

Chapter 5: Outcome Decision

With the decision situation and objectives well established, we turn to the modelling of the outcome decision, i.e. the formulation of alternatives to address the specific concerns and operational context of the lead-acid battery recycling system in British

Columbia. In chapter 5, multi-criteria decision analysis is used to produce a multiple objective model to evaluate policy alternatives for lead-acid battery recycling in British Columbia. The model ranks alternative scenarios from the decision maker's perspective based on how well they meet stakeholder's objectives. Objectives used to compare alternatives include concerns for health and safety, environmental impacts, direct economic costs, as well as equity concerns (geographical, intergenerational and financial). Overall, the model provides policy makers with a decision tool to make better decisions when evaluating and designing recycling programs. The results shows that the current program failed to meet society objectives and the overall framework provides an effective tool to assess the best strategy for the lead-acid battery recycling program in British Columbia.

The summary table below reflects the linear arrangement of this dissertation and includes the research questions and the main contributions of each chapter.

Table 1-1: Research questions and main contributions

Chapter title	Research Questions	Main Contribution
Chapter 2: Spatial econometrics analysis of the lead-acid battery recycling rate in BC	What was the recycling rate of lead-acid batteries in BC from 1995 to 2005? What were the factors influencing the recycling rate during this period? How did the following factors influence the recycling rate in 14 transportation zones from 1995 to 2005? ❖ LME lead prices ❖ fuel prices ❖ distance to the recycling plant ❖ transportation capacity ❖ presence of auto wreckers, scrap dealers and recycling depots ❖ participation of manufacturers, distributors and retailers	Identification of main factors contributing to the recycling rate in the current lead-acid battery program
Chapter 3: Learning across complex recycling systems in BC	What are the main factors that contribute to the overall performance of recycling systems in BC according to managers of stewardship programs? How can mental model interviews contribute to the identification of these factors?	Identification of key factors driving system performance in varied recycling programs in BC
Chapter 4: Structuring objectives and performance measures for the lead-acid battery recycling system in BC	What are the fundamental objectives which should guide the evaluation of the recycling system? What are the performance measures that effectively measure the achievement of these objectives? How can value focused thinking contribute to the identification of fundamental and means objectives for recycling systems?	Identification of objectives and performance measures which reflect stakeholders concerns
Chapter 5: Multi-criteria decision analysis of the lead-acid battery recycling system in BC	What is the strategy for lead-acid battery recycling system that best meet societal fundamental objectives? How can decision analytical contribute to the development and assessment of strategies for recycling systems?	Formulation of recycling scenarios; Performance assessment of recycling scenarios & Identification of preferred alternative

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Chapter 2 Statistical Analysis of Zonal Recycling Ratios[1]

2.1 Introduction

Lead-acid batteries are by far the largest single use of lead today, accounting for 75% of world lead consumption (Roberts 2003). According to recent forecasts, it is estimated that demand for lead will continue to increase at a rate of 1.5-2% per year due to growing demand for lead-acid batteries (MMSD 2001; Daramic LLC 2006). North America has the largest lead consumption in the world, accounting for nearly 30% of the worldwide use (MMSD 2001) and most of this high demand has been sustained through the increasing role of secondary production (Amistad 2006), made possible by the high recyclability of lead (Henstock 1996; Sagar and Frosch 1997).

Decreasing levels of primary lead production with old mines reaching the end of their lives (Ahmed 1996) and the growing concern over the environmental and health effects of lead have also led many countries, such as the USA (Battery Council International 2005), Norway (Hagen 1999), Sweden, Germany, Japan, France and United Kingdom (Ahmed 1996; Subramanian 1997) to accomplish high recycling ratios of over 90% for lead-acid batteries.

For the minerals sector to contribute to sustainable development, the use of its products must be considered as part of mining and mineral processing activities. Effective recycling schemes, which make use of fewer resources and minimize waste have long been identified as a prominent strategy for improving materials efficiency and access to mineral resources (Ayres 1997). With the growing demand for metals, particularly in rapidly industrializing countries, recycling has gradually increased as an important component in the production of metals (Legarth and Alting 1995).

As a result, governments have started to design and implement national programs for progressive life cycle management of products, through regulations such as take back laws and deposit refunds. Canada still lags behind Europe and the United States in implementing such programs (Clapham 2004) and a national program for lead-acid batteries is yet to be developed. However, British Columbia (BC), one of the most

[1] A version of this chapter will be submitted for publication.

populated provinces in Canada, has taken the lead and initiated a lead-acid battery collection program in 1991.

The BC Collection program was implemented by the BC Ministry of Environment[2] with the aim of ensuring that all scrap lead-acid batteries are transported to battery processors for recycling. The program is funded through a five dollar levy on each new battery sold, and is charged to the consumers. Its rationale is to subsidize transportation of batteries to two regional recycling plants, Metalex Products Ltd. and KC Recycling Ltd. (BC Ministry of Environment 1998). The Ministry of the Environment pays registered brokers Transportation Incentive Payments (TIPs) which fluctuate inversely to the London Metal Exchange price of metal. The levy-TIPS program design is similar to an Italian scheme introduced in 1990 (Ahmed 1996).

It is not clear that the existing recycling scheme effectively promotes recycling as there has been limited data gathering on the number of batteries collected over the period of operation of the program. The BC Ministry of the Environment reports on the number of batteries subsidized annually, but the total number of batteries recovered as well as the recycling ratio have not been established prior to this study. In addition, the transportation incentive payments (TIPs) have been calculated monthly based on a cost-revenue model, which was designed in 1991 and was last updated in 1995. Due to recent increases in metal prices, TIPs are practically nonexistent for most regions at present so current collection and transportation rely predominantly on domestic market forces. Previous studies have concluded the price of scrap lead is only loosely related to the LME price and is more influenced by the supply of scrap batteries (Valdez 1997; CRU International 2001; MMSD 2001).

It is essential that the evaluation of recycling schemes recognizes and examines the wide variety of variables influencing the complex system of recycling (Zhang et al. 2006; Gomes et al. 2008). Evaluation is also crucial to learning from experience in an adaptive management sense (McDaniels and Gregory 2003; Linkov et al. 2006), which enables the maximization of the broad societal benefits of recycling. Due to the complex nature

[2] The former Ministry of Water Land and Air Protection (MWLAP) was replaced by the Ministry of Environment in June 2005. Throughout this document the term Ministry of Environment is used for activities carried out by MWLAP.

of recycling schemes, several authors have developed evaluation methods adopting a systemic approach towards evaluation of efficiency of recycling performance in different jurisdictions (Grant 1999; Spengler and Schroter 2003; Shih et al. 2006; Tam and Tam 2006).

This study also uses a systems approach to examine the recycling efficiency of the provincial lead-acid battery collection program from 1995 to 2005 and to investigate how a series of variables elicited from informed stakeholders have contributed to the collection and transportation of batteries in each of the transportation zones defined in the Lead-acid battery collection program.

The chapter is organized as follows: section 2.2 discusses the design of the lead-acid battery collection program established in 1991 and currently operated by the Ministry of the Environment. Section 2.3 describes data collection and the methodology for building a multiple regression model to evaluate the level contribution of potentially important factors to the recycling ratio. Section 2.4 describes the structure of the model, and is followed by section 2.5, in which the results of the multiple regression analysis are presented. A concluding discussion is provided in Section 2.6, where recommendations for the Lead-acid battery collection program in British Columbia, Canada are presented.

2.2 The Lead-acid battery collection program in British Columbia

In British Columbia, the Ministry of Environment is responsible for developing recycling and product stewardship initiatives (BC Ministry of Environment 2004). As previously mentioned, in 1991, the Ministry of Environment introduced the Lead-Acid Battery Collection program in order to ensure that all scrap lead-acid batteries are transported to battery processors for recycling (BC Ministry of Environment 2004). The program is operated by the Ministry and its main rationale is to provide financial assistance for transportation of lead-acid batteries to recycling facilities during periods of low lead prices. More specifically, the Ministry of Environment pays registered collectors and brokers Transportation Incentive Payments (TIPs), which are set on a monthly basis and are based on the London Metal Exchange (LME) price of lead. TIPs vary for each of the transportation zones defined on the Battery Zone Map (Figure 2-1) to account for differences in transportation costs. Fourteen transportation zones were derived from eight geographic areas established by the BC government and are referred to by letters A through I. When the TIPs model was designed, the Cariboo, Skeena and Omineca-Peace regions were subdivided into smaller zones due to their large geographical size. Each zone has one or two regional centers, from which the majority of the used lead acid batteries are transported within the zone (Figure 2-1).

The TIPs formula was designed to compensate for lower scrap values when lead prices are low. In the TIPs formula described by equation (1), $Cost_g$ refers to the recycling costs for transporting a tonne of scrap battery from a particular zone to the closest recycling plant. $Cost_g$ is calculated for each zone in $CAN/tonne, based on the following costs: used battery purchase; load assembly at collection point; long distance hauling to a recycling plant; handling; breaking; smelting; and a 10% profit factor for assembling and hauling (Appendix A). *Net scrap value* refers to the price paid by the recycling plants for each tonne of scrap battery and is not dependent on the characteristics and location of the transportation zones. *Net scrap value* is based on the assumption that the price of scrap lead (set up by the recycling plants) fluctuates according to LME lead prices and is therefore adjusted monthly according to LME lead prices (Appendix A). Equation (1) reveals that, if *costs* are held constant, TIPs are high when LME lead prices are low, and vice versa. This formula assumes that a higher LME lead price would increase *net scrap value* for collectors and transporters and thus would provide adequate compensation to cover overheads.

$$TIPs_g = Cost_g - \textit{Net scrap value} \text{ (CAN\$/tonne)} \qquad \textbf{(1)}$$

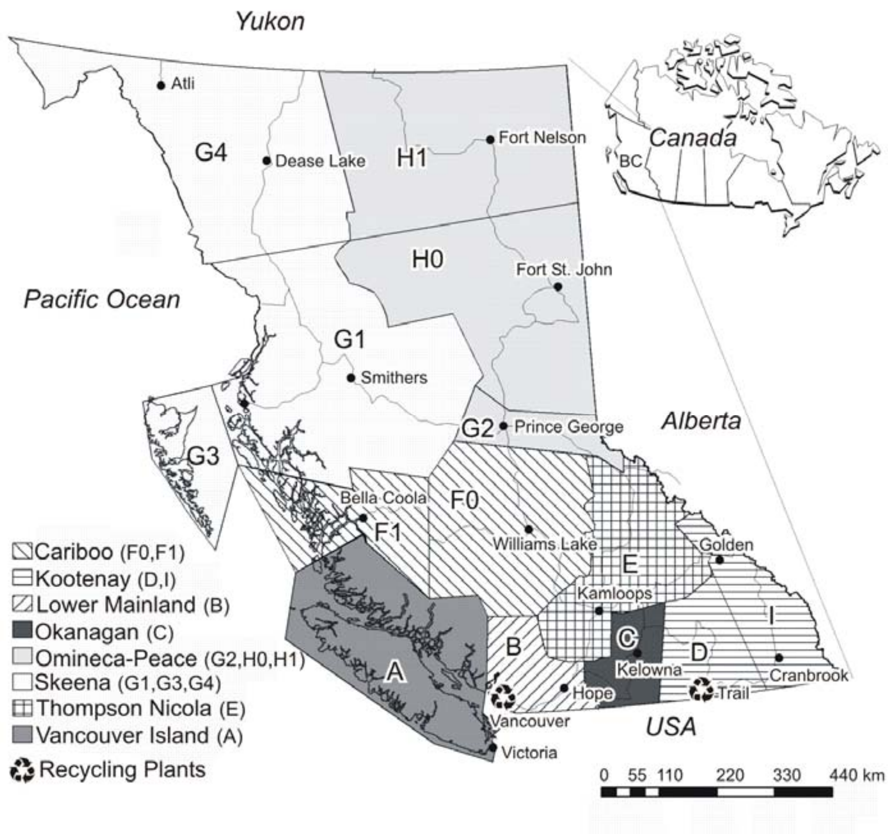


Figure 2-1: Battery Zone Map illustrating geographic areas and transportation zones

Since there are only two recycling plants breaking scrap batteries in the province and their capacity is fairly limited compared to the regional availability of lead-acid batteries, it is suspected that the price of scrap lead is only loosely related to LME lead prices and is more influenced by the market power of these plants. Therefore, despite recent increases in metal prices (Figure 2-2) the price of scrap lead set up by the recycling plant appears to be typically lower than LME lead prices. This issue is discussed in more detail in section 2.5.

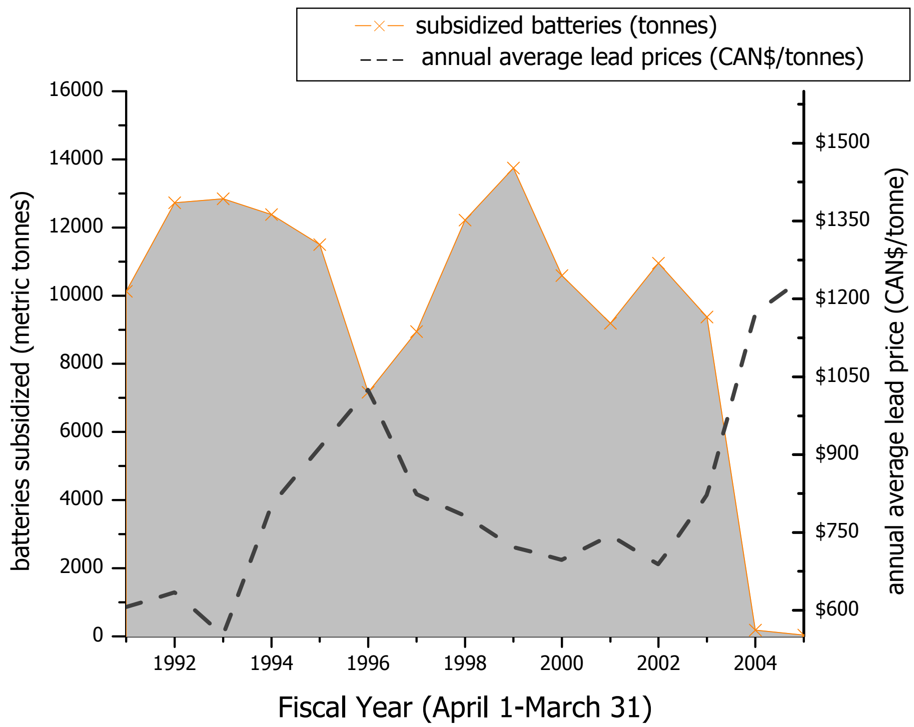


Figure 2-2: Total number of subsidized batteries compared to market lead prices

Transportation Incentive Payments (TIPs) were designed by Novatec Consultants in 1991 and the management of the program was turned over to the government in 1995 (personal communication, Novatec Consultants, August 2006). Since then, the Ministry of the Environment has consistently applied the algorithm to calculate the subsidy (Appendix A). The province of British Columbia reports only on the number of batteries subsidized (Figure 2-2) so there has been no reporting on recycling ratios since the implementation of the program.

There has been some criticism related to the revenue directed to the program. TIPs are funded through a CAN$5 dollar environmental levy charged to consumers on each battery sold at the point of retail. This levy is remitted with the social service tax and its revenue is entirely directed to the provincial Sustainable Environment Fund. During the operation of the program, TIPs payments to collectors have ranged from CAN$803 to CAN$1,486,829, while the provincial government has been collecting an average of $4Million/year from the environmental levy alone (BC Ministry of Environment 2004). The difference between the money collected and the incentives paid has been directed to fund other environmental protection activities in the province, not necessarily related to lead recycling or other heavy metal management program (Sucha Moore Associates 2002).

Unlike some programs in other jurisdictions (Ahmed 1996; Hagen 1999; Battery Council International 2003), the current program does not promote extended producer responsibility, i.e. the program does not require manufacturers, distributors and retailers to take part in the end-of-life management of their products. Therefore, the current collection scheme relies on voluntary participation of manufacturers and distributors and also on informal collection by auto-wreckers, scrap dealers, recycling depots, small businesses, regional districts and municipalities.

Given the existing context, a retrospective analysis using data collected from several sources was conducted in order to investigate how the Transportation Incentive Payment as well as other economic factors have contributed to the provincial recycling ratio from 1995 to 2005.

2.3 Interviews and questionnaires

This study is based on a mixed methods approach involving qualitative and quantitative methods. First, the weaknesses and strengths of the recycling system were identified during a series of interviews and questionnaires with stakeholders. Based on the insights obtained during this stage, a conceptual framework was established and guided extensive data collection through archival review, database search and publicly available statistics.

Initially, a subset of stakeholders involved with the recycling system were contacted and invited to participate in this study to answer questions regarding the main factors influencing the performance of the current system. Letters of contact and interview questions are available in Appendix F and Appendix G. Participants were identified from the list of waste generators provided by the Ministry of Environment in 2004. These stakeholders included scrap dealers, auto wreckers, recycling depots, retailers, transporters, producers and manufacturers, distributors and recycling plants.

All scrap batteries in the province are transported to one of the two recycling plants in the province, Metalex Products, located in Lower Mainland (zone B) and KC Recycling, located in the Kootenay region (zone D) (Figure 2-2). Metalex is a small scale combined battery recycling and secondary smelter with the capacity to process 4,000 tonnes of scrap battery/year. KC Recycling is a lead-acid battery recycling plant, which processes approximately 23,000 tonnes of scrap batteries per year, of which approximately 50% is supplied by collectors and transporters located in British Columbia. KC Recycling accounts for 83% of all scrap battery recycled in the province. Since KC Recycling does not have a built-in secondary smelting facility, all of its lead products are shipped to the nearby TeckCominco smelter, one of the largest lead-zinc smelting complexes in North America.

The relationship between all stakeholders involved in the lead-acid battery recycling system is illustrated in Figure 2-3.

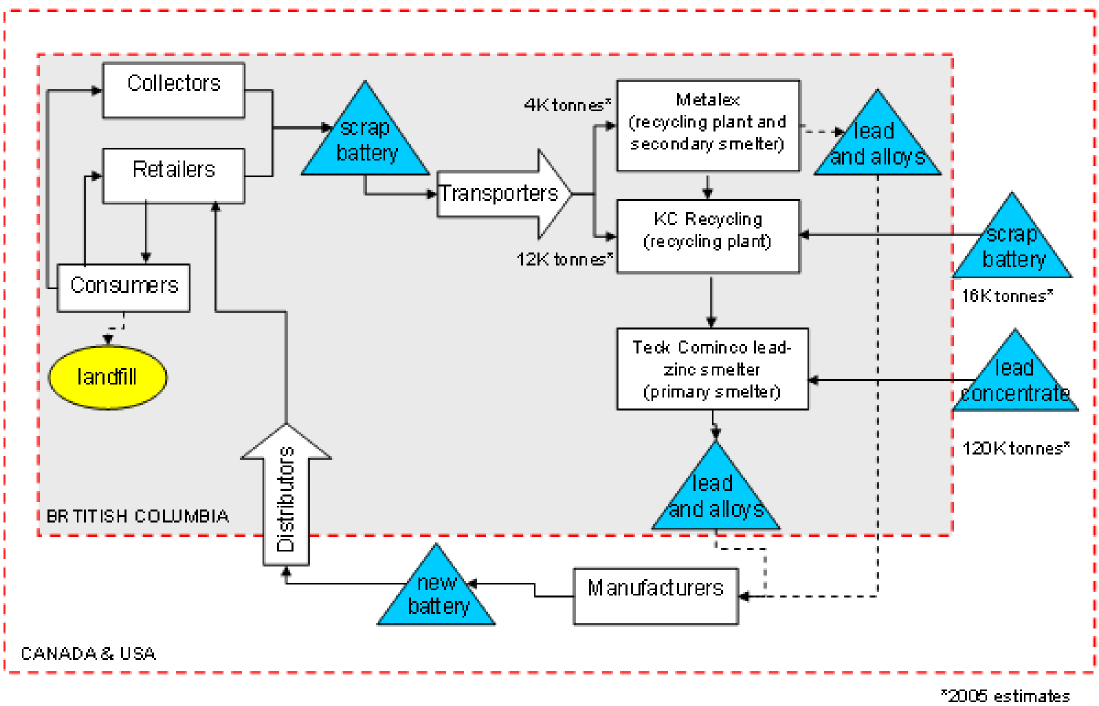


Figure 2-3: Diagram illustrating the lead-acid battery recycling system in BC

Fifty-four organizations operating in the province were selected to represent a variety of business types (Table 2-1). This sampling strategy was purposefully designed to consult with a range of stakeholders associated with different stages of the recycling system in British Columbia (Strauss and Corbin 1998).

Table 2-1: Sample of organizations contacted interviews and questionnaires

Organization category	**Involvement in the recycling process**	**Number of organizations contacted (% of total population)**	**Average volume of batteries handled per organization (2005)**
Manufacturers, distributors and major retailers (MDR)	Collection & transportation	14 (43%)	523 tonnes/year
Recyclers (auto wreckers, scrap dealers and recycling depots)	Collection & transportation	21 (10%)	96 tonnes/year
Regional Districts	Collection	12 (42%)	9 tonnes/year
Major transportation Companies	Collection & transportation	5 (36%)	1,345 tonnes/year
Recycling Plants	Collection, Transportation & recycling	2 (100%)	8,195 tonnes/year

A letter of introduction was submitted to each organization accompanied with the questions for the structured interview and a questionnaire. Stakeholders received a phone call within two weeks to schedule a 30 min to 1 hour structured face-to-face interview with the site manager. Thirty-eight interviews were performed on site. Municipalities located in Vancouver Island (zone A), Lower Mainland (zone B), Okanagan (zone C), Kootenay (zone D and I) and Thompson Nicola (zone E) were all included. In addition, seven phone interviews were conducted with organizations located in the Cariboo (zone F0 and F1), Skeena (zone G1, G3 and G4) and Omineca-Peace (G2, H0, H1) regions (Figure 2-1). The questionnaires solicited information on the amount and types of scrap lead-acid batteries handled by collectors and transporters. Site visits were very useful in providing contextual insight on the conditions of these facilities and the challenges faced by participants. The interviews also served as the basis for developing the objectives for the current recycling system which will be discussed in detail in the subsequent chapter.

The interview results were sorted into themes or categories to define the weaknesses and strengths associated with collection and transportation in the recycling system. The relative importance of each theme was determined by the number of respondents who referred to a particular theme. Figure 2-4 shows that the majority of the stakeholders (67%) contacted stated that Transportation Incentive Payments do not encourage recycling of lead-acid batteries. They also pointed out other challenges of the battery recycling system such as transportation costs, distance to the recycling plants, lack of extended producer responsibility (mandatory participation of manufacturers, distributors and retailers) and the low price of scrap paid by the recycling plants. On the other hand, the high price of lead in the past five years combined with the voluntary participation of some manufacturers, distributors and major retailers and a well-established network of *recyclers* (auto wreckers and scrap dealers) were identified as positive aspects contributing to the recycling ratio (Figure 2-5).

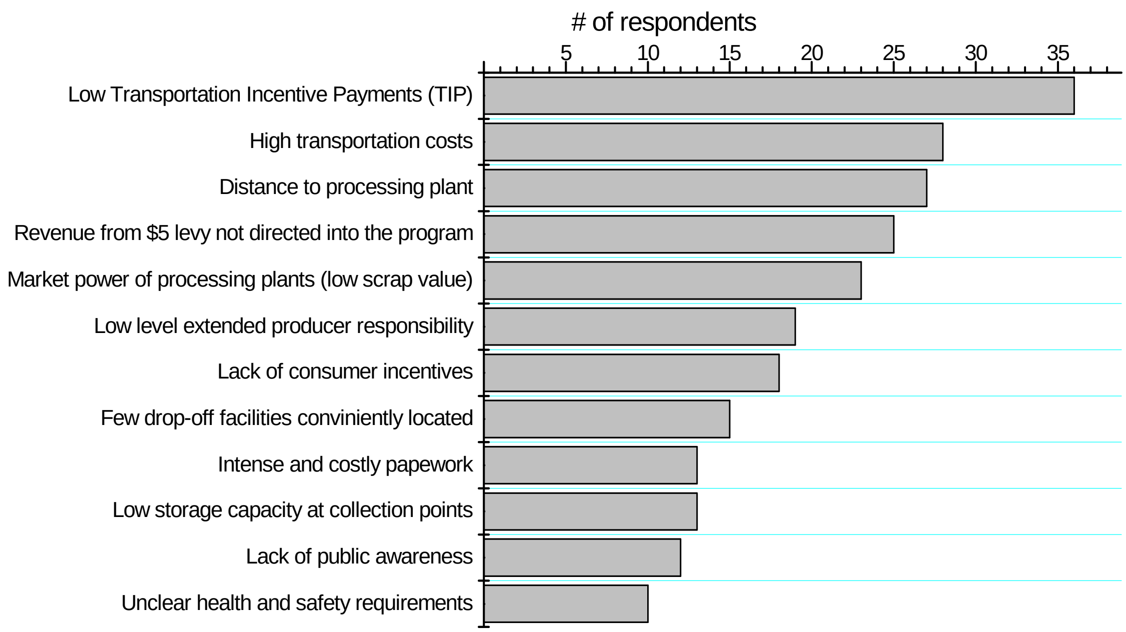


Figure 2-4: Weaknesses themes sorted by the number of respondents (n=54)

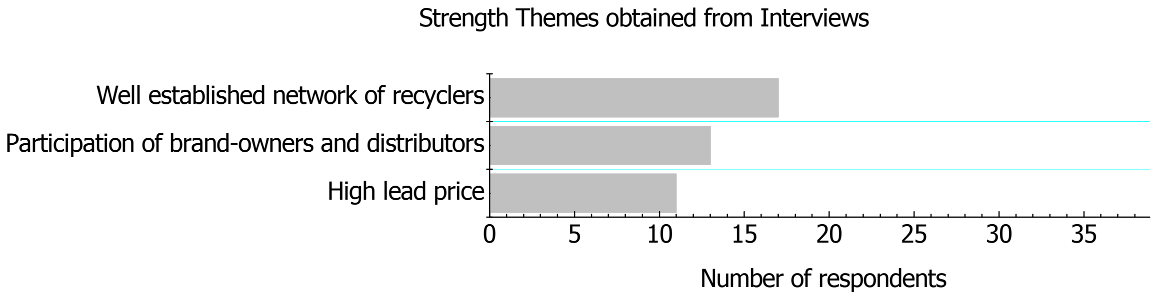


Figure 2-5: Strength themes sorted by the number of respondents (n=54)

Based on this preliminary analysis, an influence diagram was designed to highlight the major factors contributing to the collection and transportation of batteries to the recycling plants and to understand the relationship among these factors (Figure 2-6). Since our primary objective was to evaluate the efficiency of the collection system, we focused this analysis on the factors stated to be contributing to the recycling ratio. Other objectives such as environmental, health and social are addressed in Chapter 4.

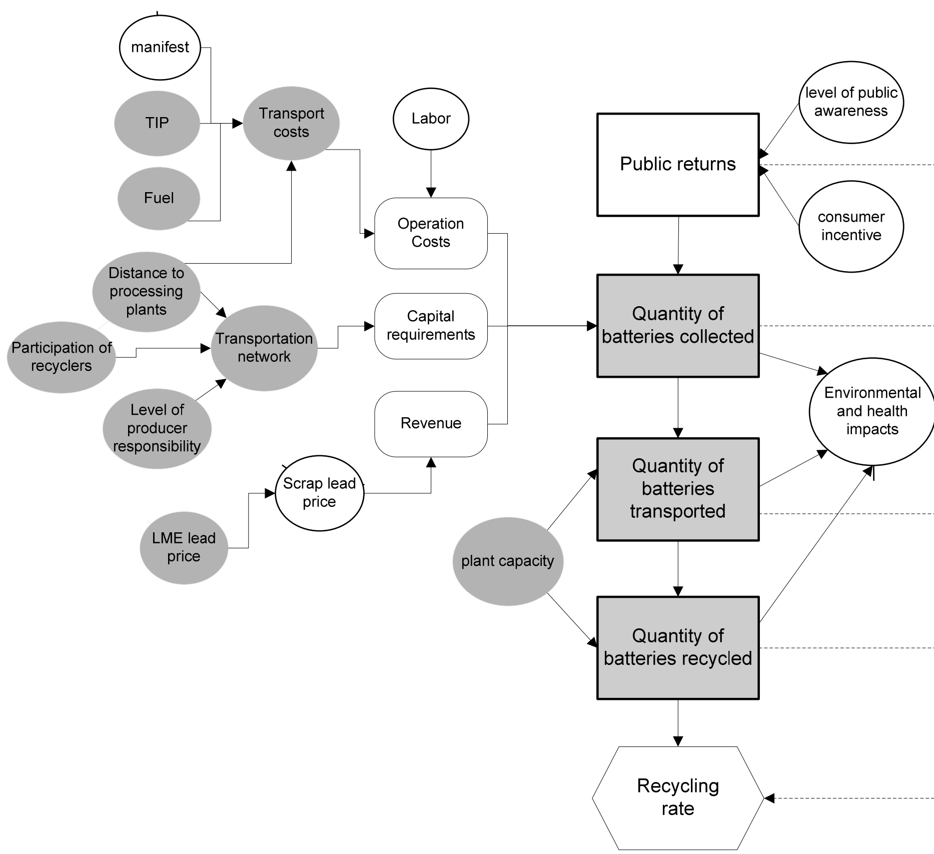


Figure 2-6: Influence diagram of the lead-acid battery recycling system

Since interviews were conducted between 2003 to 2005, the results of the interviews provided insights on the perceived weakness and strengths identified by a subset of stakeholders for a specific limited period of time. It is a perceptual model and may not identify considerations relevant to the entire period under study. A more comprehensive retrospective analysis of the lead-acid battery recycling system was therefore proposed, using this influence diagram as a conceptual framework for a regression model. The outcome variable was identified as the provincial recycling ratio and all of the other factors identified by circles were potential explanatory variables to be tested.

2.4 Model approach

The influence diagram (Figure 2-6) guided the data collection on the various factors contributing to the recycling ratio. The process of data collection for the measure of outcome variable and the explanatory variables is discussed below.

2.4.1 Recycling ratio as an outcome variable

The number or weight of lead-acid batteries recycled at any time plotted versus time is a time history whose slope at any time is the recycling ratio at that time. To obtain a comparable scale across transportation zones identified in Figure 2-1, we considered the number or weight of recycled batteries at time t relative to the number of batteries consumed during the same period. The zonal recycling ratio, $RR_{g,t}$, was therefore calculated by dividing the quantity of scrap batteries recycled from a given zone g during time t, $S_{g,t}$, by the number of batteries consumed in the same zone during time t, $B_{g,t}$.

$$RR_{g,t}(\%) = \frac{S_{g,t}}{B_{g,t}} \times 100 \qquad \textbf{(2)}$$

Since no information was readily available for calculating the recycling ratio, data on the number of batteries recycled in the province was obtained from two sources. Quantity of batteries recycled was defined as tonnes of battery collected and transported to the recycling plants. The weight of batteries collection and transportation from 1991 to 1994 were obtained from an archival search at Novatec Consultants Inc. in July 2006. Novatec Consultants Inc. designed and implemented the Transportation Incentive Model in 1991 and published annual reports on the provincial and regional recovery amounts for each fiscal year until 1994. They also kept a database with the amounts of transportation incentive payments paid to transporters and recycling plants. This information was retrieved directly from Novatec's electronic archives and did not require further cleansing. Information for the period 1995 to 2005 was obtained through a series of queries on a manifest database provided by the British Columbia Ministry of the Environment. Since scrap batteries are considered to be hazardous waste under the Waste Regulation, collectors and transporters are required to complete a form called a manifest in order to legally transport scrap batteries 1000 kg (approximately 55 automotive batteries) and greater. The manifest system enables the movement of scrap batteries within the province to be tracked and subsequently entered in a database, which contains detailed information on each individual shipment of batteries within the provincial boundaries, including the shipment date, the names of waste shipper, waste transporter, and waste receiver, the quantity of waste shipped and the quantity of waste received. The combined data set was cleansed of duplicates and typographical errors and each waste shipper was assigned a transportation zone according to its location (Figure 2-1). The quantity of scrap batteries recycled from a given zone during a month was then calculated by summing up all battery shipments from a given zone to both recycling plants, KC Recycling and Metalex.

The new battery consumption was estimated based on the consumption of major applications powered by lead-acid batteries. Historical data on passenger vehicles, commercial vehicles, and motorcycles from each municipality was provided by the Insurance Corporation of British Columbia. Figures on pleasure craft, fishing vessels and commercial vessels were obtained from annual statistics published by Transport Canada (Transport Canada 1991-2005). Due to availability constraints for data on other applications, such as general utility[3], aircraft and stationary batteries, these data were estimated based on their relative ratio to automotive batteries, according to the national recycling ratios studies published in the United States by Battery Council International (Battery Council International 2003; Battery Council International 2005). Since we acquired fairly reliable information on automotives and vessels, which are responsible for

[3] General utility includes applications such as floor sweepers, trolley cars and mine cars (Battery Council International, 2005).

at least 86% of the total annual consumption of lead-acid batteries, this method allowed us to obtain reasonably accurate estimates of battery consumption.

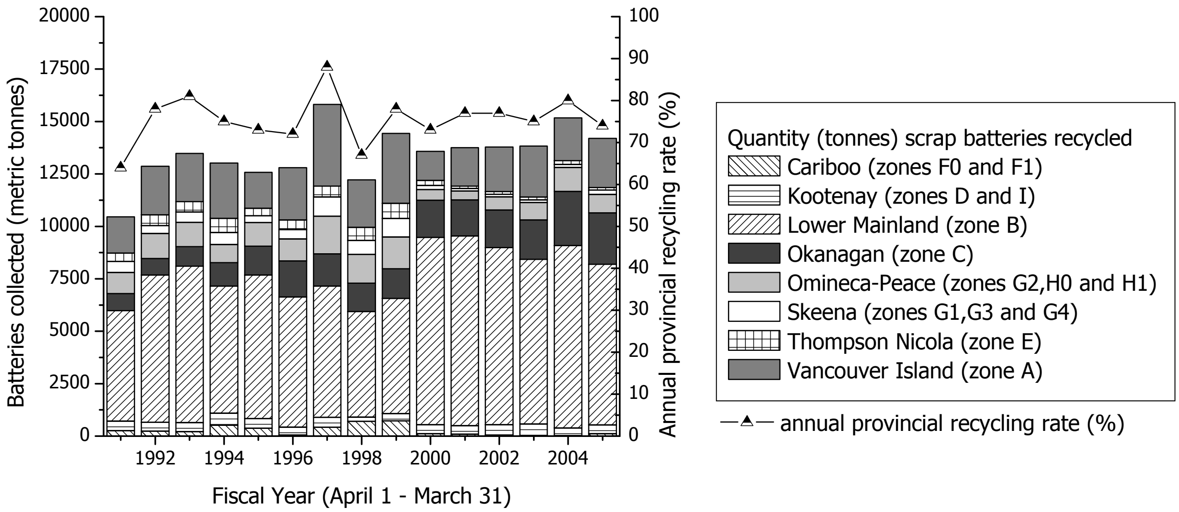


Figure 2-7: British Columbia collection rate and recycling ratio 1992-2005

After gathering all the data required, the recycling ratio was calculated by dividing the amount collected by the amount consumed. Figure 2-7 (above) shows the results of this exercise and illustrates the quantities of scrap batteries recycled in the fourteen transportation zones (combined into eight geographic areas), as well as the annual provincial recycling ratio from 1992 to 2005 (calculated based on a weighted average rate of all zones). This figure shows high fluctuations among most geographic zones, including those with higher population and that are relatively close to the recycling plant, such as the Lower Mainland and the Okanagan. It also reveals that the provincial recycling ratio varied from 64% to 88% between 1991 and 2005, with an average of 75%. The multiple regression model investigated and predicted the linear combination of explanatory variables that account for the variations in recycling ratio in each transportation zone.

2.4.1.1 Explanatory variables excluded from the model

All of the potential explanatory variables were identified in the influence diagram (Figure 2-6) but only those depicted by the grey circles were included in our analysis. Labour costs, manifest costs and scrap lead price were excluded from the regression model due to the limited variability in or absence of data. Labour costs have been nearly constant over time and across the regions and so we assumed it would not produce any change in the outcome variable. Administrative costs were also excluded for similar reasons. Manifest costs refer to the administrative costs to file a manifest, the form which enables the movement of batteries to be tracked in the province. Manifest costs were constant up to 2004, when filing costs increased from CAN$2 to CAN$14. Such changes, although substantial, are only valid for the last 15 out of 132 months of our analysis. This fact, in combination with the observation that, manifest costs are relatively small compared to fuel costs, which are included in the model, led to the exclusion of Manifest cost as a potential explanatory variable in the model.

A lack of systematic official data on the price of scrap lead, led to the exclusion of this variable from the model. Instead, LME lead prices were included, which served to test our hypothesis that the LME lead price has limited influence on the recycling ratio. Although *public returns* are not explicitly included in the regression model, the number of batteries returned by the public is captured by the overall *quantity of batteries collected*, since nearly all batteries collected by the organizations involved with the recycling business were originally obtained from consumer returns. For measuring the other variables, we used information provided in the Ministry of the Environment *manifest database* and publicly available statistics. Since the *manifest database* and provincial government agencies had limited information prior to 1995, we redefined the timeframe of our analysis from 1995 to 2005.

2.4.1.2 Explanatory variables included in the model

All the other factors identified in the influence diagram were included in the regression model. We first classified each factor as *zone specific* or *general. Zone specific* factors correspond to the situation where the effect varies within the transportation zones over time; while general factors capture generic spatial and population variations across the zones or temporal variations without zone specific effect. Participation of manufacturers, distributors and retailers (MDR), participation of *recyclers* (Rec) and Transportation Incentive Payments (TIPs) were treated as *zone specific* while London Metal Exchange lead price (LME lead), fuel costs (Fuel) and *transportation capacity* (Transp) were considered *general factors*.

2.4.2 Zone specific factors

2.4.2.1 *Percentage participation of manufacturers, distributors and retailers (MDR)*

Manufacturers, Distributors and Retailers (MDR) are not required by law to collect scrap batteries in British Columbia. However, some manufacturers and distributors such as Exide Technologies; Johnson Controls and Interstate Battery have implemented voluntary recycling programs to collect scrap batteries from retailers. This system is based on a private agreement between the manufacturer/brand-owner and the retailer, in which junk batteries are collected when new batteries are delivered to retailers. The retailer is therefore responsible for requesting old batteries from consumers at the time of purchase. As a result, these companies usually handle very large volumes of scrap batteries (Table 2-1).

The overall influence of MDR in the recycling system was measured by calculating the quantity (tonnes) of scrap batteries transported by manufacturers, distributors and retailers in each transportation zone g during time t, denoted $SMDR_{g,t}$. This data was obtained by selecting all shipments from MDR in the Ministry of the Environment *manifest database*. In order to reflect the relative size of the volume of scrap lead transported to recycling plants by these companies, this figure was then divided by $S_{g,t}$, the total volume transported to the recycling plants from each zone g during time t. This approach provided a convenient measure to indicate the zonal influence of voluntary participation of manufacturers, distributors and major retailers in the zonal recycling ratio.

$$MDR_{g,t}(\%) = \frac{SMDR_{g,t}}{S_{g,t}} \times 100 \qquad \textbf{(3)}$$

2.4.2.2 *Percentage participation of recyclers (Rec)*

Recyclers (Rec) are defined as any private organization participating in the collection of scrap batteries but not directly involved with their original chain of distribution. They are therefore excluded from the MDR category above, and primarily include auto wreckers, scrap dealers and recycling depots. These organizations are more widely dispersed across the province and have more limited storage capacity than the manufacturers, distributors and major retailers. Government organizations involved in the collection of junk batteries, including Regional Districts and municipal landfills were excluded from this category.

A similar measure to MDR was used for calculating the influence of *recyclers* in the provincial recycling scheme. All battery shipments included in this category were selected from the BC Ministry of the Environment *manifest database* and assigned to a transportation zone g. We then calculated the quantity of scrap transported by *recyclers* to the recycling plants from a given zone during time t, $SRec_{g,t}$, relative to $S_{g,t}$, the total transported from each zone g to the recycling plants during time t.

$$Rec_{g,t}(\%) = \frac{SRec_{g,t}}{S_{g,t}} \times 100 \tag{4}$$

2.4.2.3 Transportation incentive payments (TIPs)

Transportation Incentive Payments (TIPs) refers to the subsidy established under the Lead-acid Battery Collection Program in 1991. TIPs rates vary for each of the fourteen $zones_g$ and fluctuate monthly according to the London Metal Exchange price of lead. A simplified version of the TIP formula is represented by Equation 1 and its detailed algorithm was obtained during an archival search at Novatec Consultants offices in July 2006 (Appendix A). Since no modification has been made to the algorithm since 1995, it provided the necessary information to estimate TIPs monthly rates ($CAN/tonne) for each of the transportation regions from 1995 to 2005.

2.4.3 General factors

General factors do not capture specific temporal and spatial variations within the zones, but are still positioned as potential influences to the overall provincial recycling ratio. These factors are divided into two categories: factors that vary over time without any zonal specific effect; e.g. LME lead prices and fuel prices and factors that adjust for spatial and population differences across the zones; e.g. zonal *transportation capacity*.

2.4.3.1 Fuel prices (Fuel) and LME lead price (LME lead)

Fuel prices and LME lead price are considered *general factors* because they are constant for all zones and only demonstrate temporal variability. Fuel prices for British Columbia were obtained directly from the Statistics Canada Consumer Price Index (Statistics Canada 2007), which contains historical monthly indices for goods and services in British Columbia. The average retail prices for diesel fuel adjusted to 2005 dollars value were therefore included in the model.

Data on lead prices was gathered from the London Metal Exchange historical data (London Metal Exchange 2006). Like most metals, lead has been experiencing substantial price increases since 2002 (Figure 2-3). LME monthly lead prices adjusted to 2005 dollar values were included in the model. This factor was expected to help understand how lead prices affect the recycling ratio in the province.

2.4.3.2 Transportation capacity (Transp)

Although this factor measures a zonal characteristic, it is considered as a *general factor* because it did not investigate differences within the zones over time. Rather, it was included to adjust for the zonal capacity to sustain a systematic flow of scrap batteries to the recycling plant. The two recycling plants serving British Columbia, Metalex and KC Recycling, are located along the USA/Canada border (Figure 2-1), close to more densely populated areas. It was therefore expected that more remote zones, especially those in the Omineca-Peace and Skeena regions would experience more difficulties with proper collection due to the low per capita availability of scrap batteries combined with longer distances to recycling plants.

Hence, the *transportation capacity* factor was not exclusively based on distance, but rather reflects the interaction between the distance and the volume of batteries collected in each zone g. This factor was calculated by dividing the volume of batteries collected from each zone by the distance from collectors in the zone to the recycling plants, where the quantity of batteries collected was based on data from the BC Ministry of the Environment *manifest database*.

When computing the distance from the recycling plants, the zonal collection centre was used to represent a zone. The collection centre was identified as the municipality with the highest population and consequently, the highest availability of scrap batteries within the zone $_g$. Most of these municipalities are identified in Figure 2-1Figure 2-2 and all of them are listed in Table 2-2. Therefore, the distance measure does not incorporate an investigation of the distance effect within a transportation zone. This was considered undesirable as, in practice, the main source of the batteries collected is usually from one municipality within each zone. Moreover, for most zones the intra-zonal distances are a significantly shorter range that the distance to the recycling plants.

Accordingly, the *transportation capacity* factor is expressed as:

$$\text{Transp}_{g,t}\ \text{(tonnes/km)} = \frac{S_{g,t}}{r_{g,t}D_{g,Me} + \left(1 - r_{g,t}\right)D_{g,KC}} \qquad \textbf{(5)}$$

The denominator of the *distance measure* is not simply defined as the distance between a collection point and the closest recycling plant, (even though this is how it is calculated in the TIPs formula), since the closest plant may not have sufficient capacity for all batteries collected. To adjust for the fact that the batteries collected may not be taken to the closest recycling plant, the *distance measure* was expressed in the form of a weighted average, where $D_{g,Me}$ denotes the distance between the major collection centre of zone g and Metalex, $D_{g,KC}$ is the distance between the collection centre of zone g and KC Recycling, and $r_{g,t}$ is the proportion of batteries collected from zone g in month t that eventually went to Metalex. This approach also allowed the investigation of how plant capacity constraints influence the *transportation capacity* in each zone.

Table 2-2: Zonal population, main collection centre and distance to recycling plants

Region	Zone	Population*	Main collection centre	Distance to Metalex (Km)	Distance to KC Recycling (km)
Vancouver Island	A	751,992	Victoria	59	666
Lower Mainland	B	2,408,837	Vancouver	10	628
Okanagan	C	319,052	Kelowna	405	309
Kootenay	D	86,625	Trail	628	1
	I	59,296	Cranbrook	855	231
Thompson-Nicola	E	168,616	Kamloops	355	472
Cariboo	F0	62,190	Williams Lake	550	749
	F1	3,189	Bella Coola	996	1205
Omineca-Peace	G2	92,264	Prince George	785	987
	H0	58,264	Fort St. John	1237	1446
	H1	6,147	Fort Nelson	1598	1807
Skeena	G1	90,971	Smithers	1156	1372
	G3	4,935	Queen Charlotte	1697	1889
	G4	1,109	Dease Lake	1699	1964

*Source: 2006 Census Population – Statistics Canada

2.5 Validation

This study involved data collected from a variety of sources, including interviews, questionnaires, literature review, field notes, statistic reports and government databases. However, the study relied heavily on data retrieved from the Ministry of the Environment *manifest* database. Interviews, questionnaires and site visits provided very useful information for triangulation of data sources for the year 2005.

Still, in order to conduct a more complete assessment of the reliability of the dominant data from the MoE *manifest* database, all three plants involved in the recycling process (two recycling plants and one large scale smelting complex) were asked to make their historical battery intake records available for the period under analysis. Two plants agreed to provide the requested data and are referred in this section as plant A and plant B to ensure anonymity. Plant A provided its annual battery intake from 2002 to

2005 and plant B made its battery intake from 1999 to 2005 available. This information allowed the accuracy and reliability of eight continuous years of data extracted from the Ministry of the Environment *manifest* database to be tested.

A reliability score for the Ministry of the Environment data base was created (MoE reliability score) based on a ratio between figures reported by the Ministry of the Environment *manifest* database (MoE data) and the equivalent figures (tonnes) provided by each plant (plant data). More specifically, this ratio consisted of dividing the total annual scrap (tonnes) transported to a given plant through the *manifest* system (MoE data) by the total scrap (tonnes) recorded individually by the plant (recycling plant data). This method assessed the consistency of Ministry of the Environment database relative to the numbers reported by plant A and B.

$$\text{MoE reliability score (\%)} = \left(\frac{\text{MoE data (tonnes)}}{\text{recycling plant data (tonnes)}} \right) \times 100 \qquad \textbf{(6)}$$

Table 2-3: Reliability scores (%) of the Ministry of the Environment manifest database

Year	**MoE reliability scores (%)**	
	Plant A	**Plant B**
1999	Not available	103.21
2000	Not available	102.54
2001	Not available	98.27
2002	100	101.45
2003	95.55	101.85
2004	100.24	102.16
2005	103.79	99.22
Average	*99.89*	*101.24*
Standard deviation	*3.37*	*1.81*

Table 2-3 shows that *MoE reliability scores* relative to figures provided by plant A corresponded to an average of 99.89%, which means that the total amount of scrap to recycling plant A, tracked through the Ministry of the Environment database, corresponds to an average of 99.89% of the total reported by plant A (Table 2-3).

Comparable results were obtained for plant B, in which the MoE data achieved an average reliability score of 101.24% relative to figures reported by plant B. In addition, the *MoE reliability scores* relative to plant A and B also presented standard deviations of 3.37 and 1.81 respectively. These results confirm that Ministry of the Environment *manifest* database contains fairly accurate information with high reliability scores and low standard deviations, when compared to figures provided by two plants.

2.6 Model structure

With a quantitative measure for all the factors and the dependent variable quantified, we proceeded with the multiple regression analysis to estimate the location specific effects on the zonal recycling ratio. A fixed effect regression was used, in which intercepts in the regression model differ in each transportation zone. The existence of non-zero intercepts is a measure of the incompleteness of the model or the ability of the model to represent the recycling ratio.

The temporal unit of analysis was set monthly, producing 132 observations for each predictor, which is well above the minimum requirement (104 +6) for testing individual predictors in standard multiple regression with 6 predictors or explanatory variables (Tabachnick and Fidell 2001). This was also considered an adequate time step by 93% of the interview participants, who indicated that waste batteries are usually kept for less than three weeks due to limited storage capacity as well as legal requirements established in the provincial Special Waste Regulation. In fact, according to the Special Waste Regulation, collectors are not allowed to store more than 10 tonnes of waste batteries in a 30-day period. For remote zones with scrap battery availability below 10 tonnes per month, such as F1, G3 and H1, the analysis was performed with a yearly interval, since these zones transport an average of only 2.5 battery shipments annually.

As discussed, we classified the participation of manufacturers, distributors and retailers (MDR) and *recyclers* (Rec) as *zone specific* factors, while fuel prices (Fuel), LME lead price (LME) and *Transportation capacity* (Transp) as *general factors*. *Zone specific* factors account for differences within the transportation zones while general factors attribute to generic variations across zones or across time. Based on this assumption, here we consider one single model framework for the analysis of the recycling ratio of all zones.

$$RR_{g,t} = \alpha_g + \beta_{1g}MDR_{g,t} + \beta_{2g}Rec_{g,t} + \beta_{3g}TIP_{g,t} + \beta_4 Transp_{g,t} + \beta_5 LME_t + \beta_6 Fuel_t \quad \textbf{(7)}$$

Those regression coefficients denoted β above are *zone specific* if they contain a subscript g, the zone indicator; otherwise they are general coefficients. For each zone the recycling ratio was computed for each month of the period 1995-2005. This would result in 132 observations, but for an unknown reason there are no entries for the 8 month period Feb 2002 to Sept 2002. Consequently 124 observations are available for each of the 14 zones or a total of 1,736 observations. Corresponding values of the zonal and general factors were also computed. There were 59 coefficients to be determined, 56 (4×14) zonal coefficients and 3 general coefficients.

2.7 Model results

The initial model consisted of equation (7), in which the recycling ratios of the provincial transportation zones $g = A, B, C, D, ..., I$ were predicted using all explanatory variables. Zone G4 in northern British Columbia was dropped from the model because there were only 3 records of shipment of waste batteries in the database collected from this zone from 1995 to 2005.

The regression results were analyzed using a *backward stepwise method*. This method examines the variables in the model to see whether any should be removed based on their contribution to the outcome variable. If the removal of a variable makes no significant difference to how well the model fits the data, then the variable is excluded (Field 2000). Table 2-4 presents the regression results for the general factors: *transportation capacity*, LME lead price and fuel price. The columns report β coefficient estimates, standardized β coefficients, t-tests and *p*-values for each *general variable*. The results of the *zone specific* factors are presented in Table 2-5. The final row of Table 2-4 contains summary statistics for the regression model represented by equation (7). The results reveal that R = 0.940; R^2 = 0.883 and adjusted R^2 = 0.879. The R score indicates a very high multiple correlation between the predictors and the outcome. Similarly, R^2 and adjusted R^2 scores are nearly unity, demonstrating that the predictors are very good at predicting or explaining the values of the outcome variable in the sample of data on hand.

Table 2-4: Results of general factors of regression model presented by eq (7)

Outcome variable: recycling ratio

General Factors	β	**Standardized** β	**t-test**	***p*-value**	
Transp	0.020	0.141	10.743	0.000	***
Fuel	0.000	-0.161	-3.487	0.001	***
LME	0.000	-0.057	-0.670	0.503	

Summary Statistics

R= 0.940 ; R^2 = 0.883; adjusted R^2 = 0.879

The β coefficient estimates indicate the individual contribution of each factor to the model as well as the relationship between the factor and the outcome. The standardized version of β coefficient indicates the number of standard deviations that the outcome will change as a result of one standard deviation change in the predictor. Thus, the standardized β coefficients are not dependent on the unit of measurement of the factor and provide a better insight into the degree that each predictor affects the recycling ratio. The t-test associated with a β coefficient or standardized β coefficient measures whether the predictor is making a significant contribution to the outcome. If the t-test associated with a β coefficient is significant (p <0.05) then the predictor is making a significant contribution to recycling ratio. The smaller the p value and the larger the value of t, the greater the contribution of the factor to the outcome.

Table 2-4 shows that fuel price is a significant predictor of the recycling ratio (p=0.001) and its standardized β coefficient is negative (-0.161), suggesting that increasing fuel prices decreases the provincial recycling ratio. The *transportation capacity* (Transp) is also significant (p<0.001) and its standardized β coefficient (0.141) indicates that zones with higher *transportation capacity* achieve higher recycling ratios. These two results are supported by the interviews conducted in 2005 in which more than 50% of the respondents considered transportation costs and distance to the recycling plants as major weaknesses in the recycling system (Figure 2-4). As discussed in section 3.2.3, in this model, *Transportation capacity* was included in order to calibrate for specific characteristics related to zone location and population. On the other hand, the regression results revealed that the LME lead price is not statistically significant (p = 0.503), indicating that LME lead price is not a significant predictor of the recycling ratio. In fact, dropping LME lead price from the regression analysis did not compromise the overall performance of the other parameters (Appendix C).

Although the low contribution of LME lead prices to the recycling ratio may appear to be unreasonable at first, this result is corroborated by the interviews conducted in 2005, where 68% of the respondents stated that high LME lead prices were not entirely reflected in the price of scrap batteries set up by the recycling plants. In addition, sparce data collection on scrap lead prices in British Columbia from 1991 to 2006 revealed that scrap lead prices are not associated with LME lead prices (Figure 2-8). Participants indicated that scrap lead recycling was primarily driven by the limited capacity and strong market power of recycling plants. With the increasing availability of scrap batteries in North America and minimal competition, both recycling plants have acquired a dominant market position, which allows them to set up the price of scrap batteries well below LME lead prices. For this reason, recent increases in lead prices (Figure 2-2) are not necessarily reflected in the price of scrap lead established by the recycling plants.

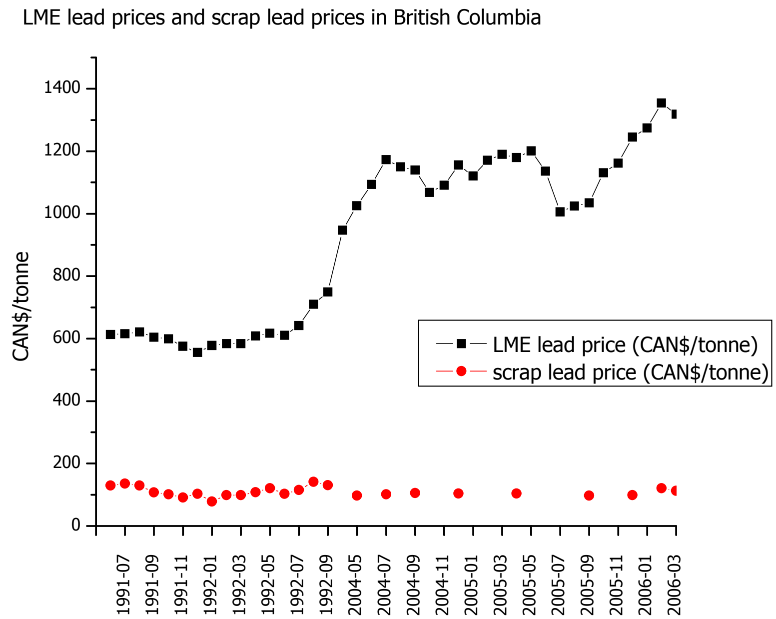
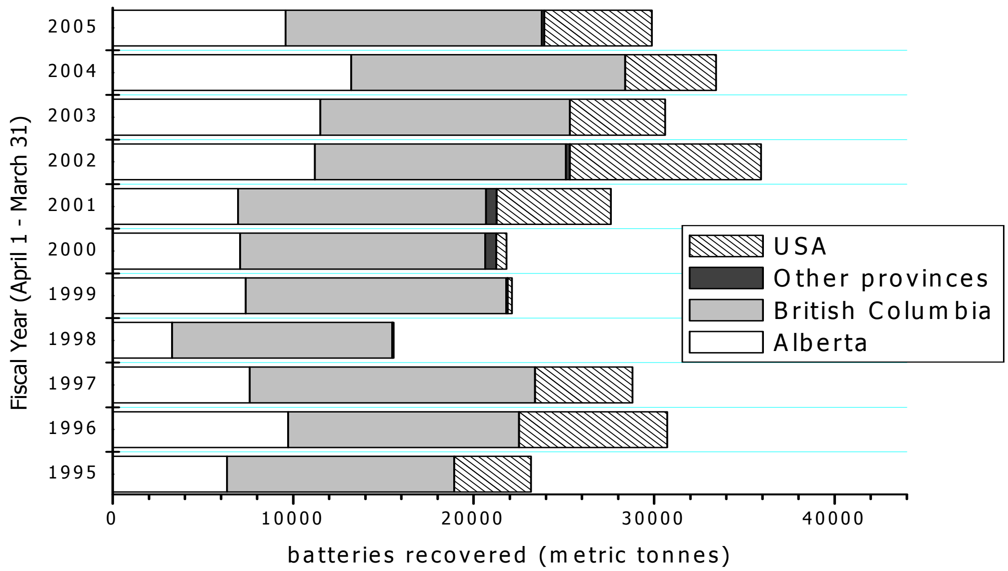


Figure 2-8: Price of LME lead prices compared scrap lead prices in British Columbia

Figure 2-9 shows that in the past 5 years, the total battery intake by both plants in the Provinces had a low of 28,000 tonnes and a high of 33,000 tonnes with growing shipments from Alberta and the USA. The provincial battery intake also experienced a retrenchment from 1998 to 2000 as it adjusted to a new smelter introduced at TeckCominco's plant, a large scale lead-zinc smelting complex located in British Columbia. Since nearly all lead supply from KC Recycling, the largest lead-acid battery recycling plant in British Columbia, is directed to the TeckCominco smelter (Figure 2-3) and the next closest lead smelter is located 2,400 km away, in Minneapolis, USA, any constraints at the TeckCominco smelter likely compromise the provincial battery recycling performance. In 2005, a four-month strike at the TeckCominco smelter also resulted in decreasing collection of batteries by KC Recycling for the same period.

This situation also suggests that marginal increases in scrap lead prices drive the collection of junk batteries from the USA and adjacent provinces to the recycling plants located in British Columbia, increasing competition for scrap batteries and reducing the overall collection in the province.

Figure 2-7 demonstrates that, despite the recent increase in lead prices, the provincial recycling ratio remains at an average of 75%, with considerable fluctuations across the zones.



Information compiled from the interprovincial manifest database provided by Alberta Environment, Saskatchewan Environment and Environment Canada, Waste Management Division.

Figure 2-9: Source of battery intake of Metalex Products Ltd. and KC Recycling Ltd.

The revised model excluding LME lead prices is rewritten in full form below:

$$RR_{g,t} = \alpha_g + \beta_{1g}MDR_{g,t} + \beta_{2g}Rec_{g,t} + \beta_{3g}TIP_{g,t} + \beta_4 Transp_{g,t} + \beta_5 Fuel_t \qquad \textbf{(8)}$$

This revised model, represented by equation (8) yielded results comparable to equation (7), despite the removal of LME lead prices. For *Transportation capacity* (Transp) and fuel prices (Fuel), equation (8) estimates indicates standardized β coefficients of 0.141 ($p < 0.001$) and -0.170 ($p < 0.001$) respectively, which are very similar to those presented in Table 2-4. Analogous results were also observed for the *zone specific* factors (Appendix C).

The standardized β coefficients for the *zone specific* factors of model represented by equation (8) are summarized in Table 2-5 and reveal some interesting results. First, the regional MDR factor, which measures the influence of manufacturers, distributors and retailers participation in each zone, demonstrates a positive influence on the outcome variable for eight regions, in which six have statistically significant coefficients (p<0.001). Similar results are observed for the factor measuring the zonal participation of *recyclers* (Rec), in which eight zones show statistically significant coefficients (p<0.001). Transportation Incentive Payments (TIPs), which measure the influence of the transportation subsidy in the outcome, do not demonstrate a dominant pattern of influence on the direction of the relationship between the predictor and the outcome. In addition, only two zones (G2 and H0), both located in Omineca-Peace, show statistically significant coefficients at 0.01 level and both of them denote a negative relationship between TIPs and the recycling ratio. Since these two regions are distant from the recycling plants, they have been able to redeem high TIPs only during low lead price periods or when the recycling ratio is low. For other regions, TIPs did not significantly contribute to the outcome and, as a result, a decision was made to drop TIPs from the analysis.

Altogether, 88% of the variability in recycling ratios was predicted by the zone coefficients in this model (equation 8).

Table 2-5: Standardized β coefficients of MDR, Rec and TIPs estimated from eq (8)

Standardized β coefficients

Zones	MDR	Rec	TIPs
A	-0.146	-0.109	-0.015
B	0.013	-0.009	0.008
C	0.127*	0.045+	-0.009
D	0.026+	0.010	-0.005
E	0.049***	0.137***	0.000
F0	0.143***	0.096***	0.010
F1	0.132***	0.040**	0.026
G1	0.054***	0.122***	0.003
G2	0.043**	0.035***	-0.072***
G3	n/a	n/a	0.000
H0	0.081***	0.112***	-0.060**
H1	n/a	0.166***	0.026
I	0.010	0.201***	-0.001

Regression estimated using panel data for 13 transportation regions from 1995 to 2005, described in Appendix C. The individual standardized β coefficient is significant at the +0.1 level; *0.05 level; **0.01 level or ***0.001 significance level. Notation *n/a* refers to variables with zero values which have been dropped from the model. R = 0.939; R^2 = 0.883;

2.8 The final model

A final version of the regression model is therefore proposed, in which LME lead prices and TIPs are removed, due to their limited contribution to the outcome variable:

$$RR_{g,t} = \alpha_g + \beta_{1g}MDR_{g,t} + \beta_{2g}Rec_{g,t} + \beta_3 Transp_{g,t} + \beta_4 Fuel_t \quad \textbf{(9)}$$

Table 2-6 displays the results of the revised model represented by equation (9), which are very similar to those presented in Table 2-5. Overall, no appreciable changes in other coefficients or in the overall reliability of R^2 relative to the previous models were observed. These results reinforce the fact that TIPs and LME lead prices have made a limited contribution to the overall recycling ratio in the province during the study period.

Table 2-6: Standardized β coefficients of MDR and Rec estimated from eq (9)

Zones	standardized β coefficients	
	MDR	**Rec**
A	-0.122	-0.093
B	0.030	0.003
C	0.120*	0.044+
D	0.024+	0.010
E	0.049***	0.137***
F0	0.146***	0.096***
F1	0.132***	0.028*
G1	0.055***	0.124***
G2	0.028+	0.024*
G3	n/a	n/a
H0	0.083***	0.166***
H1	n/a	0.147***
I	0.010	0.201***

Regression results estimated using panel data for 13 transportation regions from 1995 to 2005, described in Appendix D. The individual standardized β coefficient is significant at the +0.1 level; *0.05 level; **0.01 level or ***0.001 significance level. Notation *n/a* refers to variables with zero values which have been dropped from the model. R = 0.982; R^2 =0.964; Adjusted R^2 = 0.963

This model also confirms that *transportation capacity* (Transp) and fuel prices (Fuel) coefficients contribute positively to and are significant predictors of the recycling ratio (p <0.001). This explains why zones with larger populations such as Lower Mainland (zone B) and Okanagan (zone C) have been more successful in systematically achieving relatively higher recycling ratios than regions with lower populations, located in remote areas including the Cariboo (F0, F1), Skeena (G1, G4) and Omineca-Peace (H0) regions. However, zones G2 and G3 are exceptions to this rule and have been successful in achieving recycling ratios above the provincial average (Table 2-7).

Table 2-7: Zonal recycling ratio and BC recycling ratio from 1995 to 2005

Fiscal Year	% recycling rate of transportation zones and BC Transportation Zones														
	A	B	C	D	E	F0	F1	G1	G2	G3	G4	H0	H1	I	BC Total
1995	45	77	97	54	44	88	100	67	105	40	0	99	64	74	73
1996	71	63	78	40	56	15	86	111	108	56	0	104	60	68	72
1997	98	67	103	39	63	90	107	100	104	92	0	97	65	87	88
1998	57	53	90	27	73	95	100	100	105	86	0	102	100	27	67
1999	85	58	92	37	86	93	98	100	110	74	0	98	72	56	78
2000	36	96	122	58	29	27	41	56	96	75	0	83	67	34	73
2001	47	96	116	57	14	23	45	32	84	100	0	69	56	51	77
2002	47	81	113	79	18	7	41	29	108	76	0	34	50	40	77
2003	60	83	121	84	17	6	42	34	103	85	0	26	99	62	75
2004	50	91	132	51	23	6	28	42	101	82	0	51	101	44	80
2005	57	80	122	55	15	29	30	58	107	74	0	27	103	53	74

Region G2 (south of Omineca-Peace) has benefited from a network of *recyclers* and MDR in the region, which have been actively collecting junk batteries since 1995. Also, G2 was identified as one of the two regions which took advantage of the Transportation Incentive Payments during periods of low lead prices (Table 2-5). Another advantage, which may have favoured the performance of zone G2 is its small geographic size compared to other remote zones located in Omineca Peace and Skeena regions, such as G1, H0, and H1. This means that collectors in zone G2 have a much smaller territory to cover compared to most zones and its key battery source area is located close to Prince George, the most populated city in the Omineca-Peace region (Figure 2-1). As a result, it appears that zone G2 has been able to collect scrap batteries from adjacent zones and achieve recycling ratios slightly over 100% (Table 2-7).

Interestingly, zone G3 has also been able to maintain a relatively high recycling ratio (Table 2-7) despite the absence of MDR and *recyclers* (Table 2-8 and Table 2-9). Zone G3 consists of the Queen Charlotte Islands, an archipelago located in Northern British Columbia (Figure 2-1), more than 1,500km from either recycling plant (Table 2-2). Despite its remote and isolated location, the Queen Charlotte Islands have developed an effective recycling scheme organized and funded by the Skeena Queen Charlotte Regional District, which has been collecting junk batteries from consumers, small businesses and recycling depots located on the island. Despite the high costs of ferry transportation, the Regional District has been able to ship its junk batteries along with other recyclable goods inland and then transport them to recycling facilities located in zone B, Lower Mainland (personal communication, Queen Charlotte Islands Regional District, May 03, 2007).

Table 2-8: Percentage contribution of MDR in total scrap transported to recycling plants

Fiscal Year	Participation of MDR in total scrap transported from zone *g*/BC to recycling plants (%) — Transportation Zones: A	B	C	D	E	F0	F1	G1	G2	G3	G4	H0	H1	I	BC Total
1995	43	57	56	65	11	45	11	8	28	100	0	16	0	0	48
1996	46	61	56	1	8	39	0	15	36	0	0	30	0	0	50
1997	37	66	75	5	11	39	28	18	42	0	0	29	0	0	49
1998	52	66	80	44	38	40	0	18	28	0	0	36	0	0	54
1999	43	71	86	23	41	61	0	14	40	0	0	22	0	0	55
2000	45	62	87	77	1	71	0	0	85	0	0	0	0	0	61
2001	69	57	82	96	4	68	0	0	100	0	0	0	0	1	61
2002	63	70	76	48	0	0	0	0	45	0	0	0	0	0	65
2003	74	75	71	54	1	0	0	0	50	0	0	0	0	1	69
2004	82	80	77	60	11	0	0	0	51	0	0	2	0	2	73
2005	87	81	88	76	3	0	0	24	28	0	0	0	0	2	76

Table 2-9: Percentage contribution of Rec in total scrap transported to recycling plants

Fiscal Year	Participation of Recyclers in total scrap transported from zone *g*/BC to recycling plants (%) — Transportation Zones: A	B	C	D	E	F0	F1	G1	G2	G3	G4	H0	H1	I	BC Total
1995	56	35	44	0	86	30	24	19	55	0	0	66	100	94	42
1996	54	35	38	0	88	61	0	33	19	0	0	58	100	100	41
1997	62	32	25	53	88	37	0	38	12	0	0	62	100	98	43
1998	47	30	17	41	61	30	0	41	25	0	0	49	41	100	35
1999	53	25	14	42	56	19	0	49	30	0	0	34	92	100	35
2000	54	36	13	16	98	24	100	57	4	0	0	85	0	100	37
2001	31	42	17	2	95	32	0	49	0	0	0	82	0	94	38
2002	37	28	24	24	100	100	0	0	46	0	0	0	0	100	33
2003	26	24	29	42	99	100	0	31	45	0	0	100	100	99	29
2004	18	18	22	22	89	100	100	47	49	0	0	85	100	97	24
2005	13	15	11	21	97	100	100	65	72	0	0	100	100	98	21

Zone G1 (south of Skeena region) also has a low number of *recyclers* (Table 2-9) and MDR (Table 2-8), and has experienced a notable reduction in the participation of MDR since 1999. Since then, approximately half of the scrap batteries have been collected by *recyclers* (Table 2-9) and the other half primarily by the Skeena-Queen Charlotte Regional District located in Prince Rupert. Nevertheless, recycling ratios in zone G1 have barely exceeded 50% over the past 6 years. Except for zones G1 and G3 located in the Skeena region, the vast majority of the scrap batteries transported to the recycling plants are collected by the private sector, including *recyclers* and MDR.

It is suspected that the recycling ratios of zones D and I (both located in the Kootenay region), in which KC Recycling is located, are higher than the reported figures since small battery shipments below 1,000 kg do not have to be *manifested*, and therefore, may not have been included in the database provided by the Ministry of the

Environment. As a result, our regression model might not have captured all battery shipments directly transported to the recycling plant by consumers, small retailers and municipal landfills. In fact, during site visits to the Regional District of Kootenay Boundary, located in Trail (zone D), a substantial effort by the regional district to collect scrap batteries from the general public and small businesses was observed. For instance, the Regional District has established educational programs to inform consumers of locations for the return of scrap batteries, along with other recyclable materials, and these batteries are transported directly to KC Recycling.

Table 2-6 shows that zone A (Vancouver Island) and zone B (Lower Mainland) do not demonstrate a strong contribution of *recyclers* and MDR to the recycling ratio, as none of them present statistically significant β coefficients. However, region B, which represents 50% of the population of British Columbia and, consequently, the highest availability of scrap batteries in the province, has achieved recycling ratios over 80% since 1996 and there is a clear contribution of *recyclers* and MDR to the collection of scrap batteries in this region, seen in Table 2-8 and Table 2-9. Although region A has not been able to sustain similar rates, Table 2-8 and Table 2-9 also show that *recyclers* and MDR have both participated in the collection of scrap batteries in this region.

This apparent inconsistency can be explained by the fact that shipments occur at intervals less than one month and since we have sampled at one month, we may not be capturing the true behavior of the participation of MDRs and Recs. The oscillatory behavior is likely the reason the coefficients in Zones A and B are not significant. Despite the oscillations, there could be fluctuations in the participation of MDRs and *recyclers* over the short term. For example, five participants from Zone A and B indicated that *recyclers* and MDRs are competing for the scrap of small and medium retailers located in heavily populated areas of these two regions. These retailers may be accumulating scrap batteries over a period of time and eventually sell their batteries to MDR or *recyclers* that offer the best price. As a result, the participation of MDRs increases and the participation of *recyclers* decreases over the years. This pattern is evident in Figure 2-10 after 2001. The interaction between MDRs and *recyclers* might also explain the high anti-correlation (r = -0.992) between these factors. Therefore, although *recyclers* and MDR jointly contribute to the collection in these regions, the regression model was unable to explain their individual contribution to the recycling ratio. Similar situations have also been observed in regions B and C. Hence, the model cannot represent the recycling ratio for zones A, B and C except by fitting a non-zero intercept.

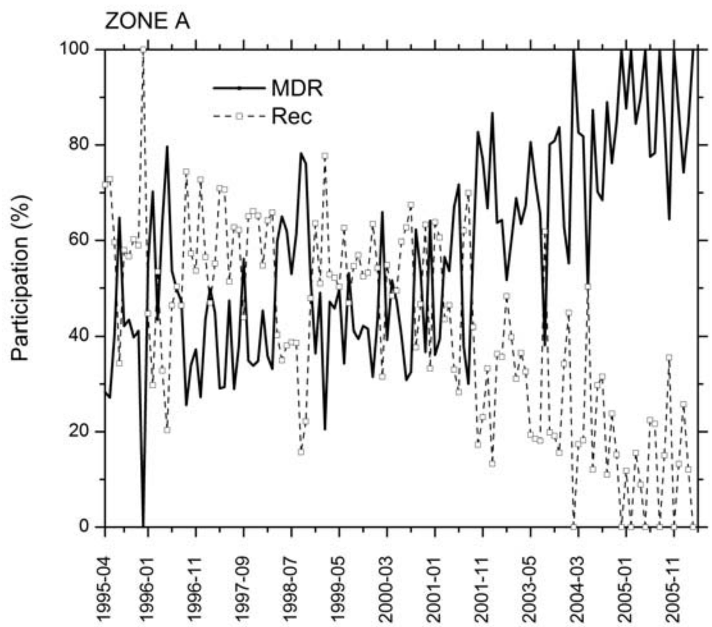


Figure 2-10: Contribution of MDR and Rec to battery collection in zone A

Conversely, the regression model indicates a strong contribution of MDR and/or Rec in regions F0, F1, G1, G, H0, H1 and I (Table 2-6). As a result, we observe a dominant pattern of participation of Rec and MDR in these regions for a continous period of time. For instance, figure 2-9 demonstrate the strong participation of MDR from 1995 to 2001, follow by a strong participation of Rec from 2001 to 2005. For this region, the regression model was able to explain the individual participation of these factors given the low coefficient of correlation between MDR and Rec in zone F0 (r =-0.02).

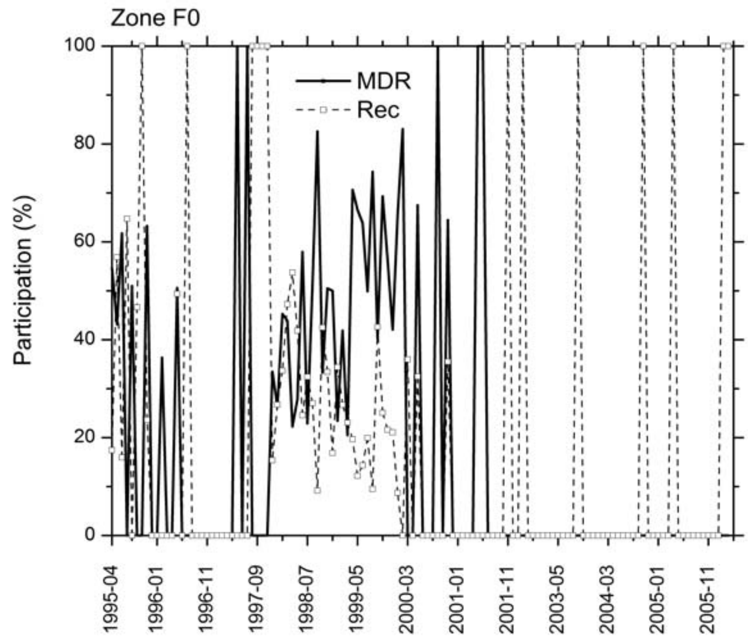


Figure 2-11: Contribution of MDR and Rec to battery collection in zone F0

The zonal recycling ratio of zone A (See Table 2-7) suggest that considerable volume of scrap batteries (40-53%) in this zone has not reached the recycling plants in the past 5 years. Some of these batteries may have been transported to the recycling plants without being manifested and therefore might not have been captured by the *manifest database* provided by the Ministry of the Environment. However, most batteries collected in this zone came from the most populated cities located close to the ferry terminals, especially Victoria, Nanaimo, and Port Alberni; which suggests that there is a need to improve the transportation network in less populated areas of Vancouver Island. There is also a potential for improvement in zone B since countries like the United States, Europe and Japan have successfully achieved overall recycling ratios of over 95% (Ahmed 1996; Subramanian 1997; Battery Council International 2005). This assertion is supported by a Waste Composition Study conducted in Lower Mainland in 2004 (GVRD 2005), which reported 914 tonnes of lead-acid batteries disposed of at the Greater Vancouver Regional District (GVRD) waste disposal facilities[4], which serve 85%

[4] The 2004 Waste Composition Study involved the analysis of a total of 139 samples of solid waste received at three facilities: the Waste to Energy Facility (WTE, Burnaby Incinerator), the Vancouver South Transfer

of the population in Lower Mainland (zone B). This figure accounts for roughly 53,000 battery units[5] or approximately 16% of all batteries collected within GVRD in the same year. Although the 2004 Waste Composition Study is difficult to compare to a previous study conducted in 2001[6], as it followed a different methodology, the results suggest that the total quantity of batteries in waste increased by 103% in 2004 compared to 2001 .

Current market conditions seem to favour zones with large population and close proximity to the recycling plants. Figure 2-12 and Figure 2-13 show histograms of the weight of battery loads transported by trucks to the recycling plants in 1995 and 2005. In 1995, 60% of the truck loads received by KC Recycling and Metalex were less than 6 tonnes, compared to 15 tonnes in 2005. The average truck load transported to KC Recycling and Metalex also increased from 8 tonnes in 1995 to 15 tonnes in 2005. Most of the small truck loads came from small collectors, especially small retailers, auto wreckers, scrap dealers and recycling depots. Table 2-9 confirms that *recyclers* have reduced their overall participation in scrap battery collection in the province over the years from 42% to 21%. This situation appears to have particularly affected the recycling performance of zones E (Thompson Nicola), F0 and F1 (Cariboo), G1 and G4 (Skeena) and H0 (Omineca-Peace), which have lower populations (Table 2-2) and rely heavily on the private sector for collection and recycling of batteries.

Station (VTS) and the Surrey Transfer Station (STS). The study was conducted from September 8 to November 9, 2004.

[5] The BC Lead Acid Battery Program (MWLAP 2004) uses 17.2 kg or 38 pounds as the average battery weight.

[6] The 2001 Waste Composition Study reported 449 tonnes of lead-acid batteries in waste at GVRD waste disposal facilities. This information is garnered from Appendix B. Data based on waste composition at two representative facilities (NSTS and Burnaby Incinerator) and the annual tonnages received at the eight waste disposal facilities in the GVRD.

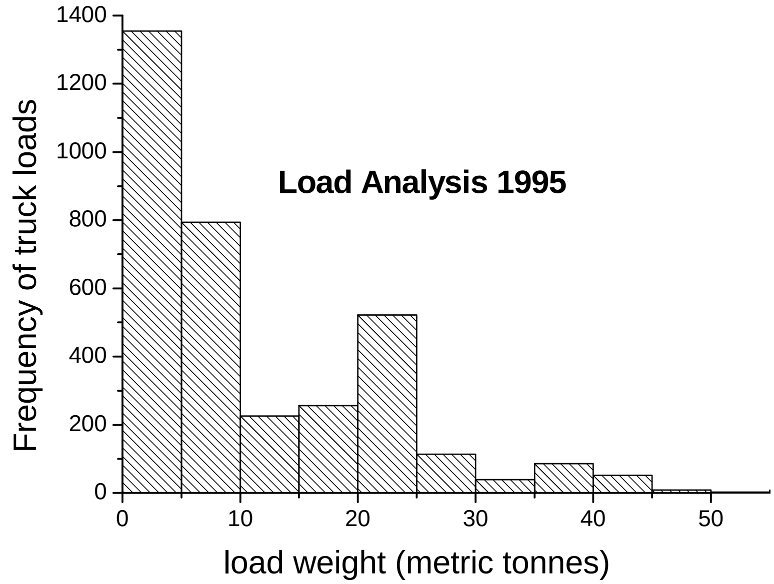


Figure 2-12: 1995 histogram of truck loads transported to
KC Recycling Ltd. and Metalex Produts Ltd.

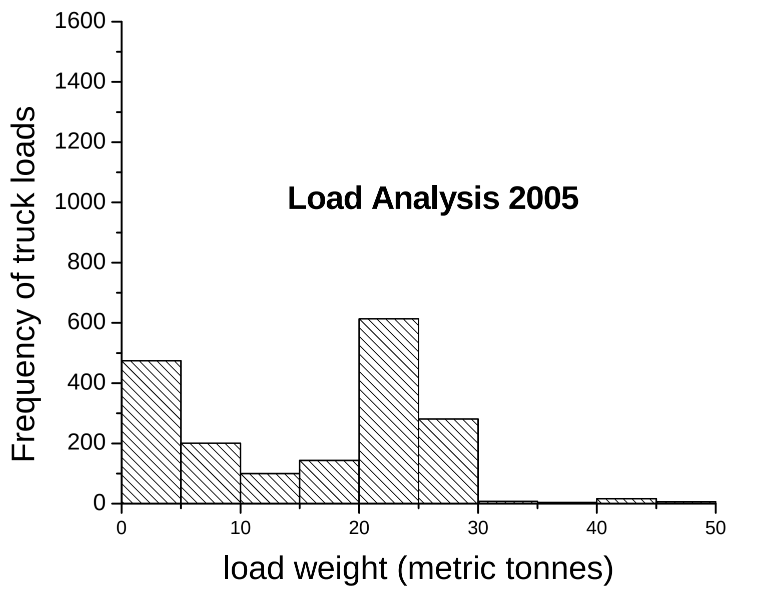


Figure 2-13: 2005 histogram of truck loads transported to
KC Recycling Ltd. and Metalex Products Ltd.

Moreover, the standardized β coefficients shown in Table 2-6 and results shown in Figure 2-10 and Figure 2-11 also reveal that MDR have a higher degree of contribution to the recycling ratio in zones A, B, C, D, F0, F1, G2, compared to *recyclers*. This indicates that the participation of MDR exceeded the percentage contribution of *recyclers* especially in more populated areas and in zones with relative proximity to the recycling plants. On the other hand, *recyclers* have outstripped the degree of contribution of MDR in zones E, G1, H0, H1, I (Table 2-9).

2.9 Conclusion

The regression model results parallel the results obtained from interviews in which the main weaknesses identified by stakeholders included: low Transportation Incentive Payments (TIPs); high transportation costs, distance to the recycling plant and market power of recycling plants (Figure 2-5). Their chief complaint was that the Transportation Incentive Payments failed to provide adequate incentives for collection and transportation of lead-acid batteries in most regions, a fact which was corroborated by the results of the multiple regression model. This subsidy was created based on the assumption that during high price periods, subsidies would not be necessary for collectors, as the higher price of scrap lead would provide adequate compensation to cover overheads. This has proven not to be the case, as Transportation Incentive Payments (TIPs) did not contribute to recycling ratios in 11 out of 13 transportation zones included in the analysis (Table 2-5) and was negatively correlated in the other two zones.

Another common complaint raised by stakeholders (Figure 2-5), was related to the fact that the revenue obtained from the CAN$5 environmental levy charged on new lead-acid batteries (Figure 2-2) is not directly linked to the management of the Lead-Acid Battery Collection Program. Over the past 12 years, TIPs payments to collectors have ranged from $803 to $1,486,829 annually and the provincial government has collected an average of $4Million/year from the environmental levy alone . Since TIPs are inversely proportional to LME lead prices, they are practically non-existent for most zones given the high lead prices we are currently experiencing. The difference between the money collected and the subsidy paid has been directed to the Sustainable Environment Fund to fund other environmental protection activities not necessarily related to lead-acid batteries and this is not appreciated by those involved in Lead-Acid Battery recycling.

The current program also fails to provide consumer incentives to return lead-acid batteries. The general public are usually not well informed about the availability and locations of used battery drop off facilities. The $5 dollar environmental levy is not a deposit and therefore is not redeemable upon return, a factor which might encourage return. Lack of incentives, combined with distance to drop-off facilities, contributes to low rates of return by the general public. In order to encourage the general public to return their batteries, the Regional District of Kootenay Boundary has established an educational program to inform people about the locations for return of scrap batteries among other recyclable materials. The Regional District of Central Okanagan in Kelowna also organizes annual events to promote collection of used batteries from the public. None of these initiatives are financed through the provincial Lead-Acid Battery Program.

A level playing field regulation is definitely not in place. Although many manufacturers, distributors and retailers (MDR) have established voluntary programs to collect scrap lead-acid batteries from retailers, they have favoured the most heavily populated zones such as Vancouver Island (zone A), the Lower Mainland (zone B) and the Okanagan (zone C) (Table 2-8) . Generally, *recyclers* have played a more important role in less populated regions such as Thompson-Nicola (zone E) and east of Kootenay (zone I) and in regions more distant from the recycling plants north and central Omineca Peace (zone H0 and H1) and central Skeena (G1) (Table 2-9). However, the lack of incentives for systematic recycling and increased fuel costs (Table 2-4) have compromised the overall recycling ratio (Table 2-7). In addition, the current program poses high disposal costs for municipalities, especially in Omineca Peace, Skeena and Thompson Nicola regions, which have not been able to sustain high recycling ratios over the period of the recycling program. Similar problems are also observed in highly populated zones such as Vancouver Island (zone A) and Lower Mainland (zone B), where recycling ratios have fluctuated considerably since the implementation of the program in 1991 (Table 2-7).

The current Lead-Acid Battery Program should therefore be restructured to encourage the principles of producer extended responsibility, in which manufacturers, distributors and retailers are required to participate in the collection of scrap lead-acid batteries. USA, Europe and Japan have successfully achieved recycling ratios of over 95% based on extended producer responsibility programs involving the battery chain of distribution, including consumers. This seems to be a successful model that could be implemented by others or mandated by the government.

Recent global prices increases for lead are unprecendent with the current LME price being over $3,000/tonne. If these levels hold into the future, it is unlikely that the current TIP formula will even calculate a positive value to provide a subsidy for this recycling program. Since the real price of lead scrap falls far below the LME price, ther is no clear incentive for the transporters to deliver scrap laead to the two recycling facilites.

As a result, the provincial recycling ratios have averaged 75% during the operation of the recycling program in British Columbia and will likely continue at this level or decrease, despite the recent escalation in LME lead prices. This is explained by the strong buying power and limited recycling capacity of the two recycling plants in the province, which control the price of scrap lead below LME lead prices posing challenges to the transportation of scrap batteries within British Columbia. This situation was raised consistently during interviews (Figure 2-5) and was also confirmed by the regression model results of equation 7, in which LME lead prices demonstrated a limited influence on predicting the recycling ratio (Table 2-4).

Clearly, the Lead-Acid Battery Collection Program was not designed through a process that valued continued stakeholder input and long term evaluation. TIPs were designed by experts and policy-makers based on the regional market conditions of 1995. The TIPs formula neglected a number of critical factors such as the regional price of scrap and the limited capacity of available recycling plants. In addition, the TIPs formula has not been updated since 1995 and has not taken into account recent increases in fuel prices, which have been identified as an important impediment for collection of scrap batteries (Table 2-4). These problems could have been mitigated if a more flexible framework was in place. Stakeholder and industry input must be incorporated not only before, but also during program operation, in order to ensure better allocation of resources.

An effective system should have a simple mechanism that allows evaluation of performance and adaptation over time. In order to revamp the current program, the Ministry of Environment needs to improve data collection on the number of batteries sold in the province and the total revenue obtained from the $5 environmental levy. The available data indicate that the current program performs well below average compared to many other recycling programs implemented in the USA, Europe and Japan (Ahmed

1996; Subramanian 1997; BC Ministry of Environment 2004; MWLAP 2004; Battery Council International 2005). Furthermore, the sensitivity of the recycle rates to fuel costs, regional distances, and the relative voluntary participation of manufacturers and recyclers are likely to lead to future declines unless the system is changed. It also provides some indication of the types of changes that can be implemented to create a more effective recycling strategy.

However, it should be borne in mind that the regression results do not provide explicit information on which elements would contribute to a more effective strategy, taking into account the specific challenges in British Columbia. The derivation of a comparative analysis of the key components that influence the performance of varied recycling systems therefore forms the next stage of this research described in Chapter 3. Moreover, the analysis presented in this chapter does not provide indicators that can be used to describe and assess a more effective strategy, taking into account not only the recycling ratio but also the broad environmental and social aspects of the system. The derivation of performance indicators and recycling policy strategies for the lead-acid battery program are the subject of chapters 4 and 5.

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Chapter 3 Learning Across Complex Recycling Systems[7]

3.1 Introduction

Canada and the USA are considered the world's largest per capita waste generators (BC Ministry of Environment 2004). Even though the percentage of materials recycled in North America has steadily increased over the last two decades, total municipal solid has escalated simultaneously and these waste stream increases have outpaced gains in recycling over the same period (Clapham 2004). In Canada, 31 million tonnes of waste are generated annually and the cost of disposal, which is usually borne by general taxpayers, is estimated to be $3.4 billion annually (Clapham 2004). Only 24% of Canadian waste is recycled (NRCAN, 2004), and Canada's per capita consumption rate is among the highest in the world (Rees 1995).

Why do we generate so much waste? The simple answer is that we do not pay the full environmental and social costs of producing and recycling of materials we consume. Also, market prices do not reflect the "total value" of commodities, as ecosystem services are not captured by the monetary value of goods (Friedland et al. 2003). As a result, established patterns of over consumption in industrialized countries, especially in Canada and the USA, have been demonstrated to be among the most important threats to the natural environment and human health globally (Wackernagel et al. 1997). To attempt to turn around this situation, governments and industries have started to establish stewardship programs, with the intent of internalizing the full social costs of recycling and safe disposal of the products and materials we consume.

Waste management often involves complex systems, which rely on the interactions of consumer and retailer behaviours, which are in turn influenced by the organizational practices, incentives and policies of those who operate and regulate recycling systems. Designing and evaluating effective waste management policies is therefore a difficult task, which has to take into account the variety of actors, who play diverse and interrelated roles in the recycling system. Understanding the range of responses and

[7] A version of this chapter will be submitted for publication.

behaviours in these systems is crucial to the task of identifying the incentives and instruments driving system performance.

In British Columbia, the Ministry of the Environment (MoE) is responsible for designing, developing and implementing waste management and product stewardship regulations. Over time, waste management, including recycling programs, has expanded dramatically and most programs are currently managed by industry-led stewardship agencies; that is, non-profit organizations formed by brand-owners and distributors of regulated products. Funding for these programs is either generated through advance disposal fees paid at point of retail or integrated as part of the price of the product. Today, there are a variety of regulated product categories in the province, managed by seven stewardship initiatives comprised of six industry-led programs and one government program. The stewardship agencies are involved with products that range from paint and medications to beverage containers and each of them operates independently based on a business plan approved by the MoE. The government-led program is the lead-acid battery collection program, which has been operated by the MoE since 1992.

There is a wide variety of programs in Canada and the lack of systematic evaluation makes it extremely difficult for governments and industry to identify best practices and lessons learned across stewardship programs. The purpose of this study is to develop a qualitative systems analysis approach to identifying the key factors that contribute to the overall performance of waste management systems in British Columbia. First we discuss the systemic nature of waste management systems and the need for a more integrated approach in the evaluation of these programs. Secondly, we present a literature review of all stewardship programs in British Columbia, Canada, based on reports and internet sites publicly available. Then, expert interviews informed by influence diagrams were conducted to identify the managers' perceptions of the key factors that contribute to the effectiveness of waste management systems. This comparative study provides essential information on the dynamics of existing waste management systems and especially on the incentives and policy instruments that influence organizational behaviour and drive system performance.

3.2 Overview of stewardship programs in British Columbia

In 1991, the MoE implemented the first generation of recycling programs, which included the Financial Incentives to Recycle Scrap Tires (FIRST) and Lead-Acid Battery Collection programs. These programs were entirely managed and operated by the government and funded through government levies assessed on the sale of new tires ($3.00/tire) and batteries ($5.00/battery). As mentioned above, this is in contrast to the other regulated products programs, which are managed by industry stewardship associations.

In 2004, a new provincial recycling regulation was enacted, which included existing industry-led stewardship programs and required producers to establish targets and report on performance. Products included in the new regulations include beverage containers, medications, oil, oil filters and residuals[8] (gasoline, paint, solvents and flammable liquids). The tire product category was later included in the regulation in 2006, when this program shifted from a government program to an industry-led program managed by tire distributors and retailers. Electronics waste was also incorporated into the regulation in 2006 and the program started operating in July 2007. The lead-acid battery collection program is now the only recycling program operated by the provincial government and therefore excluded from the new regulation. Table 3-1 lists the major stewardship agencies responsible for managing recycling programs in British Columbia.

The provincial *Recycling Regulation,* enacted in 2004, makes the producer responsible for the life cycle management of their products, including financing the collection, recycling and disposal of products. In general terms, the producer is defined as the "first-seller of the product in the province, the product manufacturer, distributor or brand-owner". It could also be an importer, broker or retailer who sells the product directly to a consumer, including those whose sales are transacted by catalogue or over the Internet (McDonough and Braungart 2000).

[8] **"residual"** means the portion of a product that remains after the consumer of the product has no further use for it (British Columbia Recycling Regulation, 2004)

Table 3-1: Waste management programs in British Columbia

Stewardship agency (set up date)	Products	Revenue Source	Collection facilities	Consumer incentive	Transportation arrangements	Recycling or recovery rate 2005
BCUOMA – BC Used Oil Management Association (1992)	Used lubricating oil, used oil filters, used oil containers	Industry fees from producers who have the choice of how they pass it on to the retailers	Return to retail	None	Return incentives to collectors (haulers), and infrastructure development incentives to oil container processors	Oil: 70.7% Oil filters: 76.8% Oil containers: 51.2%
Brewer Distribution Association	Refillable bottles and cans for domestic beer, ciders and coolers	Industry fees internalized in price and revenues from reused containers	Return to retail	Deposit refund	Fee for service	Aluminium cans: 90% Refillable glass bottles: 90%
Encorp Pacific (1994)	All non-alcoholic beverage containers, non-refillable bottles for wine, spirits and coolers, electronics waste	Unredeemed deposits, recycling fee disclosed on receipts, revenue from recycled containers.	Exclusively operated depots	Deposit refund	Fee for service and dedicated service providers	Aluminium cans: 81% Plastic bottles: 72% Polycoat bottles: 54.6% Glass bottles: 69% Pouches bottles: 59.2% Non-refillable bottles: 71% Electronics waste: N/A
Product Care (1994)	Post consumer paint, solvents and flammable liquids, pesticides and gasoline (packaging not included)	Industry fees from producers who have the choice of how they pass it on to the retailers	Multi-materials depots	None	Fee for service	Post consumer paint: 6.3%* Flammable liquids/gasoline:1%* pesticides: 6.1%* Aerosol paint: 2%*
Tire Stewardship BC (2007) From 1991 to 2006: Ministry of the Environment	Used tires	Industry fees internalized in price. From 1991 to 2007: government levy	Return to retail	None	Freight incentive & tipping fee to transporters, and incentive credit to processors	Unknown
Post-Consumer Pharmaceutical Stewardship Association (1997)	Unused and expired medication (packaging not included)	Industry fees internalized in price	Return to retail	None	Fee for service	18.1 tonnes* (% not reported)
Ministry of Environment (1991)	Used lead-acid batteries	Government levy	Voluntary participation	None	Transportation incentive payments	76% (chapter 2)

* residual products based on % of product sold

The *Recycling Regulation* aims to shift policies and programs towards waste management and recycling systems financed and operated by producers and users, rather than by general taxpayers. The MoE and local governments (municipalities and regional districts) often cooperate with the stewardship agency during the design and implementation of its plan and delivery of services to the general public. The local government may choose to participate as a service provider or contractor providing facilities and supporting services for product collection, but responsibility should not be shifted to other levels of government without consent (BC Ministry of the Environment 2006). Table 3-2 summarizes the roles of MoE, producers and local governments (municipalities and regional districts) in light of the *Recycling Regulation Guide* published in 2006.

Table 3-2: The roles of MoE, producers and local government

MoE's role	**Producer's role**	**Local government's role**
• define waste management policies • approve stewardship plans • review annual reports • assist producers in interpreting the regulation • issue compliance and enforcement actions	• comply with the approved plan, related laws and regulations • provide free consumer access to collection facilities • develop a consumer awareness program • provide a dispute resolution procedure • adhere to pollution prevention hierarchy • reduce life cycle impacts of products • assess recycling/recovery performance • assist retailers in informing the public	• provide facilities as a "service provider" at landfill and other sites • inform the public • assist producers with local land use and business licences • impose bans on materials going to landfills

Stewardship agencies are appointed by a producer to act on its behalf, to prepare a plan, implement a program and report on its progress. They are not-for-profit entities established under the British Columbia *Society Act* or federal legislation. Existing producers can follow the requirements prescribed in the Recycling Regulation, develop their own program, or, most commonly, join an existing stewardship agency to meet their obligations. For instance, the Electronics Stewardship Association in British Columbia (ESABC) is an example of the latter, where producers formed their own stewardship agency. This agency, in turn, contracted out the management of the electronics recycling program to Encorp Pacific, an existing stewardship agency for non-alcoholic beverage containers, to collect computers, monitors, desktop printers and TVs. This electronics stewardship program is not included in the study because it started operating in July 2007.

The *Recycling Regulation* also includes requirements applying to all programs and determines schedules for regulating different product categories. The stewardship agencies are responsible for submitting an audited report annually to the MoE, detailing the effectiveness of their stewardship program in the previous calendar year. Producers must assess program performance and are encouraged to report on the major components of the program, including the level of producer responsibility, stakeholder consultation, free consumer access to collection facilities, public awareness, assessment of the environmental impacts, the existence of dispute resolution procedures, consistency with the pollution prevention hierarchy, the recovery rate, transparency and accountability. However, the regulation does not develop performance measures and targets for most of these criteria, except for the recovery[9] and recycling rates[10], which are established at a 75% minimum for all products.

The level of producer responsibility also varies from one program to another. Encorp Pacific, the Post-Consumer Stewardship Pharmaceuticals Association and Product Care are examples of programs in which producers are responsible for operating the recycling system. The Tire Stewardship Program and the BCUOMA rely primarily on retailers, rather than producers, for collection of their products. For all these programs, industry fees are charged at the point of retail or internalized in the price of the product in order to fund the recycling system. In contrast, the lead acid battery program is completely financed through government levies and producers and retailers are not formally involved in the design and operation of the recycling program.

Some stewardship agencies also pay specific monetary incentives to consumers, collectors, transporters and processors. For example, Encorp Pacific and the Brewers Distribution Association provide consumer incentives through deposit fees redeemable at collection points. The BCUOMA provides freight incentives to registered collectors (transporters) and infrastructure development incentives to registered oil container processors. Similarly, the Tire Stewardship Association provides incentive credit to processors, and freight incentives and tipping fees to transporters. All other agencies

[9] Recovery rate: quantity collected divided by quantity sold
[10] Recycling rate: quantity recycled divided by quantity sold

have established some sort of compensation for contractors paid on a fee for service basis (Table 3-1).

As mentioned, the *Recycling Regulation* establishes a 75% recovery rate as a minimum performance target for all product categories. However, recycling or recovery[11] rates are not adequate targets for all waste management programs because some of these products are considered *residuals*, which means that only a portion of a product remains after consumption. Residual products include used oil, gasoline, paint, solvents and flammable liquids, gasoline, pesticides. To calculate recovery rates for these products, the British Columbia Used Oil Association (BCUOMA) bases reports on the assumption that only 70% of the estimated volume sold is recoverable. Product Care reports on the volumes of gasoline, paint, solvents and flammable liquids recovered compared to the volumes of products sold and the Pharmaceuticals program only informs the total weight of medicines collected. Clearly this latter is not an adequate measure of recovery rate since it does not take into account increases in the amount of product sold.

For the remaining products (non-residuals), recycling rate is based on the total volume of materials recycled divided by total estimated sales. Encorp Pacific and the Brewers Association of Canada have successfully achieved recycling rates of over 75% for aluminum cans and refillable alcoholic bottles, while the majority of remaining regulated products fail to meet the established target. In addition, there was no official historical reporting on the collection rate of either tires or lead-acid batteries under Provincial Government stewardship. The figures reported in Table 3-1 for Lead Acid batteries are based on the results presented in Chapter 2. The new tire program recently began collecting statistics on the number of tires sold and plans to annually report recycling rates in the future.

Another stipulation of the *Recycling Regulation* is that the stewardship plan adequately provide for "the management of the product in adherence to the order of preference in the pollution prevention *hierarchy*" (BC Ministry of the Environment 2006). The pollution prevention hierarchy, depicted by the inverted triangle in Figure 3-1, requires that pollution prevention is not undertaken at a lower level unless or until all feasible options for pollution prevention at a higher level have been undertaken. For instance, *source reduction* is the highest level of the hierarchy. This indicates that reducing or eliminating unused portions of the product, including its packaging material and toxic components are the preferred methods of pollution prevention. Reuse, recycling and recovery are the successively lower level options for managing the waste after it has been generated. Proper treatment and disposal are not options for reducing waste and are considered only if none of the previous options are feasible.

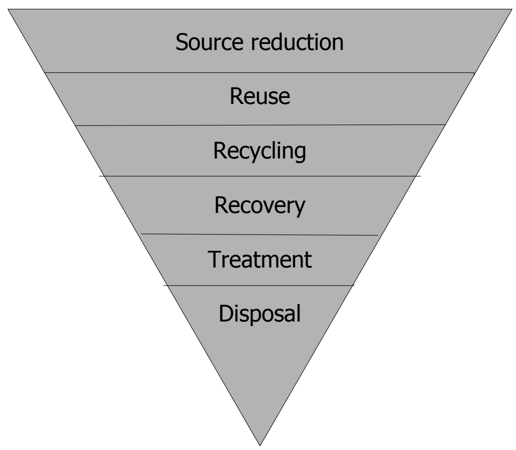

Figure 3-1: Pollution prevention hierarchy

The Recycling regulation guide clarifies that the hierarchy needs to be tested and assessed at the product-specific level. For instance, reuse may apply to the entire product, such as in the case of refillable alcoholic beverage containers or to a portion of the collected product; as is the case for e-waste components. In the situation where products may be suitable for reuse, such as glass beverage containers, the hierarchy implies that producers should assess the reuse potential of these products. In other cases, producers may not be entitled to apply the hierarchy to assess packaging materials, since not all stewardship agencies are responsible for recycling all of their packaging. This is the case of the residual products managed by Product Care and the Pharmaceutical Stewardship Association, where mostly product residuals with containers are collected, while empty containers for all regulated products are not necessarily accepted in the collection facilities. Implicitly, the burden of finding alternative recycling and disposal options for the packaging of consumed products falls on consumers and is not tracked by the stewardship agencies.

3.3 Recycling systems as complex systems

Given the wide variety of programs operating in British Columbia and Canada, both the general and specific characteristics of the product and its chain of distribution must be identified when assessing stewardship initiatives. Recycling programs have been predominantly evaluated using life cycle analysis (LCA). However, LCA imposes extreme constraints and limitations on the character of environmental problems (BC Ministry of the Environment 2006) and does not provide a successful mechanism for incorporating qualitative information (Craighill and Powell 1996; Hertwich et al. 2000). McLaren et al (1996) consider that LCA studies rely on static linear models of the underlying system and fail to draw attention to the structural peculiarities of systems, in particular to the presence of dynamic features.

This chapter does not offer a critique to LCA or other approaches. Rather, it introduces a qualitative systems approach to identify the critical factors that drive performance in recycling systems. According to Fowler (2000), a systems approach "usually requires a shift in paradigm from a linear, sequential, and quasi-steady-state perspective, to one, that accommodates nonlinearity, networked relationships, and truly dynamic behaviour". In recent years, some studies have attempted to take more systemic approach to investigate the role of market incentives and policy instruments in fostering recycling performance. Vlachos et al (2003) developed a model which enables a comprehensive description and analysis of the systems involved in material recovery, taking into account capacity considerations, alternative stewardship policies involving a take-back obligation and consumer behaviour. This model proved effective in analyzing a variety of scenarios and thus identifying efficient policy instruments along the material supply chain. Fullerton and Wu (2007) designed a simple general recycling model to evaluate the effectiveness of various policy instruments, including subsidies, manufacturer take back programs and deposit refund systems. Calcott and Walls (1998) evaluated how incentive-based policies are capable of promoting *design for environment* and recycling by using a simple model that incorporates four stages in the product life cycle and two types of resource. These studies have concluded that recycling systems by themselves cannot generate the optimal levels of recovery and design for environment, unless they are combined with adequate policies and instruments throughout the series of stages which form the recycling process.

The particular problems posed by modeling the dynamic properties of recycling systems have not been addressed in the literature in depth, and there is a recognized research need for the further development of analysis and evaluation of recycling systems. In this chapter, we extend prior contributions by constructing a single qualitative systems analysis that can be used to evaluate and compare incentives and policy instruments in virtually any recycling system. Understanding the challenges and successes across these systems is crucial, in order to transfer lessons learned and identify interventions likely to be successful in improving system performance.

3.4 Expert interviews with managers of stewardship agencies

The managers of six stewardship agencies were contacted to gather information on the key factors that shape the nature of recycling systems. Participants were selected through a *purposeful* sampling design, which consisted of identifying individuals who were likely to be "information-rich" with respect to the purposes of a study (Calcott and Walls 2005). A letter of introduction (Appendix F) was submitted to the manager of each provincial stewardship agency accompanied with the questions for the structured interview (Appendix G). Each manager received a phone call or follow-up email within two weeks to schedule a one-hour interview on site. One manager declined to participate.

The interviews used *influence diagrams,* which allowed for a systemic representation of the main factors influencing the performance of a system (Strauss and Corbin 1998). Clemen and Reilly (1998) explain that an *influence diagram* is a simple, graphical representation of the factors that influence the state of the world, including the decisions that can trigger or shape the processes captured in the nodes. Factors in the influence diagram are linked with arrows in specific ways to show the causal relationship among elements of the recycling system. The data gathered through internet search and reports combined with the researcher's experience were used to develop a snapshot of all these factors (presented in Figure 3-2).

The interview questions and the *influence diagram* were mailed in advance to all five managers who agreed to participate in this study. Four face-to-face interviews were scheduled during the first two weeks of July 2007 at a time and location convenient for each interviewee. One interview was conducted over the phone since the interviewee was located outside the province. The Brewer Distribution Association and the Ministry of the Environment were not available for interview during the timeframe of this research. However, we have been able to take into account specific characteristics pertaining to the program managed by Brewer Distribution Association given its substantial similarities to the program managed by Encorp Pacific and the availability of information from publicly available sources. The government program on lead-acid batteries was directly assessed by the researcher based on interviews and site visits with a range of stakeholders, as described in Chapter 2.

Although all interviews were designed to last one hour, three participants volunteered to extend the time of the interview for up to two hours. All of the participants read and signed the interview consent form and agreed to be tape-recorded for later selective transcribing (see Appendix H).

The interview was divided into two parts, each lasting approximately 30 min. During the initial phase of the interview, managers were asked to describe their perceptions of the key factors that contribute to the performance of the waste management system. More specifically, participants were encouraged to discuss the challenges and opportunities associated with different stages of the recycling system represented in the influence diagram. The interview questions were open-ended and expanded on the topics covered in the questionnaire (Appendix G) in order to capture the details of manager thinking. Vague examples were probed for full, specific details to ensure the accuracy of the incident as recommended by Flanagan (1954) (e.g., "Can you think of a specific example where this [characteristic] was demonstrated?"). After each example the respondent was asked, "Is there anything else you would like to add?" until he or she could give no more examples. The process was repeated for each stage of the waste management system illustrated in Figure 3-2.

In the second stage, participants were asked to refer once again to the *influence diagram* (Figure 3-2) and to point out any potential gaps or inconsistencies in its graphical representation. Then, thinking in terms of the current policy, they were invited to rank the level of importance of the twelve elements represented by the grey circles of the influence diagram (Figure 3-2), in which level 7 refers to *the most important* aspects and level one refers to *the least important* aspects that influence the performance of recycling systems. Participants were also prompted to talk about the association between the aspects highlighted in the initial stage of the interview and the ranking being provided at this phase. Morgan et al (2001) explains that influence diagrams are particularly useful for helping people identify the interactions of elements in a system and figure out what things are worth of attention in a complex situation. This approach has already been used to capture the beliefs of technical specialists about various phenomena related to climate change, nuclear energy and HIV/AIDS (Clemen and Reilly 2002). The intention is to compare the importance of each factor across different recycling systems and to construct a single description, summarizing the pooled knowledge of experts.

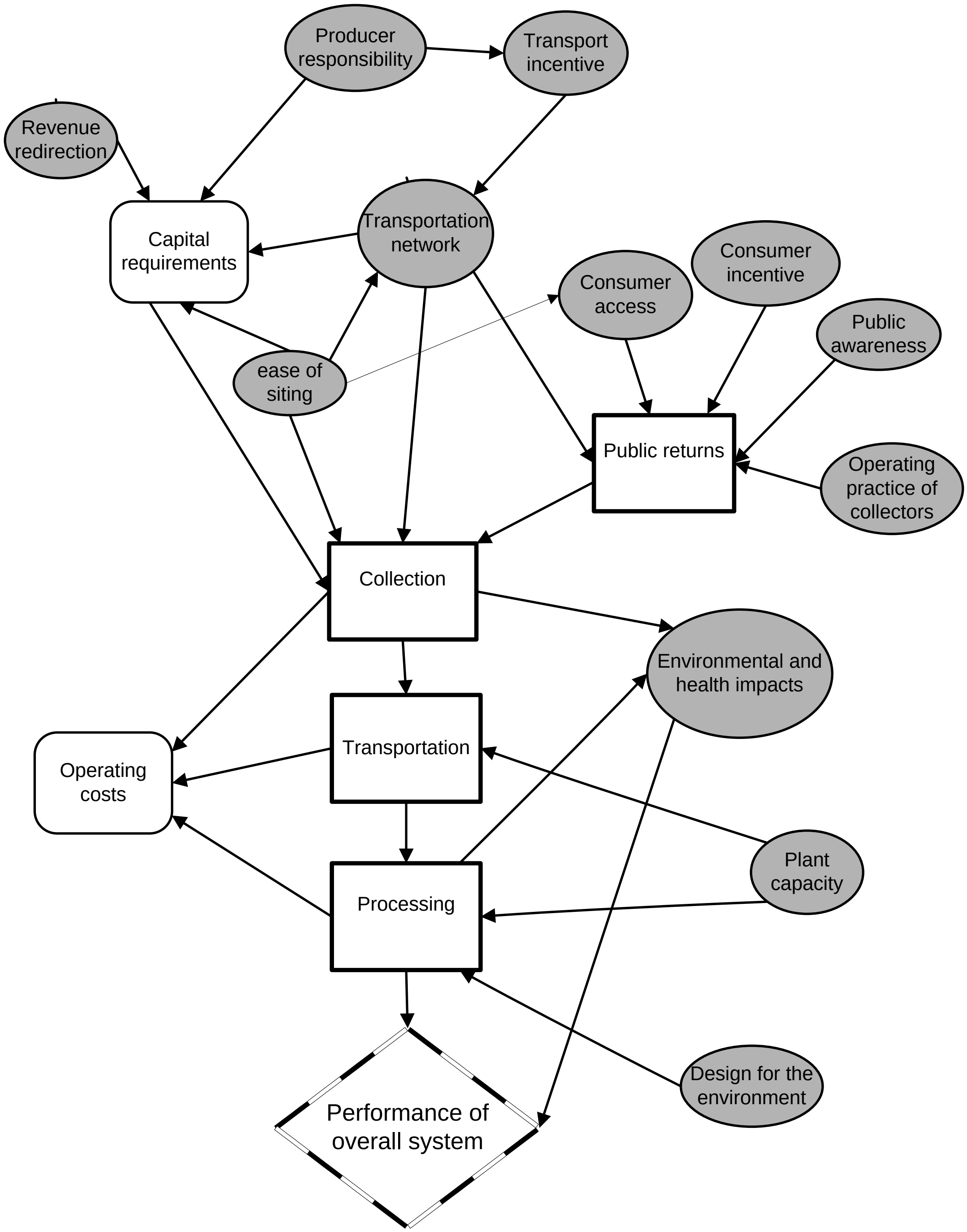

Figure 3-2: A general influence diagram of a recycling system

3.5 Interview results

All interview tapes were transcribed verbatim in order to identify themes associated with a particular element of the recycling system. The results were sorted and combined intuitively according to highlight the comments associated with each of the twelve different factors of the influence diagram. A draft was sent to all participants who were given the opportunity to review their ranks and direct quotes of their comments prior to publishing. The results of the ranking exercise are presented in Table 3-3 and Table 3-4 and reflect the participant's judgments of the level of importance of these factors to the success of their programs.

The Q-methodology was used to study the dimensions of phenomena as they were perceived by the subjects (Barrett 1961; Dennis 1986; Morgan et al. 2001). This approach can be employed to study any concept that can be described by components (Stephen 1985). The subject is instructed to rank-order them according to a "condition of instruction" from "most important" to "least important" (von Essen and Sjoden 2003). The ranking of each factor is determined by the subject and its meaning is dependent upon the centrality or lack of it from the subject's point of view (McKeown 1984; von Essen and Sjoden 2003). The final rank is called a Q-sort and represents how a person models his or her opinions and feelings on an issue (Barrett 1961). Q-methodology thus permits an understanding of a person's priorities in relation to a specific purpose (in this study, performance of a recycling system). As it is based on the methodology of relative ranking, neither calculation of means or standard deviations provide meaningful statistical results.

Two sets of categories emerged during the analysis of participants' responses: *consensus factors and distinguishing factors*. *Consensus factors* of recycling systems (Table 3-3), are classified as those which received similar ranking from the vast majority of participants (i.e. most results gravitated towards the same half of the grid). Flitcroft (1984) clarifies that consensus items are defined as statements whose position on the scale all participants across the factors agree upon.

According to Flitcroft (2007) other items are referred to as distinguishing items, which are defined as "those statements that score highly in one factor and significantly lower in another". In this study, distinguishing factors (Table 3-4) reflect those aspects that received a wide range of responses among participants, and reflect context specific characteristics associated with the type of material

It is important to note that this ranking is not meant to assess the level of performance of each factor, but rather, its perceived importance relative to other factors in the performance of the overall recycling system (Flitcroft et al. 2007). For instance, a low ranking on *capacity of processing plant* does not necessary represent that a particular recycling program experiences low processing capacity. It indicates that *capacity of processing plant* is not considered a crucial issue for that particular recycling scheme and that issues denoting a higher ranking are more important to the success of the program according to the participant's perspective.

Table 3-3: Consensus factors of recycling systems ranked by respondents

General factors influencing the system	Relative level of importance						
	1 *(least important)*	2	3	4	5	6	7 *(most important)*
Revenue direction							●●●●●●
Public awareness						●●●	●●●
Producer responsibility				●		●●	●●●
Consumer access				●●	●●●		●
Operating practice				●	●●	●●●	
Transport network			●		●●●	●●	
Design for the environment		●●	●●	●●			

Note: dots indicate ranking of individual participants on each factor

Table 3-4: Distinguishing factors of recycling systems ranked by respondents

Context specific factors influencing the system	Relative level of importance						
	1 *(least important)*	2	3	4	5	6	7 *(most important)*
Environmental and health impacts		● ●				●	● ● ●
Ease of siting	● ●			●	●	●	●
Capacity of processing plant			● ● ●			● ●	●
Transport incentive	● ● ●	●				● ●	
Consumer incentive	● ● ● ● ●						●

Note: dots indicate ranking of individual participants on each factor

In the following sections, the individual items identified in the expert interviews are described and supporting statements from the expert interviews are used to contextualize each item.

3.5.1 Revenue direction

Revenue direction refers to the destination of the revenue collected by stewardship agencies. For instance, the revenue collected through levies by all industry stewardship agencies is directed to pay the costs of running their recycling programs, including administration, collection, transportation, recycling, research and development, quality assurance and legal costs. As a result, all participants considered this one of the *most important* factors influencing the performance of programs. In contrast, to the other programs, the revenue collected through the lead-acid battery program is only partially directed into the program and this limited revenue direction to the program was considered one of the *most important* aspects compromising the performance of the system.

3.5.2 Public awareness

All recycling programs rely on public participation to bring the materials back to collection sites. As a result, all participants ranked public awareness as *very important* and recognized public awareness programs as fundamental in determining the success of a recycling program. In general, the awareness programs mentioned by the participants included a contract with the Recycling Council of BC Toll-Free Hotline service, retailer brochure distribution, news releases, local advertisements and websites with up-to-date depot and program information. In addition, Encorp Pacific has been conducting annual public surveys to investigate purchase and recycling behaviour with respect to beverage containers. Participants highlighted the following challenges in implementing public awareness programs:

One of the challenges is the expectation of consumers to be able to bring all household products (…) We do have communication materials at the depots and at most retailers to help consumers to understand. (…) As much as possible, we try to inform people before they make the trip. (Product Care)

Right now, we rely on the pharmacists and health professionals to inform the consumer that there is a program for unused and expired medication. The difficulty here is that we don't want to send a mixed message. When we have a prescription (…) it's difficult to advertise to bring your unused or expired medication back to the pharmacy when your doctor and health professionals have advised you to finish your medication. There is a mixed message here. (Post-Consumer Pharmaceutical Association)

Level of public awareness ties into people's values and beliefs. If people have good values and beliefs in that area, is much easier to sell it. (…) People drive to do their shopping and they should drive the same distances to take it back. (BCUOMA)

3.5.3 Producer responsibility

Most of industry-led stewardship programs were initially formed by producers or transferred from the government to producers. There are still two stewardship programs managed primarily by retailers, but these programs included the participation of producers and manufacturers on their board of directors.

Overall, producer responsibility was considered *very important* by five out of six respondents and *moderately important* by one respondent. This last respondent belongs to a program, which relies primarily on retailers to get its products collected. They stated:

We came to the conclusion that the only way to do tire levy in this province is to do it at the retail level and have the dealer that is selling the tire submit it. Because there are no clean lines of distribution between them, it can't come directly from the manufacturer.

That's why tires are unique to any other BC recycling program. It has to be done right at the retail level because that's the only way you can capture all the levies. (Tire Stewardship BC)

The only program that has not incorporated any formal participation from producer and manufactures is the lead-acid battery program, operated by the provincial government. Despite this, as discussed in Chapter 2, voluntary participation of manufacturers has been an important factor in the performance of this program.

3.5.4 Consumer access

One participant indicated their collection network as one of the *most important* factors, three participants ranked it as *very important* and two participants ranked it as *moderately important* to the success of their programs. There are basically three types of collection strategies used to enhance consumer access and convenience: multi-materials depots, use of retailers (in case a return to retail policy is in place) and licensed or exclusively operated depots. These sites vary according to type of products being collected by stewardship programs.

Product Care relies primarily on multi-material depots established in collaboration with local government and private business. They stated:

"We tend to be located in sites where there are other similar types of activities where there are other waste or recyclable products consumers are bringing in - one stop shops. We do not have an independent depot that is 100% owned by Product Care, it is always in conjunction with another business (…) 40% are municipal and the rest are either beverage containers return centers or other kind of organizations such as recycling associations. (…) None of our depots handles only our materials and I don't think they would survive handling only our materials. It is a benefit to us that there are these operations out there. It is a benefit to our consumers as well. Consumers do like convenience." (Product Care)

Encorp's collection network centers on licensed depots exclusively designed to take beverage containers. Encorp also adopts alternative strategies to enhance consumer access in specific areas.

"Consumer convenience and access to collection facilities is really fundamental in determining the extent to which the public will participate. (…) We have depots in virtually all communities in the province with a population greater than 15,000 (…). When you get in some small towns and unpopulated areas of the province, the

collection infrastructure is made up by retailers who are selling the beverage containers in the first place. (…) In some of the native band communities we would have one of our depots operations who goes up, in what is called a mobile depot and they would go into the community every second Saturday". (Encorp)

For most of the other agencies, their collection networks rely predominantly on return to retail, which has also been noted by participants as a very convenient option for the general public. For example, the Post Pharmaceutical Stewardship Association praised their return to retail system due to its simplicity and greater availability to the population.

It is important to make it simple for the public. The strength of the program in BC is that it's so convenient for individuals to return medication to any pharmacy – almost to any pharmacy in the province (Post Consumer Pharmaceutical Stewardship Association).

The BCUOMA is also investigating options to expand its collection network by working collaboratively with regional districts and local governments.

The other things we are thinking about is the possibility of providing infrastructure assistance to some local governments. Right now there is no provision and these are some of the stuff our board will be looking at (BCUOMA).

3.5.5 Operating practices of collection sites

Operating practices of collection sites is a category intended to encompass overall good practice, including customer service, management and compliance with health and safety requirements. Operating practice was considered *important or very important* by five respondents and *moderately important* by one respondent. The quotations below stress some of the challenges noted by participants in managing operating practices at their collection sites. It is important to note that although operating practices differ according to the type of product being recycled, this factor was considered imported by all respondents.

The challenges we face with it are quite similar to if you start up a new retail chain – this is what it is. It is reverse retail, people bring things back and leave with the money, as opposed to regular retail, which is the other way around. But it goes to the same challenges particularly because these are small businesses run by independent entrepreneurs. We do not own any depot and the challenge we face is working with them helping them constantly improve their costumer service, the quality and the *capabilities of their location and constantly trying to have them reinvest in the facilities to maintain contemporary standards. (Encorp)*

Operating practice of collectors is very important. We don't want people cheating/scamming on the system (…) We energized the existent private sector to deal with collectors and processors in our payment system. Ultimately it works quite well but we still have improvements to make. There are always things you learn and things that could be improved. (BCUOMA)

I would say operating practices at collection depots is very important in terms of following procedures for safety. (…) There is definitely more onus on responsibility. It requires manpower and supervision, etc. (…) Other materials that are non-hazardous don't have to worry as much about how the product is stored, contained, labelled. (Product Care)

3.5.6 Transport network

Five participants considered their transportation network to be *important or very important* aspects of their program and one participant ranked it as *not very important*. Stewardship agencies have used a variety of service providers and transport logistics to optimize their coverage in remote and urban areas in the province. Below we draw attention to two examples provided by Encorp and Product Care.

"We use a number of different service providers. Some are dedicated – this is the only thing they do. They are sole free hands operators who only work for us. (…) They are entrepreneurs we hire and we use dedicated transporters throughout Lower Mainland, Vancouver Island and Okanagan. In the other regions we contract with an existing transportation company" (Encorp)

We pay the transporters on set rates to do pick up. We tell them where to go, when to pick up and what to pick up. Our system is a managed approach, we select our contractors and they are contracted to us. Tires and oil use a transportation incentive system to target are commercial services that change oil and remove tires, whereas there is nobody out there regularly taking leftover paint. It is a different kind of product. (Product Care)

3.5.7 Design for the environment

Design for the environment focuses on introducing design changes to products and packaging in order to minimize their environmental impacts during production, consumption and disposal. Interestingly, *design for the environment* was considered *not very important* by most participants and four respondents assigned to it their lowest overall ranking. In general, participants framed their responses around their limited impact on decisions made by manufacturers and noted that other factors outside their control drive product design. They emphasized that their primary role is to take materials out of the waste stream and ensure that each material pays for its recycling and disposal costs.

It is a very competitive market the beverage industry and it is always changing the composition of beverage containers and sometimes they will change it in such a way that makes it difficult for recycler. The processor may not be set up to handle that particular formulation of plastic – that is an ongoing challenge. But largely the companies that are producing these products are really quite mindful of that usually. We probably have more difficulty with those products coming from offshore particularly from Asia because they are less involved with recycling themselves in those countries. (Encorp)

Sometimes there are two sides to the "design for environment" story. Latex paint has a lot of good aspects to it but the leftover product can be a problem when it gets to us. (…) A lot of times the options for design for environment are beyond our control, let's take pesticides, it is the federal government or municipal governments who decide who should be allowed to use the products and how should be manufactured. There is not much we can do about it. (Product Care)

I don't think changing the container type would make any difference to recyclability because what they are used to hold is the problem or what the container has been in contact with – the perception of recyclers is that the container has been contaminated. (Product Care)

The environmental handling charge is only a very small portion of how manufactures decide on what kind of package to use. Much more influential are things like shipping costs, government regulations, incentive to make it profit. For instance, if you look at the thickness of the aluminums cans for beverage containers or for soft drink containers, what has driven the market more is a need to cut the waste down because of transportation costs and to be competitive in the market place. (…) Sometimes people get so wrapped up in the design for environment and they forget it is only one small component of so many other factors that influence that product or packaging (BCUOMA)

I am sure the tire people told you what are the major factors in the design of a tire: safety, longevity costs are huge factors on tires. You don't want to be on the road driving 110km/hr and have a tire fail on you. The recycling aspect often works in reverse , the better they design a tire the more challenging it is to recycle it because you want to make sure it is safe (BCUOMA)

The market is driven by demand and to product design depends on what's on the shelf, its attractive and sell. So it does have some importance but it is not something I can influence. (Post Consumer Pharmaceutical Stewardship Association)

3.5.8 Environmental and health impacts

Environmental and Health impacts refer to potential environmental and health risks during the collection and processing of materials. This issue was considered particularly important for materials regulated as hazardous waste: lead-acid batteries, used oil, gasoline and flammable liquids. These products require special handling, storage and transportation in order to avoid risks to human health and to the natural environment. Therefore, managing environmental and health impacts properly was considered *important* or *very important* to these programs.

It is important for us because we are dealing with hazardous materials. Because of the nature of our products there are other [health and environmental] requirements that apply to us but don't apply to other programs. (…) (Product Care)

Oil containers are not only messy but you have to make sure that if the bag breaks they don't drip oil on the road. You have to have spill prevention in the truck, drip trays, etc. And then you have the further challenge of separating the oil from the containers. (BCUOMA)

3.5.9 Ease of siting

Ease of siting refers to the ability to site new collection facilities in the province. The difficulty in establishing collection sites, particularly in populated areas, was raised repeatedly by three participants, who considered siting a major impediment for expanding the collection network in some locations. The other three programs have not experienced any issue associated to siting as their collection networks rely primarily on return to retail.

There are always places we would like to have more collection sites, such as – the west side of Vancouver. It is very hard to get a location we can use. It is very residential. Otherwise, in the interior of British Columbia, it is hard to be everywhere, it is very large land area. (Product Care)

It is very challenging especially in urban areas. (…) In Cranbrook and places like that to site a depot is not an issue for most stewardship programs. But you just imagine in the west end of Vancouver with the high-rises, the challenge I think is that the local government needs to do their zoning. They actually have to build those kinds of facilities right into their urban planning and they haven't done that. (BCUOMA)

The gaps emerge where communities are growing, not so much in remote communities as they are not growing in size. They have been there, they are remote people, we *know where they are and we find various ways to look after them. But most particularly in the fast growing regions like the Okanagan Valley, here in Fraser Valley and in the Lower Mainland. These are areas where population growth is occurring quite rapidly and so that means there is a requirement for additional depots because we are trying to maintain convenience of access and trying to minimize the amount of drive people have. (…) The very specific area [that needs to be better covered] is the city of Vancouver – this is the area in which we are significantly under-serviced. (Encorp)*

3.5.10 Transport incentive

Some agencies, such as the Tire Stewardship Program and BCUOMA have established monetary incentives for transporters. These two programs ranked their transport incentive as *very important* for their program and highlighted the importance of constantly adjusting incentive rates to keep up with changes in transportation costs.

We call it a return incentive and obviously this is very important because we want to ensure that a reasonable amount of materials are collected. The return incentive reflects the driving distance. In the Kootenays we raised it a bit higher than other areas because it is a very mountainous terrain and there is some huge mountain passage they have to go over. (BCUOMA)

Because transportation subsidies did not keep pace with fuel, labour and insurance costs, haulers in order to stop and pick up the tires instituted tipping fees in the Lower Mainland and Vancouver Island. The Tire Stewardship BC recently eliminated tipping fees and will not allow transporters to charge them. Instead, we increased all of the 200 km and down incentive rates and we are now in the process of adjusting the fees over 200 km (Tire Stewardship BC)

3.5.11 Capacity of recycling plants

Capacity of recycling plants was ranked as a *very important* factor by three participants. This seems to be a recurrent issue for programs handling materials with low market value (tires) and with limited options for processing (flammable liquids, paint, gasoline).

If you don't have a financially stable processor, you don't have a program. WE are lucky here in BC to have one of the best tire recyclers in North America. You got the product and then you got to be able to process it and then you got to make money selling it in order for the program to run. (Tire Stewardship BC)

Our options for processing are very limited but we manage. We have to compromise sometimes because of distance and costs. (Product Care)

3.5.12 Consumer incentives

Consumer incentives are available in the form of redeemable deposits for the two recycling programs collecting beverage containers. This issue was therefore not applicable to all programs. For the programs where they existed, consumer incentives were considered *very important* although one participant mentioned that *"other similar programs have been able to achieve a higher recycling rate without a deposit refund"*. In addition, another participant from BCUOMA, when asked about the viability of a deposit refund system in his program replied that "*deposit refund systems are incredibly complex incentives to run and the last thing you want are the children trying to drag dirty oil filters to collect a refund for them. It doesn't make sense. If you look across North America, there are few places where deposit systems have been put in place other than for beverage containers and the reason for that is that because a lot of beverage containers are consumed outside of the home and outside of a place of business".*

3.6 Conclusion

As discussed previously, according to participants' responses, we identified two categories of factors influencing the recycling system: consensus factors and distinguishing (or context specific) factors.

3.6.1 Consensus factors

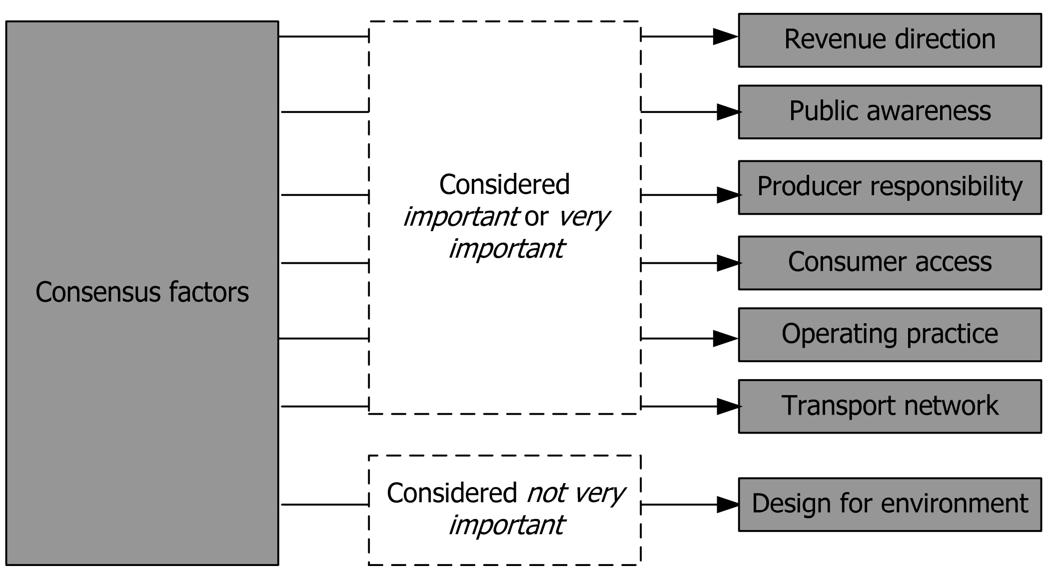

Figure 3-3: General factors influencing recycling system performance

Revenue direction, public awareness, producer responsibility, consumer access, operating practice, transport network were considered *important* or *very important* aspects that positively influence the performance of **all** stewardship programs. These aspects were classified as consensus factors in our analysis because they were considered essential to the success of all stewardship programs in British Columbia. Consensus factors should be taken into account when designing and evaluating the success of all recycling programs.

Producer responsibility and *revenue direction* are intrinsically related because all industry-led stewardship programs are funded through levies or industry fees internalized in price. These fees are essential to cover the capital and operating costs of these programs. The lead-acid battery program is the only stewardship initiative directly managed by the provincial government and there is no mechanism in place to ensure that all revenue collected from the environmental levy is redirected to the program. This situation contradicts the principle of government accountability and prevents effective allocation of resources to address the current deficiencies within the program (as discussed in chapter 2)

Stewardship agencies are also responsible for developing public education and awareness programs. Sometimes not all materials within a product category are included in the recycling program and this generates confusion to the general public. For example, hospital medications are not included in the Pharmaceuticals Program, only empty paint containers are not collected by the Product Care Program and milk is exempt from the beverage containers program. In addition to the challenge of providing reasonable access to consumers, stewardship agencies need to inform the public about the materials accepted at their collection sites. Ideally, the Recycling Regulation should require that the stewardship agencies take responsibility for all products and containers within a product category.

Stewardship programs have utilized several options to enhance *consumer access*, ranging from licensed depots, return to retail and multi-materials depots. Multi-materials depots seem to offer a higher level of convenience to the public, since a variety of products can be returned at one single facility. However, most programs have adopted a combination of strategies, which include community events and partnerships with local business and regional districts. Regional districts have expressed concern over the need for reducing burden of recycling on local government and taxpayers (Barrett 1961; Kosmak 2006). Many regional districts are still financing existing stewardship programs due to the lack of adequate collection facilities and infrastructure in some regions. For instance, the GVRD spends approximately $24 million annually to dispose of and recycle a variety of products, including materials already included in current stewardship programs (Gaudart 2007). Some stewardship agencies, like Product Care, have established a good model by working in cooperation with and providing compensation to regional districts across the province.

Although the MoE encourages producers to test the level of *consumer awareness* about their program and review their communication strategies annually, this is not common practice among most stewardship programs. Several studies have indicated that waste management behaviours are influenced by knowledge of recycling programs (Gaudart 2007) and public awareness (Hansmann et al. 2006), which suggests that knowledgeable and environmentally conscious consumers are more likely to recycle. On the other hand, understanding how well-informed consumers are about a particular program is crucial for designing effective communication strategies. Encorp Pacific has been particularly effective in using a province wide market segmentation study to profile consumer behaviour, attitudes and track public awareness in different regions serviced by its program (McDonald and Ball 1998). In contrast to this, other agencies have not been evaluating the level of public response to their programs systematically. Four stewardship agencies plan to conduct public awareness surveys in the year 2008.

All participants recognized that an effective *transport network* is crucial for the success of any recycling programs given the vast geography of the province and the large distances between populated areas. As a result, many stewardship agencies have utilized a number of service providers to enhance coverage in urban and remote areas. The operating practice of collection sites was also considered very important to program effectiveness given that collection facilities are on the front lines of all recycling schemes. Their overall standards of practice, including customer service and environmental management directly affect the performance of recycling programs.

The extent to which stewardship programs lead to *design for the environment* is questionable. Participants did not consider this a *very important* aspect because *"it is not under their control"*. Much that is written on recycling policies seems to take it on faith that any form of producer responsibility program will drive *design for the environment* incentives, but there is very little careful conceptual thinking on how design improvements occur through the system and there is sparse documentation of real-world changes that have been made in response to policies. Some product design changes to plastic oil containers have been attributed to the BC Used Oil Management Association program (Encorp Pacific 2007), but in general EPR programs have not been able to spur improved product design in British Columbia. According to the stewardship agencies, product design is more influenced by current market trends than by recycling costs. In addition, many participants pointed out that recycling often represents a small portion of production costs and in some cases (e.g. tires and paint) where recycling profits are very marginal, increasing the recyclability of the product, may in fact impact overall product performance.

The *Recycling Regulation Guide* suggests that the stewardship agency be responsible for specifying performance targets on how their products are managed according to each level of the pollution hierarchy and recommend the use some environmental management tools, such as life cycle assessment, risk assessment and design for environment. There is, however, no evidence that any of the stewardship agencies are utilizing such tools for assessment of performance of their products. Our results indicate that it is very unlikely that stewardship program will implement these tools since this assessment involves a comprehensive evaluation of all steps of product life cycle, including those that are not under the control of the stewardship agencies. In addition, the existing set of evaluation criteria need to be reviewed in order to establish clear objectives and performance measures for the variety of dimensions of EPR programs.

3.6.2 Context specific factors

Environmental and health impacts, ease of siting, consumer incentives, transport incentives and capacity of processing plant were classified as distinguishing or context specific factors (Figure 3-4) since their level of importance varied according to the type of material and its associated collection network.

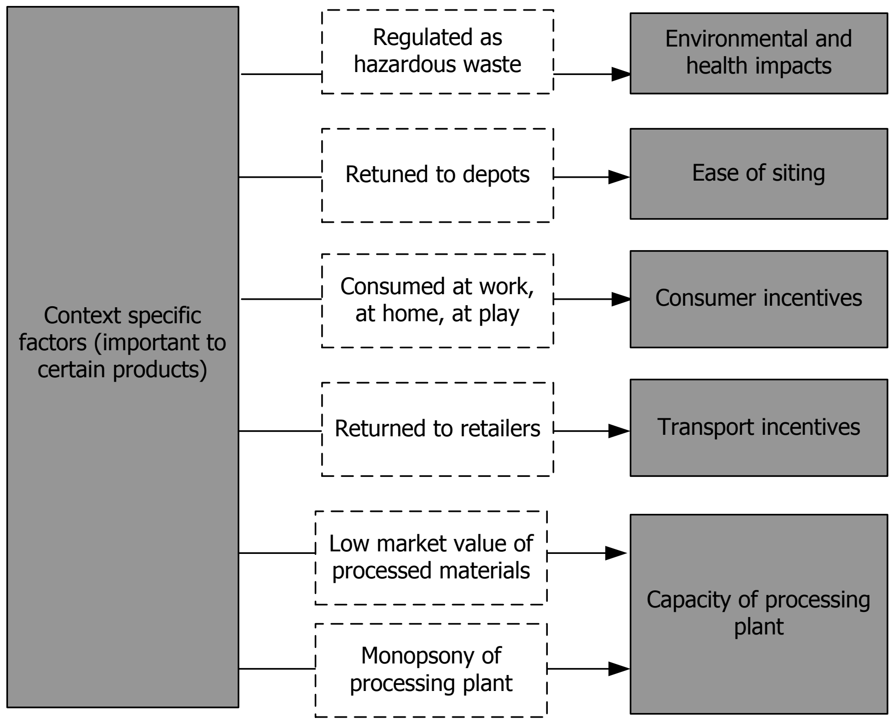

Figure 3-4: Specific factors influencing recycling system performance

Environmental and health impacts were considered particularly important for products classified as hazardous wastes. Hazardous wastes are wastes that could harm human health or the environment if not properly handled or disposed of. More specialized facilities are required to deal safely with these wastes, as they must not be sent to ordinary landfills or discharged to sewer systems. Hazardous wastes range from paints, oils, and solvents to acids, heavy metals, and pesticides. All facilities handling hazardous waste have to comply with the Hazardous Waste Regulation in British Columbia, which establishes special storage and transportation requirements for these products in order to minimize risks to human health and the natural environment.

Ease of siting was considered to be a crucial factor for recycling programs that don't benefit from the current retail chain of distribution and rely on recycling depots and return centers. The biggest challenge for these programs is to site new facilities in highly populated areas given the rising cost of Real Estate and also local community opposition to new depots. Recycling programs, which rely on return to retail, use the existing retail chain and don't necessarily need to site new facilities for collection of their products and have not identified this issue as important.

A *Transport incentive* payment was present in three stewardship programs and was considered particularly useful for those recycling programs, which relied on return to retail such as tires and used oil programs. These programs rely on the existing retail chain for collection of their products and the transportation subsidy provides an additional incentive for the transportation of these products to the processing plant or to recycling facilities. On the other hand, as discussed in Chapter 2, the transportation incentive established by the lead-acid battery program has failed to encourage recycling because it fluctuates according to the London Metal Exchange price of lead and does not take into account regional market conditions. Nevertheless, *transportation incentives, in general* seem to be effective instruments for encouraging systematic collection and transportation of materials in "return to retail" systems, provided that a flexible mechanism is in place to adjust incentive levels to changes in regional market prices.

Consumer incentives are present in the form of deposit refunds in the beverage container programs. Deposit refund systems have been widely recognized as an effective policy mechanism for encouraging consumer returns and reducing waste disposal for beverage containers (OECD 2006). However, deposit refunds may also give rise to greater administrative costs than advance disposal fee because of its costly mechanism of refunding deposits to consumers (Kulshreshtha and Sarangi 2001). Previous studies have concluded that deposit refunds also depend critically on the average value of the time it takes consumers to return empty containers and the average value of the beverage container litter (Palmer et al. 1997; Kulshreshtha and Sarangi 2001). In general, deposit refunds are considered an effective instrument for beverage containers since their consumption takes place in all sorts of different settings (at work, at play and at home).

Calcott and Walls (2005) also argue that producers should not be permitted to keep unclaimed deposits, as they should bear the social costs of disposal for products that end up as waste. In British Columbia, the stewardship agency managing the beverage container recycling program is entitled to keep unredeemable deposits. This situation represents a disincentive to recycling, since revenue to the agency is reduced when the rate of return is increased. Also, since recycling fees do not reflect all costs of recycling, producers may be motivated by a further incentive, which they will not generally have, unless they lose the deposit of unredeemable containers.

Capacity of processing plant is a factor whose importance varies by material type and by the value of the returned materials in the recycling market. In general, commodities with greater value and higher recyclability such as aluminium and oil are less likely to face issues associated with recycling capacity. However, Holland and Lassere (1998) explain that it is necessary to examine the regional demand for recyclables, in order to evaluate the potential value of recycling. This explains why commodities with high market value, such as lead-acid batteries, can also experience challenges due to a limited regional demand, i.e. small number of processing plants located in the province. Therefore, the existence of a monopsony, i.e. a single processor buying large quantities of recyclable materials, is also a limiting factor in the recycling business.

3.7 Discussion

The use of influence diagrams informed by expert interviews helped in the identification of factors that, according to participants' perceptions and experiences, shape the nature of recycling systems in the province. It also provided valuable conclusions regarding which interventions are more likely to contribute to better performance in varied recycling system in British Columbia. The influence diagram summarizes the major features of the system, pooling the knowledge and opinions of appropriate experts. Considered qualitatively, such a diagram specifies those issues that are worth considering, when designing policy alternatives. Considered quantitatively, it provides a basis for determining the relative importance of those issues, taking into account the similarities and differences across recycling systems.

Even without being overly precise, this comparative study provides useful information on the dynamics of existing recycling systems and especially on the factors that should be taken into account to foster improved recycling performance in existing and new stewardship initiatives. Overall, collection and transportation present a great deal of difficulty, because products originate from multiple origins and head to a single destination. The challenge is to find the adequate combination of instruments to maximize consumer returns (consumer access, public awareness, and consumer incentives) and improve logistics (transport network, ease of siting and transport incentives). In addition, some of these factors are context specific and have been demonstrated as particularly important for different type of products (hazardous vs. non-hazardous, consumed at home vs. consumed at different settings), different types of collection network (return to retail vs. return to depots) and different market values of recyclable materials.

It was also found that stewardship programs do not necessarily promote *design for the environment* because of a lack of understanding regarding the roles and responsibilities of stewardship agencies (responsible for recycling) and producers (responsible for manufacturing) in British Columbia. According to Thompson (1988), decisions made at the conceptual design stage are responsible for over 70% of the costs of product development, manufacture and service. Therefore, even though producers are becoming more responsible for how materials and natural resources are used, to be environmentally more sensitive, the pollution prevention hierarchy (Figure 3-1) must be infused throughout the entire product life cycle. This assertion relates to the complete product making process: it pertains to the extraction of raw materials, from which the product (including its packaging) is to be made; the processes to be employed in the manufacture the product; the distribution of the product to the customer; the life of the product; and also its reuse, recycling and disposal.

Gungor and Gupta (1999) explain that *design for environment* can be broken down into many stages, including, manufacturing, consumer use and the end-of-life of the product; and "throughout these stages, different forms of design strategies can be envisioned as the pieces of *design for environment"*. In practice, this is particularly challenging, because many organizations are involved in the product life cycle and, as discussed by the interview participants, sometimes they face conflicting optimal design strategies among themselves (e.g. optimization of recycling performance does not necessary mean improved safety or longevity). Therefore, improved communication between the stewardship agencies and the producers is crucial for better life cycle assessment of product design and to avoid "end of pipe" solutions. In addition, product design decisions need to be better communicated with consumers. Consumers are also becoming more aware of the impacts of their purchase decisions and of the impact of the end-of-life of the product in the natural environment. Ultimately, the aim must be to promote the concept of 'shared responsibility', with all parties involved in and responsible for reducing the footprint of products they design, produce, consume and recycle.

The results presented in this chapter form a valuable contribution on the type of elements that should be considered for designing recycling scenarios in British Columbia. These findings are also applicable to most regions in Canada, where population is sparsely distributed, distances are greater and an active market economy is in place. These conclusions will be revisited in Chapter 5, in which recycling scenarios for the lead-acid battery recycling system in British Columbia will be formulated and then assessed based on a set of performance indicators compiled in Chapter 4.

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Chapter 4 Structuring Objectives and Performance Measures[12]

4.1 Introduction

As discussed in chapter 2, the existing recycling scheme for recycling lead-acid batteries in British Columbia is ineffective, as the recycling rate achieved is an average of 75%, with high levels of fluctuation between the different transportation zones. As we saw in Chapter 3, evaluation of recycling performance of this type of recycling system should take into account not only the recycling rate, but also the environmental and social impacts of recycling at the regional and global level. A comprehensive evaluation tool is therefore needed, in order to properly assess the performance of the recycling system over time and also identify aspects that should be taken into account when designing new strategies

In light of the results of the analysis in the previous two chapters, In Chapter 4, we use value-focused thinking to design a robust series of evaluation measures for the current recycling system in British Columbia. Value-focused thinking allows the structuring of objectives and performance measures based on stakeholder values (Gungor and Gupta 1999). Keeney (1988) explains that values are 'what people care about' and should be the foundation of decisions of public interest. This chapter describes the general methodological approach to identifying objectives based on clearly articulated stakeholders' values and then discusses its application to the problem at hand. The Chapter begins by outlining different approaches for evaluating recycling schemes and is followed by a section which describes how value-focused thinking was applied as a method for eliciting and structuring stakeholder objectives for the lead-acid battery recycling system in British Columbia. In the following section, the results of the stakeholder consultation process, described in the methodology, are presented and this serves as the basis for developing indicators and performance measures for the recycling system. The chapter ends with a discussion of how this work provides a robust set of objectives that can be used to evaluate recycling systems in general.

[12] A version of this chapter will be submitted for publication.

4.2 Concepts for analysing recycling schemes

The predominant methodology employed in the evaluation of recycling schemes to date has been Life Cycle Analysis (LCA). LCA is a technique for assessing the existing and potential environmental impacts associated with a product by compiling an inventory of the relevant inputs and outputs of a product system and evaluating the potential environmental impacts associated with those inputs and outputs (Keeney 1992). A number of studies have applied this methodology to managing the supply chain of lead-acid batteries at the regional level. For instance, Tsoulfas et al (2003) discuss life cycle analysis (LCA) of spent batteries and use this approach to assess recycling and disposal schemes in different parts of the world. Daniel et al (2002) used LCA to compare the impacts of disposal and recovery scenarios of lead-acid batteries in Greece.

It is worth noting that throughout its development, LCA has been regarded as a quantitative analytical tool. There are a number of difficulties with the conventional processes or approaches to LCA (Pesso 1993; Daniel et al. 2003). The first stage in the analysis involves quantitative comparisons of materials flows, which can be an extremely valuable exercise, if done carefully. However, a rigid boundary, necessarily somewhat arbitrary, is required to make the analysis tractable. This boundary generally excludes many of the processes and environmental discharges important in the lead-acid battery Life Cycle (Weidema 1993; Tillman et al. 1994; Matthews et al. 2002). In addition, the process is also inherently time consuming and expensive (Ayres 1995; Matthews et al. 2002).

The most important shortcoming of this technique, however, is that it is difficult to accommodate, at the inventory stage, qualitative information such as the public perception, occupational safety and risks and the 'renewability' of resources (Ayres 1995; Craighill and Powell 1996). Socolow and Thomas (1996), for example, propose that the key criteria that an ideal lead-battery recycling system must meet include: maximal recovery of batteries after use, minimal export of used batteries to countries where environmental controls are weak, minimal impact on the health communities near lead-processing facilities, and maximal worker protection from lead exposure in these facilities. Conventional LCA usually does not capture these elements, despite the fact that they are essential for policy purposes (Socolow and Thomas 1997).

Recently, the LCA community has recognized the importance of characterizing those effects that raise societal concern (Miettinen and Hamalainen 1997). This trend reflects the recognition by LCA analysts that environmental stressors affect society in different ways and many social issues cannot be dealt with solely by quantification or through scientific approaches (Anex and Focht 2002). As a result, in recent years there has been an increasing interest in combining LCA methods with more constructive approaches such as value-focused thinking and decision analysis (Weinberg 1972; Cowell et al. 2002; Rahimi and Weidner 2004). These decision analytical tools have been recognized as particularly useful for scoping and for understanding the recycling process and its ecological and human health impacts.

Value focused decision analysis has been identified as an appropriate framework for analysing recycling systems because they are complex, involve multiple stakeholders with a variety of potentially conflicting concerns and because they incorporate significant uncertainties (Udo de Haes 1993; Miettinen and Hamalainen 1997). Value focused thinking decision analysis has been implemented to guide decision making in a range of resource management issues of public interest, including resource planning at BC gas (Miettinen and Hamalainen 1997; Keeney and McDaniels 1999), water management (Hobbs and Horn 1997), fisheries management (McDaniels et al. 1999), mining policy decisions (McDaniels 1995) and nuclear waste management (Keeney 1988; Gregory and Keeney 1994). Similarly, life cycle study contents can also be structured based on decision analysis tools; so that resources can target those questions that merit the most effort. Several studies have illustrated how the integration of decision analysis can improve LCA as a tool for policy analysis (Miettinen and Hamalainen 1997; Brans et al. 1998; Tillman 2000; Keeney 2004).

This study uses decision analytical tools to organize a series of objectives identified by stakeholders involved in the lead-acid battery recycling system in British Columbia. This process allows consideration of a broader range of objectives, than has been used in previous studies. These objectives will be used to evaluate and assess the best course of action for the provincial lead-acid battery recycling system in Chapter 5.

4.3 Methods: value focused thinking

In recent years, the growth of stakeholder participation in decisions of public interest has resulted in demands for effective decision making processes. However, public decisions are often controversial and involve conflicting economic, social and environmental interests (Miettinen and Salminen 1999). The lead-acid battery recycling system is a typical example of a complex decision, as it involves multiple stakeholders with a variety of objectives. Although recycling is usually considered as a strategy for waste minimization, the recycling process itself also has the potential for creating significant economic and environmental and social impacts. However, performance evaluation has generally been based exclusively on the percentage of batteries collected, without taking into account the potential impacts involved in the recycling system. The absence of a comprehensive set of performance indicators makes effective evaluation of these systems extremely difficult to accomplish. Thus, addressing stakeholder objectives at each stage of the recycling process, including collection, transportation and processing is crucial in order to create performance measures for evaluation of recycling system, capable of driving broadly improved performance.

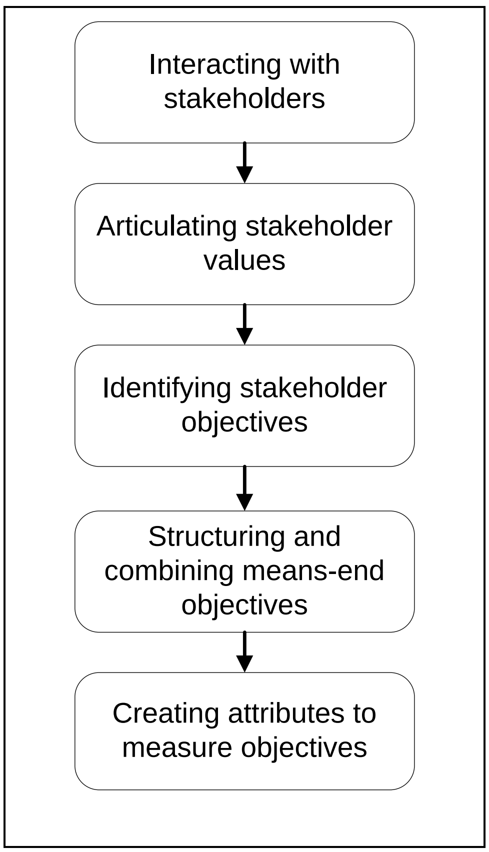

Figure 4-1: Sequential steps in value-focused thinking

Value-focused thinking provides a structured process for identifying the objectives and performance measures in problems of public interest (Gregory and Keeney 1994). This process starts by selecting and interacting with stakeholders involved with the issue. The next step consists in identifying stakeholder "values" (Figure 4-1). Keeney (1994) explains that "values" should be the primary focus of the decision as they are the "principles for evaluating the desirability of any possible alternatives or consequences". In order words, values are "what matters" for an individual or group; they are the things that are cared about and which raise concern in a given context. Since these values are fundamental for identifying objectives, they should form the basis for evaluating decisions involving stakeholders (Keeney 1992). Traditional decision framing that focuses on alternatives fails to meet societal objectives because it does not carefully articulate stakeholder "values" before formulating solutions (Keeney and McDaniels 1992).

Once values have been identified, they are structured into means and ends objectives. This process offers a solid conceptual basis for relating objectives to one another and also provide a deeper and more accurate understanding of the objectives over which the performance measures or attributes should be constructed (Hammond et al. 2002). The next sections of this chapter describe how this logical approach was used to identify and structure objectives and performance measures for the lead-acid battery recycling system in British Columbia.

4.4 Interacting with stakeholders

From July to December 2005, in-depth interviews were conducted with 54 representatives from organizations from 22 municipalities in British Columbia). To maintain the focus and manageability of the study, the sampling strategy aimed to purposefully select a sample of participants with a wide range of experiences and perceptions related to the recycling system. Collectors and transporters were identified from the list of waste generators provided by the Ministry of Environment in 2004, which contains information on any individual, partnership or company in British Columbia that produces or stores more than 1,000kg of lead acid batteries in the province. Fifty-four companies were sampled to represent a variety of settings: small, medium, or large business; rural or urban setting; and primary or secondary waste generator. Battery collectors included scrap dealers, auto wreckers, recycling depots, retailers, brand-owners, manufacturers, distributors and recycling plants.

There are two recycling plants and one large scale lead-zinc smelting plant involved with recycling and processing lead-acid battery in the province: Metalex, KC Recycling and TeckCominco Trail Operations. Metalex is a small scale combined battery processor and secondary smelter which exclusively processes lead acid-batteries to reclaim lead, plastic, and acid electrolyte. KC Recycling is a lead-acid battery recycling plant which breaks approximately 75% of all acid batteries collected in British Columbia. KC Recycling also receives batteries from the USA and two other provinces in Canada, namely Alberta and Saskatchewan. Since KC Recycling does not have a built-in smelting plant, its lead-bearing material is sold to a large-scale lead-zinc smelting complex, TeckCominco Trail Operations, located in Trail, British Columbia. Metalex and KC Recycling also recover the polypropylene casings from lead-acid batteries, which are sold to plastic recycling companies for making plastic moulded products. It should be noted that Metalex and KC Recycling frequently exchange scrap batteries with each other for processing. Such exchanges are necessary to keep inventories flowing, in order to prevent scrap batteries being stored over the allowable permit levels (Bob Paul, May 2005, personal communication, Ministry of Environment).

TeckCominco Trail Operations is an integrated zinc and lead smelting and refining complex. Its production capacity totals approximately 290,000 tonnes/year of zinc and 120,000 tonnes/year of lead. Twenty other metal and chemical products are also produced in this complex. Approximately 10% of the total lead input in TeckCominco Trail Operations comes from lead-acid batteries, the majority of the remaining 90% is provided by the lead-zinc concentrate produced at Red Dog mine in Alaska.

All scrap lead-acid batteries generated in the province are transported to Metalex or KC Recycling in order to be processed. The relationship between all stakeholders involved in the lead-acid battery supply chain in British Columbia is illustrated in a simplified diagram below (Figure 4-2).

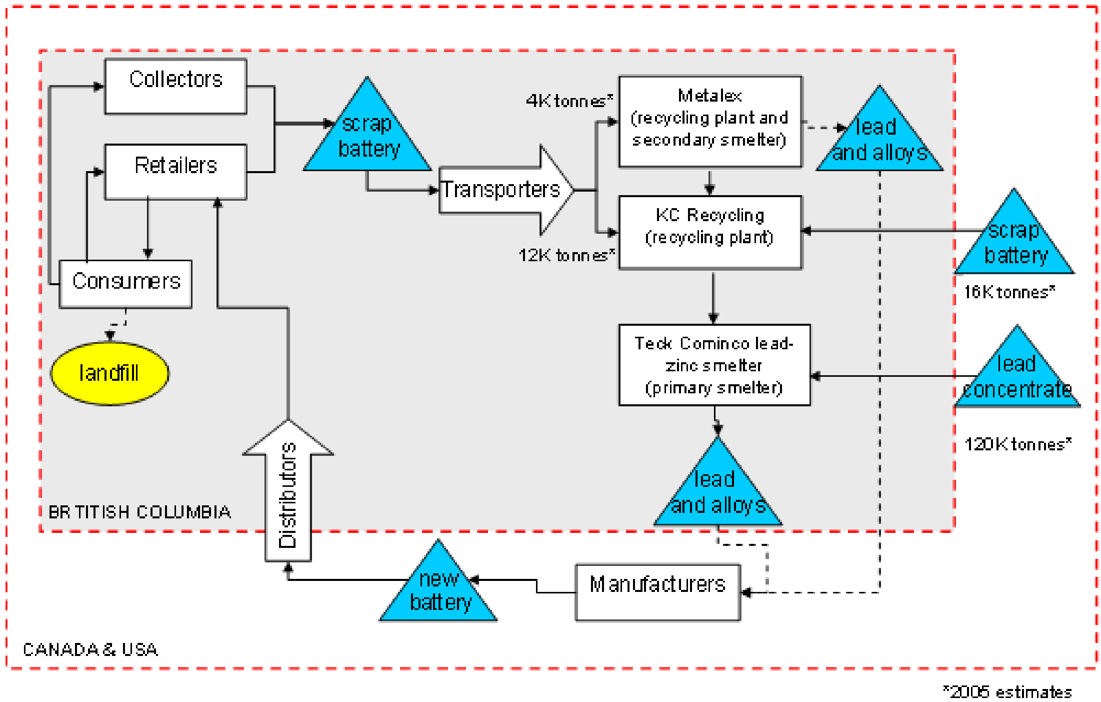

Figure 4-2: The recycling system in British Columbia

Approximately 57% of scrap batteries are generated and collected in the Lower Mainland where the majority of the companies contacted were located. A letter of introduction was faxed or emailed to 70 companies, including the recycling plants, accompanied with the questions for the structured interview and a questionnaire. Stakeholders received a phone call within two weeks to schedule a 30 minute to 1 hour semi-structured interview with the site manager. All participants were assured of anonymity and confidentiality. Most interviews (81%) were performed on site and the remainder were conducted over the phone. Questionnaires provided information on the amount and types of scrap lead-acid batteries handled by collectors. Site visits were very useful in providing contextual insight on the conditions of these facilities and the challenges faced by participants. Fifty-four interviews (14 manufacturers, brand-owners and wholesalers, 21 recyclers, 12 regional districts, 5 transportation companies and 2 recycling plants) and questionnaires were completed in 22 municipalities, 11 companies were no longer in business and 5 companies were unwilling to participate.

4.5 Translating stakeholders concerns into objectives

During the in-depth interview process, companies were asked to express their concerns with the current system and suggest alternatives that would address these concerns. The interviews were structured according to the Value Focused Thinking methodology, adapted from Keeney (1994). The interviews started by asking participants background questions about their participation in the current recycling system. They were then asked to describe their concerns, overall impressions and expectations regarding the performance of the lead-acid battery recycling program. The participants were also encouraged to talk about the major issues associated with each phase of the recycling system. The interview guide is included in Appendix G.

The interview results were sorted into themes or categories to create a final set of issues associated with each phase of the recycling system. The number of respondents who referred to a particular theme is represented by the numbers in brackets (Table 4-1). For example, Table 4-1 reveals that low level of consumer incentives and producer responsibility are the major issues associated with the collection of batteries. In the transportation stage, the main problems identified by respondents included low transportation incentives, the long distances to the recycling plants and the low prices of scrap lead. Companies also raised concerns related to occupational health and the environmental impacts of breaking and processing lead-acid batteries. Other issues such as the lack of stakeholder consultation, performance evaluation and revenue direction were also brought up during interviews.

Table 4-1: Summary of the stakeholder responses to the interview questions (n=54).

What do you think are the major issues associated with collection of lead-acid batteries?	• Low level of producer responsibility (19) • Lack of consumer incentives to bring it back (18) • Few drop-off facilities (15) • Low storage capacity (13) • Public unawareness of environmental impacts (12) • Low returns from public(10) • Inadequate storage facility (5) • Unclear health and safety requirements (4) • Lack of adequate training to store hazardous waste (4) • Worker exposure to acid electrolyte (4)
What do you think are the major issues with transportation of lead-acid batteries?	• Low transportation incentive payments (36) • Distance to processing plant (27) • Low price of scrap lead paid by processing plants (23) • Fuel costs (15) • Freight costs (13) • Expensive and labour intensive paperwork (13) • Unclear health and safety requirements (10) • Lack of adequate training to handle hazardous waste (5) • Delay in scheduling licensed trucks (2)
What are the major issues with breaking and processing lead acid batteries?	• Lead exposures (workers) (5) • Lead emissions to communities (5) • Waste disposal from recycling plant (5) • Waste disposal costs (3)
Are there any other issues?	• Revenue from $5 levy not directed into the program (25) • Lack of stakeholder consultation (6) • No performance evaluation (4)

The list shown in Table 4-1 provided insights about their concerns associated with the recycling system in British Columbia. The overall approach was used to help stakeholders articulate their objectives, which are used in the Value Focused Thinking methodology as the foundations for the decision making process. However, we found that objectives are usually difficult to articulate at the initial stage of the interview process and that talking about concerns and shortcomings proved to be an effective way to stimulate thinking about a decision situation (Keeney 1992). Thus, we asked stakeholders to consider the problems experienced with the recycling system, and then we used their list of concerns to articulate the reasons for each concern. Establishing the reasons for each concern involved returning to the selectively transcribed interviews and identifying the reasons discussed by each interviewee. This approach proved to be very effective and minimized any difficulties we might have encountered when asking stakeholders to articulate values and objectives up front.

4.6 Articulating means and end objectives

Very few studies have established a clear and comprehensive set of objectives for evaluating recycling schemes. Sucha More & Associates (2002) developed a set of indicators of stewardship principles and business delivery options for British Columbia, including: producer/user responsibility, results-based, flexibility, transparency, stakeholder and industry involvement and level playing field. However, these indicators did not integrate stakeholder objectives and did not follow a systematic methodology to avoid misclassification.

Using value-focused thinking, a set of objectives emerged from a combination of interview responses and observations at site visits. These objectives were organized into the means-end objectives framework presented in Figure 4-3. More specifically, after each individual was invited to talk about the main challenges and concerns faced in the recycling system, they were asked to describe the objectives associated with this issue that they felt were important to improve the overall performance of the system. For instance, one issue of concern associated with collection of lead-acid batteries was "low public returns" (Table 4-1). The objective associated with this issue was usually stated as "increase public returns". For this, and any other objective, one question was always asked, "why is this important"? Interviewees in turn provided different responses such as "to reduce number of batteries going to landfill", "to increase quantity of batteries recycled" and "to share costs and responsibilities associated with recycling". We then kept asking the question "why is this important?" until a fundamental objective was reached. The fundamental objectives capture the essential reasons for interest in the decision situation and describe the "consequences that public directly care about", which will later serve as the basis for creating performance measures relating to this decision situation (Keeney 1992).

To provide more details, following the same example, the next question to ask is "how would you increase public returns"? One answer in this case was that mandatory take back from manufacturers, distributors and retailers would facilitate collection scrap batteries from customers. Another answer suggested that the implementation of consumer incentives such as deposit refunds would also increase collection from consumers. These responses indicate that producer responsibility and consumer incentives (e.g. deposit refunds) are potential means of attaining the means objective of "increase public returns" and, ultimately, the fundamental objective of "increase equity in resource consumption patterns". After pursuing all of the objectives suggested by each participant, the means objectives were then structured into categories. Responses were scrutinized in order to remove duplicates and separate means from fundamental objectives. Keeney (1988) clarifies that means objectives are "objectives that are important only for the influence on achievement of fundamental objectives". More usefully, the diagram easily illustrates how the issues listed as major concerns in the collection of lead-acid batteries, such as "consumer incentive", "public returns", "public awareness" relate to each other and contribute to the fundamental objectives.

The combined means-objective framework (Figure 4-3) offers a big picture of different stakeholder values and the causal relationships among the objectives. In the next round of interviews, a sub-set of 8 participants representing different stages of the recycling system were asked to review their combined objectives to ensure that their values were represented either implicitly or explicitly and to provide their opinions on appropriate performance measures for each objective. Some suggestions were made to clarify the description of the fundamental objectives and the final means-end objective framework is presented in Figure 4-3.

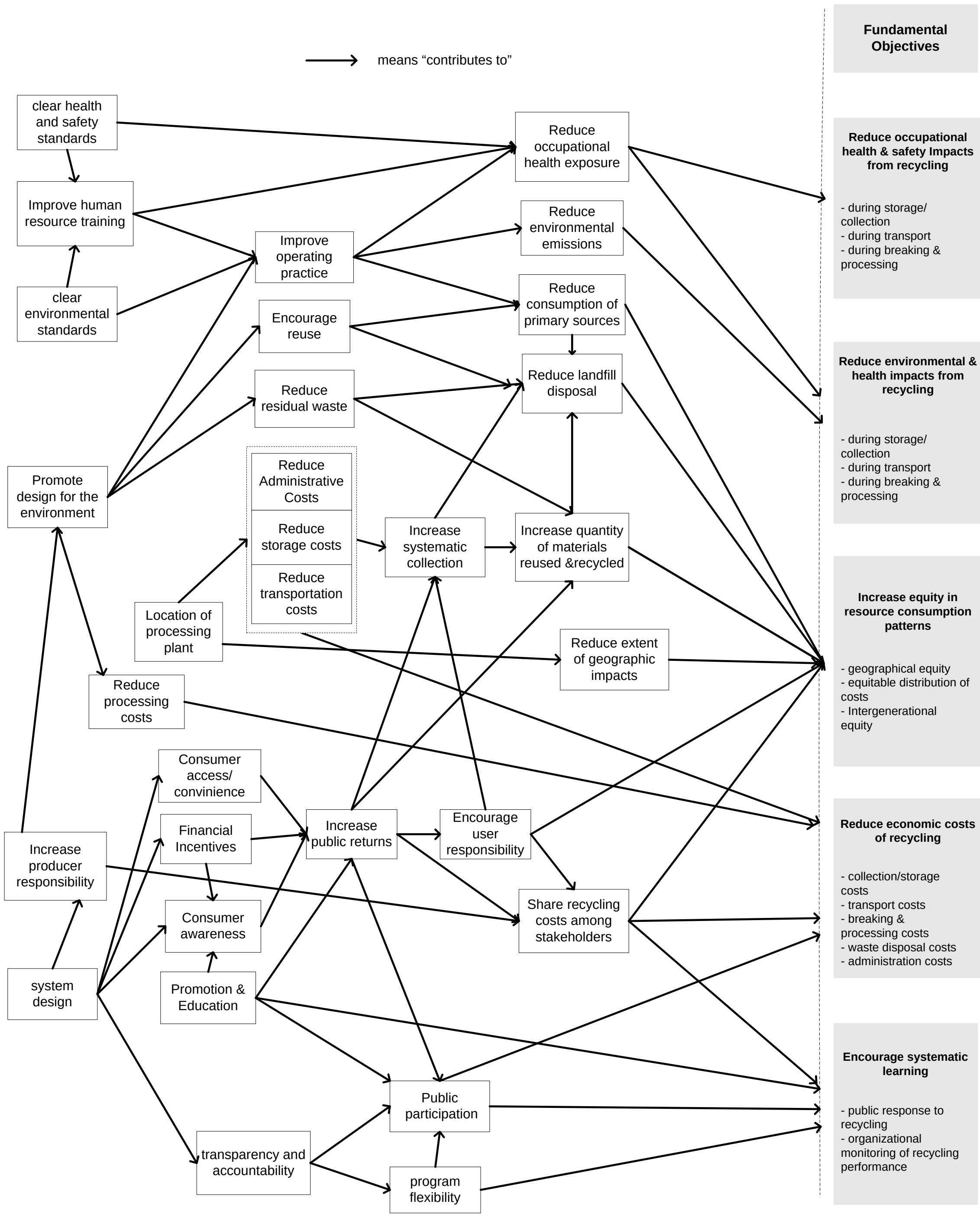

Figure 4-3: The means-end objectives network of the lead-acid battery recycling system

This approach assisted in the definition of five fundamental objectives for the recycling system (Figure 4-3), which are also illustrated in the fundamental objectives hierarchy or value tree (Figure 4-4). In essence, the fundamental objectives comprise all results that are important in the decision situation. Each subdivision of a fundamental objective hierarchy specifies the aspects included in the definition of that fundamental objective. For example, occupational health and safety impacts are specified in terms of the effects during each stage of the recycling system, i.e. during collection, transportation, breaking and processing of scrap-lead acid batteries (Figure 4-4). Keeney (1992) clarifies that fundamental objectives should be complete, compact, operational, concise, understandable, non-redundant and measurable (Keeney 2004). A good set of fundamental objectives is crucial for the identification of attributes or performance measures, which is discussed in the next section.

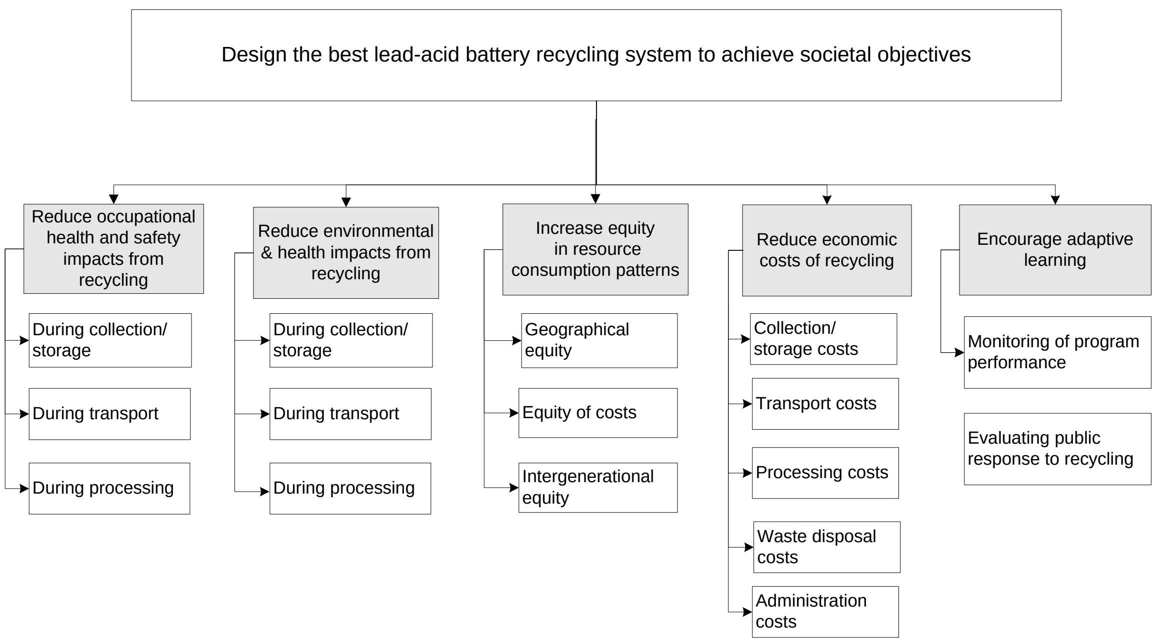

Figure 4-4: Fundamental objectives hierarchy of the recycling system in BC

4.7 Results expressed as attributes

In this chapter, the terms 'attributes' and 'performance measures' are used interchangeably. Attributes clarify the meaning of an objective and are essential for measuring the achievement of a particular objective. This measurement is necessary to indicate the level to which these objectives are met when evaluating alternatives strategies for the future.

After all objectives had been identified and refined, the next step was the construction of performance measures or attributes. The initial set of performance measures was collected from insights during the interview process and also through an in depth literature review. Some suggested measures for environmental and economic impacts of recycling were identified in previous LCA studies (Keeney 1992; Ayres 1997; Daniel et al. 2003; Tsoulfas et al. 2003; Salomone et al. 2005). Occupational health indicators were also obtained from previous exposure assessments conducted at lead-acid battery recycling facilities. The experience of recycling programs in other jurisdictions, including Portugal, France (Daniel et al. 2003), Italy (International Lead and Zinc Study Group 2001) and USA (Ahmed 1996) were also useful in revealing general aspects of recycling schemes that influenced system performance.

In addition, two experts from the School of Health and the Environment at the University of British Columbia were contacted in order to provide feedback on the performance measures associated with occupational health, environmental and health impacts of lead. The final set of objectives and associated performance measures are provided in Table 4-2 to Table 4-7.

Previous research has identified three types of attributes: natural attributes, proxy attributes and constructed attributes (Battery Council International 2003; Keeney and Gregory 2005). Natural attributes are usually quantitatively measured and "directly measure the degree to which an objective is met" (Keeney 1992). For instance, the objective "reduce economic cost of collecting and storing batteries" has the natural attribute "cost measured in dollars spent per battery". Natural attributes have the advantages of being easily quantifiable and are intuitive, that is, their significance is easily comprehended by most people (Keeney and Gregory 2005).

Proxy attributes involve a quantitative measure that is related to the measurement of an objective, but does not directly measure the achievement of an objective. For instance, for objectives involving "occupational health and safety impacts to workers during processing", a natural attribute would be a measure of worker mortality or morbidity associated with lead exposure. In this case, a proxy attribute could be created based on the “concentration of blood lead levels in workers”, which is a common measure used to assess high lead exposure to lead. Certainly, the concentration of lead in workers’ blood levels is associated with the level of mortality or morbidity but it does not directly measure mortality and/or morbidity. However, concentration of blood level levels in workers may be selected because of its convenience and availability, compared with the much more difficult situation of measuring mortality and morbidity and determining an approach for determining the contribution of lead to these outcomes. Blood tests are relatively easy to collect and have been universally adopted as the primary biological parameters for monitoring lead exposures to workers (Keeney 1992). Often, proxy attributes are chosen because the difficulty in collecting data on natural attributes (Mayer and Wilson 1998). Proxy attributes share the advantage of intuitiveness with natural attributes, however, they must be applied more cautiously than natural attributes, with reference to the influence diagrams produced. This is because many proxy attributes are means objectives which contribute to a variety of fundamental objectives, thus leading to potential double measuring of fundamental objectives.

Constructed attributes are designed to measure the achievement of objectives when there are no natural attributes directly associated with the objective. For instance, we developed a constructed attribute to measure the “equitable distribution of recycling costs”. Simply using a number to describe this attribute is not possible as there are several aspects involved in the definition of this objective and no natural scale exists to measure it. For these situations constructed scales represent the most effective way to provide a qualification of issues (Gregory 2005; Keeney and Gregory 2005). As a result, a constructed scale was created based on fundamental aspects associated with “equitable distribution of costs”, which included variations in cost sharing among key stakeholder groups (government, consumer and producers) ordered in a well defined five point constructed scale. Constructed scales are similar to a Likert point scale[13] but the key distinction is that the constructed attribute levels are ordered by statements carefully defined to indicate possible consequences. The most effective constructed

[13] Likert scaling is a psychometric response scale often used in surveys and questionnaires to measure positive or negative response to a statement. A typical five point likert s**cale** asks the respondent whether they Strongly Agree - Agree - Undecided - Disagree or Strongly Disagree with a particular question.

attributes provide careful descriptions of each level of the constructed scale (see Table 4-4 for an example) rather than simply qualifiers (e.g. good, medium, poor). Gregory (1992) explains that "collectively, the set of consequences levels should cover the range of possible consequences related to the corresponding objective".

Selecting attributes is an important part of the process and regardless of their type, attributes should be measurable, operational and understandable (Gregory 2005). In the following sections we discuss each of the attributes proposed for measuring the achievement of objectives for the lead-acid battery recycling system in more detail. The attributes are presented in tabular format in Table 4-2 to Table 4-7.

4.7.1 Attributes for occupational health and safety impacts

In terms of occupation health and safety impacts, each stage of the recycling process requires separate consideration, since occupational health and safety hazards vary within each phase of the recycling process. Therefore, a separate set of natural and proxy attributes was developed to address the health effects on workers and when applicable, the indirect effects to workers' families, during collection, transportation, breaking and processing of lead-acid batteries.

At the collection and transportation stage, the occupational health concerns are mainly associated with spillage of acid electrolyte, the diluted sulphuric acid solution in which the lead electrodes are submerged (Keeney 1992). Battery electrolyte is corrosive and may cause skin irritation and chemical burns. Ingestion and respiration of acid electrolyte may also cause severe irritation of the nose, mouth, throat and stomach, followed by severe burns and vomiting (Technical Working Group of the Basel Convention 2002). Workers are usually more susceptible to the health effects of electrolyte than the general public due to a higher risk of direct exposure. A natural attribute for this objective "reduce occupational health impacts during collection/storage" would be the number of worker injuries associated with this exposure.

In the absence of data associated with the natural attribute, a proxy attribute may be established. According to international standards and provincial regulations, scrap lead-acid batteries should not be drained at collection points and batteries must be stored inside an acid-resistant container during collection and transportation. A proxy attribute would include the percentage of batteries stored according to UN packing instructions 801, which stipulates that batteries should be stored inside sealed containers, on wooden slatted crates or on pallets. These measures assess the potential of spillage of acid electrolyte in the work environment. As a suitable proxy attribute is available to measure this attribute it is not necessary to assess more complicated constructed attributes.

The most significant occupational health impacts of lead-acid battery recycling are associated with lead exposure during breaking and smelting. In addition to acid-electrolyte, workers in secondary and primary lead smelters are potentially exposed to levels of lead that are associated with adverse health effects. The ideal natural attribute to measure the occupational health impacts of lead would be the mortality and the morbidity rate associated with lead exposure. Blood lead levels above 10 μg/dL in adults have been associated with increased risk of cardiovascular disease, myocardial infarction, stroke, cancer and lung cancer and mortality (CCOHS 2007). Other health risks associated with high lead exposure include anaemia, deterioration of the central nervous system, renal effects, hypertension and blood pressure (Mayer and Wilson 1998; Menke et al. 2006).

Mortality could be measured using the number of deaths occurring during the year divided by the total exposure, or person-time at risk, during that year. For example, if in 10 workers exposed to lead in a given year, one person died four months into the year (one-third of a person-year at risk of death), three people died six months into the year, and the remaining six people lived to the end of the year, then the total exposure for the year would be $1/3 + 3\times1/2 + 6\times1 = 7.83$ person-years. Since the total number of deaths was 4, the mortality rate for the exposed group would be $m = 4/7.83 = 0.51$. This would be compared with the results for the "unexposed" group and the rate in the exposed divided by the rate in the unexposed would be the "rate-ratio or risk-ratio", that is =1 for no difference, and >1 if there is an effect in the exposed group. Similarly, the morbidity rate refers to the number of individuals who have contracted any disease listed above during the year (the incidence rate) or the number who currently have the disease (the prevalence rate), divided by the size of the worker population exposed to lead.

Table 4-2: Attributes for occupational health and safety impacts from recycling

Objective: Reduce occupational health and safety impacts from recycling	**Natural attributes**	**Proxy attributes**
Occupational health impacts during collection/storage	- # work injuries due to exposure to acid electrolyte	- % batteries stored in compliance with UN packing instructions 801 (in sealed containers, on wooden slatted crates or on pallets)
Occupational health impacts during transportation	- # of work injuries due to exposure to acid electrolyte	- % batteries stored in compliance with UN packing instructions 801(sealed containers, on wooden slatted crates or on pallets)
Occupational health impacts during breaking & processing (due to acid electrolyte and lead exposure) o impact on workers o impact on worker's family	- worker mortality rate (employee deaths/person years at risk) - worker morbidity rate (employee disease/person years at risk) - Intellectual development of worker's children for different age groups (Health Canada 2006)	- % female workers with blood lead levels in excess of 50% or more of exposure limits of >10 ìg/dL (Worksafe BC 2007) - % female workers with blood lead levels in excess of 50% of exposure limits of >10 ìg/dL (Worksafe BC 2007) - % worker's children blood lead levels >10 ìg/dL (Health Canada 2006) - Level of compliance to OHS regulation: Provision of shower facilities, separate room for storing food; (6.63 Personal Hygiene); Surface cleaned regularly and free from accumulators of lead dust (6.64 Work Surfaces), lead dust removed from work areas (6.65 Lead Removal), Level of employee instruction and training (6.66 Instruction and Training) (Worksafe BC 2007)

When data for calculating mortality and morbidity rate are not available, blood lead levels may be used as proxy attributes. Because lead is accumulated in body tissues, several studies have conducted biological monitoring for assessment levels of occupational exposure to lead in primary and secondary lead smelters (Mayer and Wilson 1998; Karlsson 1999; Dahodwalla and Herat 2000; Tsoulfas et al. 2003; Donguk and Namwon 2004; Ye and Wong 2006). In Canada, most provincial governments require that lead exposed workers be monitored for blood lead levels and blood level intervention levels for children and adults have been established at 10 µg/dL. Some countries have set a lower limit for women than for men since the effects of lead on reproduction may occur at lower levels of exposure. Blood levels considered to pose negligible risk have decreased steadily over the years (Fonte et al. 2007) and evidence suggests possible adverse health effects on children at blood levels of only 10 µg/dL. Since pregnant women are considered a sub-population of special concern as a result of the potential for lead exposure to the developing of fetuses (Mayer and Wilson 1998), it is suggested that results of lead exposure to women and men working at recycling plants be analyzed separately. Female workers exposed to high levels of lead during a long period of time are more susceptible to miscarriages and stillbirths (Mayer and Wilson 1998).

Moreover, the risk of lead exposure among lead-exposed workers' families has long been identified as a public health concern, with several studies indicating higher levels of lead exposure among family members, especially children (Roscoe et al. 1999; Aguilar-Garduño et al. 2003; Health Canada 2004). Blood lead levels are by far the preferred indicator used in all of these studies and have also been included as a proxy attribute in Table 4-2. Other potential proxy measures for take home lead exposure would be the level of compliance with specific control measures. For instance, the Occupational Health and Safety (OHS) Regulations in British Columbia provide specific guidelines on personal hygiene, work surfaces and lead removal to prevent lead skin, hair, clothes and vehicles from being contaminated and carried out to home (Piacitell et al. 1997; Worksafe BC 2003). These measures include the provision of shower facilities in breaks and at the end of shifts, the separation of street clothing and work clothing, the provision of a separate room isolated from the work area for storing food and for drinking (Health Canada 2004). These guidelines extracted from the regulation have been included in Table 4-2 as proxy attributes for reducing the health impacts on workers' families. Although a natural attribute (mortality and morbidity rate) would be a better measure, this is not practical in most circumstances since epidemiological studies are very costly and time consuming to implement. In this case, proxy measures are more useful for routine hazard assessment related to occupational and take home exposures.

4.7.2 Attributes for environmental and community health impacts

The links between environment and health have long been discussed in the literature and, as a result, many governments and international agencies now recognize the need to strengthen the role of environmental and health considerations in decision-making processes (Worksafe BC 2003). Environmental and health impacts are interrelated and vary according to the stage of the recycling process. Similar to occupational health impacts, previous LCA studies have also concluded that most of the environmental and health impacts of recycling are concentrated in breaking, smelting and refining (Davies and Sadler 1997; Tsoulfas et al. 2003). Tsouflas et al (2003) concluded that breaking and smelting are responsible for approximately 94% of power demand, 98% of resource consumption and 70% of the airborne emissions of the recycling process. Salomone et al (2005) also presented similar results, in which smelting and recycling process contributed more than 95% in all of the impact categories under study (greenhouse effect, terrestrial toxicity, human toxicity, photochemical oxidant formation, odour, eutrophication, aquatic eco-toxicity and air acidification). In addition, the community health impacts from collection and transportation are more dispersed and not concentrated on a specific community, and thus the acuity of concern is lower.

Given the lack of data and the limited community health impacts associated with collection and transportation, only environmental impacts attributes (and not community health impacts) have been included for these stages. Therefore, for the purpose of this study, the non-occupational health impacts on communities are addressed only in the breaking and smelting stages.

During collection and storage, the key environmental impacts are associated with risk of sulphuric acid leakage to groundwater and site contamination. The storage area is required to have an acid resistant and impermeable ground cover, which must retain any leakage and direct it to a collecting container to avoid site contamination (Salomone et al. 2005).

Table 4-3: Attributes for environmental and health impacts from recycling

Objective: Reduce environmental and health impacts on communities from recycling	**Natural attributes**	**Proxy attributes**
Environmental impacts during collection/storage • Groundwater contaminations • Land use	- tonnes of sulphuric acid leaked to groundwater OR # of spills - hectares of contaminated sites: soil quality guideline for industrial land use >600mg/kg; (CCME 1996)	- % batteries stored in compliance with UN packing instructions 801(sealed containers, on wooden slatted crates or on pallets)
Environmental impacts during transport • Groundwater contamination • Airborne emissions	- tonnes of sulphuric acid leaked to groundwater OR # of spills - tonnes of carbon monoxide[14] - tonnes of carbon dioxide[2] - tonnes of Nox[2] - tonnes of VOC[2] - tonnes of particulates[2]	- % batteries stored in compliance with UN packing instructions 801(sealed containers, on wooden slatted crates or on pallets)
Environmental and Health impacts during breaking & processing • Airborne emissions • Water contamination • On site releases (air, surface water, land) • Waste disposal • Land use • Noise • Odour • Energy consumption	- community morbidity rate - community mortality rate - Intellectual development (IQ) of children resident in local area (for different age groups) - hectares of lead contaminated sites, soil quality guideline for industrial land use: >600mg/kg; agricultural land use: >70mg/kg; residential land use: >140mg/kg (CCME 1996) - lead levels in private water wells close to site: > 0.010 mg/L (Health Canada 2006) - Noise levels (dB)- kWh electric energy (KWh) - Liquid fuels (oil, etc.) (Megajoule)	- adult blood lead levels (>10 ìg/dL) (Health Canada 2006) - children blood lead levels (>10 ìg/dL) (Health Canada 2006) - tones of carbon monoxide[15] - tones of carbon dioxide[3] - tonnes of sulphur dioxide released to air[3] -kg of lead released to air[3] -tonnes of particulate matter released to air[3] - kg of lead disposed off site[3] OR - % batteries sheltered from rain and other sources; % batteries protected against leakage (ground cover or collecting container); - community complaints about noise - community complaints about odour

[14] Based on Daniel et al (2003)
[15] Based on emissions to air and water reported by lead-acid battery processing facilities in the National Pollutant Release Inventory (NPRI) http://www.ec.gc.ca/pdb/npri

In California broken batteries have left a legacy of highly contaminated soil and groundwater (Technical Working Group of the Basel Convention 2002). Previous LCA have identified the following airborne emission during the transportation of lead-acid batteries from storage/collection facilities to recycling plants: carbon dioxide, carbon monoxide, nitrogen oxides, particulates and volatile organic compounds (Department of Toxic Substances Control 2002; Daniel et al. 2003; Tsoulfas et al. 2003). Daniel et al (2003) also developed a model for calculating airborne emission factors for various vehicles types in urban, rural and highway terrain. Performance measures identified for measuring the environmental impacts during collection and transportation of lead-acid batteries included those associated with groundwater contamination, land use, airborne emissions and energy demands collected from the studies previously mentioned and listed in Table 4-3.

The breaking and smelting of lead-acid batteries poses a greater risk to communities because of the significant airborne emissions and lead compounds released during these stages. Thus, in these stages, it is particularly important that health impacts to communities are closely monitored in addition to impacts on the natural environment. Although the health impacts of occupational lead exposure have been well documented, the health effects of environmental exposure to lead, within the general population, remain a focus of continuing epidemiological research. Lead represents a major human health risk to those living close to recycling plants, as it can be easily adsorbed through inhalation and ingestion (Daniel et al. 2003). In contrast to occupational lead exposure, ingestion or gastrointestinal absorption is the main intake route for both adults and children in non-industrial settings (Health Canada 2004). In adults, approximately 10% of lead ingested is absorbed but young children are more sensitive to lead compounds and absorption may be as high as 50% (Technical Working Group of the Basel Convention 2002). Several cohort studies have identified worrying levels of blood lead in children living in proximity to primary and secondary lead smelters (US Environmental Protection Agency 1986; McMichael 1989; Trail Lead Program 2001; Lalor et al. 2007; Morrison and Gulson 2007). These studies include two at the primary lead-zinc smelter in Trail, British Columbia, which is responsible for processing 75% of all scrap batteries generated in the province (Trail Lead Program 2001; Hilts 2003; Morrison and Gulson 2007).

Absorbed lead, both inhaled and ingested, enters the blood stream where it is distributed to the tissues and systems of the body such as liver, kidney and bones. Some of the lead ingested is eliminated from the body. Of the fraction eliminated 75% is in urine, 16% in feces and 8% in hair and nails (Hilts 2003). The health effects of lead that accumulates in the body are similar to those in occupational health exposures and include anaemia, hypertension, ischemic heart disease and cerebrovascular disease. In children, the most common health effects include mental retardation, anaemia and gastrointestinal diseases (Technical Working Group of the Basel Convention 2002).

The USA Center for Disease Control produces a regular surveillance report in the Morbidity and Mortality Weekly Report (MMWR) on blood lead levels in the United States. The World Health Organization also published a report describing a method for estimating the health impact of lead exposure within the general population (Fewtrell et al. 2003).

Ideally, morbidity and mortality should be used as measures of community health effects, as these measures are natural attributes and offer a direct link between the disease burden on a population and lead exposure. However, since the health effects of lead are proportional to blood lead levels (Fewtrell et al. 2003), in the absence of data describing the morbidity and mortality of a population, blood lead levels may be used as a proxy attribute to monitor health impacts at the community level. This indicator is already measured at several sites (Trail Lead Program 2001; Lanphear et al. 2006; Lalor et al. 2007; Morrison and Gulson 2007). In addition, established guidelines for the maximum allowable concentrations of lead contaminants in air (Morrison and Gulson 2007), drinking water (Health Canada 2004) and soil at industrial sites and for the protection of residential, parkland and agriculture properties exist (Health Canada 2007). These guideline data are included in Table 4-3.

4.7.3 Attributes for equity in resource consumption patterns

Ideas of justice and equity are now very prominent in the discussions of environmental sustainability. One of the ways in which this manifests is that the impacts and costs of pollution and environmental degradation are not necessarily experienced by the same people who cause and benefit from them (CCME 1996). In this vein, this objective reflects the extent of the geographical impacts of recycling, the intergenerational impacts of resource consumption, and the importance given to achieving an equitable distribution of costs by producers, consumers and local governments.

The equitable geographic distribution of recycling impacts reflects the importance of establishing domestic recycling schemes within the country or within two or more countries in a regional context (Okereke 2006) in order to avoid export of hazardous waste to environmentally unsound destinations abroad. Established patterns of over consumption in industrialized countries such as Canada and USA have been shown to be the most important threats to natural environment and human health globally (Technical Working Group of the Basel Convention 2002). In order to prevent the uncontrolled dumping of toxic waste in developing countries, in 1998, the Basel Convention invoked a legally binding multilateral export ban on hazardous waste and recyclables from OECD countries to non-OECD countries. In addition, smelters and refineries are required to be licensed and to adopt the best available technologies stipulated by the United Nations Environmental Program Guidelines in order to take part in recycling schemes. The Basel Ban Amendment is yet to be ratified by 62 of the Basel Parties and the Convention is also studying mechanisms for accepting applications from non-OECD countries that meet specified criteria for environmental performance (Wackernagel et al. 1997).

Because natural attributes and proxy attributes that measure these equity concerns directly or indirectly are not available, a constructed scale was produced, to reflect the current state of debate on the export of hazardous waste and limiting the extent of the geographic impacts of lead-acid battery recycling in developing countries. In this constructed scale where level 4 denotes the best level of performance and level 1 the worst. Since the UN guidelines are becoming a de-facto international standard for transboundary movement of hazardous waste in many countries, including Canada, these guidelines formed the basis for the construction of this scale.

Table 4-4: Constructed scale for equitable distribution of geographic impacts

Attribute level	Description of attribute level
4 (best)	Products are transported and recycled within Canada and USA. Breaking and smelting facilities meet international UN guidelines.
3	Products are transported to and recycled in facilities in OECD countries or countries which ratified the Basel Ban Convention with no allowance for onward export. Breaking and smelting facilities meet international UN guidelines.
2	Products are transported to and recycled at facilities located in non-OECD countries or countries which have not ratified the Basel Ban Convention. Breaking and smelting facilities are certified according UN guidelines.
1 (worst)	Products are transported to and recycled at facilities located in non-OECD countries. Breaking and smelting facilities are not certified according to UN guidelines.

Another sub-objective identified under this category was defined as "intergenerational equity in consumption of primary resources". Effective recycling schemes which make use of fewer resources and minimize waste have long been identified as an prominent strategy for improving materials efficiency and access of non-renewable metal ores to future generations (Ayres 1997; Stone 1999). Per capita metals consumption is by far the highest in the more industrialized countries. For instance, in 2000, the USA, Canada, Western Europe, Japan and Australia, accounted for 14.6% of the world population, and consumed around 60% of world aluminium, copper and lead (MMSD, 2002). These metals are relatively easy to recycle compared with other materials (van Berkel 2007) and containment and reuse of the scrap metals generated by society, especially in industrialized countries, would be an effective strategy for improving intergenerational equity in consumption of primary resources. A natural attribute for measuring the achievement of this objective in British Columbia was defined as the provincial recycling rate, i.e. the total of lead-acid batteries recycled divided by the total of lead-acid batteries consumed in British Columbia.

The limits of traditional regulatory approaches to life cycle management of products have been stimulating a growing concern over producer and user responsibility in Canada and overseas. Such initiatives aim to shift the burden of recycling from general taxpayers to producers and consumers and to promote the design of eco-efficient products. As a result, many governments have mandated national programs for progressive life cycle management of products through regulations such as take back laws and deposit refunds. For lead-acid batteries, most of these recycling schemes are financed through a levy or a deposit charged on the sales of batteries. In some countries, in addition to the levy, a mandated non-profit consortium has been created by lead-smelters, scrap collectors and the government in order to manage the program (Wernick and Themelis 1998; Hagen 1999). In the USA, high recycling rates are attributed to recycling laws that prohibit the disposal of spent lead-acid batteries and require batteries to be collected through a take-back program involving producers and consumers. With this in mind, a constructed scale was created to assess the distribution of recycling cost among producers, consumers and governments, in which the best level (5) denotes *shared responsibility* between producers and user.

Table 4-5: Constructed scale for equitable distribution of recycling costs

Attribute level	Description of attribute level
5 (best)	Shared responsibility between producers and users – Producers are responsible for managing waste products covered by the recycling plan according to the pollution prevention hierarchy. Recycling costs are shared equally between producers and consumers.
4	Producer & user responsibility – Producers are responsible for managing waste products covered by the recycling plan and recycling costs are totally financed by consumers.
3	Government & user responsibility – Government is responsible for managing the recycling program and recycling costs are totally financed by consumers.
2	Full government responsibility - Government is entirely responsible for managing and recycling costs are financed by general taxpayers.
1 (worst)	No formal program – program relies solely on informal collection and domestic market forces.

Shared responsibility implies that producers will be responsible for managing the recycling program of their products according to the pollution prevention hierarchy. In order words, producers are required to establish a direct channel of communication with the stewardship agencies in order to evaluate options to improve product design and reduce the life cycle impacts of products. In addition, the net burden of recycling should be borne by both producers and consumers, and moreover, that the portion of burden borne by producers and consumers are the same (Ahmed 1996). Therefore, regardless of payment methods, recycling and management cost should be shared by both the producers and the consumers.

4.7.4 Attributes for measuring adaptive learning

Even though *adaptive learning* is in fact a means objective, here it is explicitly included as a fundamental objective in order to foster long term performance of other fundamental objectives. Learning through adaptive management has been discussed extensively in the literature as a useful way to gather information about uncertain variables in complex decision making involving multiple objectives (Yamaguchy 1999). This approach allows the original decision to be adjusted and improved over time as new information is gathered about the process.

The *Adaptive learning* approach can be particularly useful for improving organizational monitoring of system performance. One difficulty often found in current recycling programs is the lack of systematic monitoring of the impacts of recycling. Most recycling programs focus on the recycling rate as a single measure of performance, neglecting the social, health and environmental objectives of the system. In order to design an effective recycling program it is crucial that a more integrated approach is established. As with equity measures, natural scales of adaptive learning do not exist. It would be theoretically possible to include a series of proxy measures of the series of aspects of the recycling system that are and are not measured. However, it is more satisfactory, to aggregate these proxy measures into a constructed scale. The constructed scale created to measure the level of systematic monitoring of recycling objectives is shown in Table 4-6. In this case, level 3 (best) involves monitoring of economic, social and environmental objectives of recycling, including recovery/recycling rate, while level 1 (worst) involves no mechanism for systematic monitoring of system performance.

Table 4-6: Constructed scale for systematic monitoring of program objectives

Attribute level	Description of attribute level
3 (best)	Program performance is consistently monitored according to economic, social and environmental objectives, including recovery/recycling rate.
2	Program performance is consistently monitored primarily based on the recovery rate/recycling rate
1 (worst)	No mechanism for systematic monitoring of program performance in place

Similarly, another constructed scale was created to measure the level of public response to the recycling program. Public response was identified as one of the most challenging aspects of recycling collection (Table 4-1) crucial for success of the recycling program. Several studies have indicated that waste management behaviours are influenced by a number of factors, including knowledge of recycling programs (McDaniels and Gregory 2004), convenience (Hansmann et al. 2006), socio-demographics (Barr 2003), type of ethnic groups (Barr 2003) and the types of communication media used (Perry and Williams 2007). Hence, it is also important that recycling programs frequently assess how the public responds to the recycling system in order to investigate effective strategies for increasing public returns. Table 4-7 presents an example of a constructed scale for evaluating public response, in which level one (worst) refers to "no mechanism for evaluation of public response to recycling" and level three (best) denotes annual assessment of public response to recycling taking into account the level of public awareness and the rate of return by geographic region. Such evaluation is necessary in order to investigate the specific challenges in remote, rural and urban areas and study options that address the realities of each region, an issue that is especially important in British Columbia, where population density variation and distances are both very great.

Table 4-7: Constructed scale for public response to recycling

Attribute level	Description of attribute level
3 (best)	Public response to recycling is assessed annually and revised taking into account the level of public awareness and the rate of return in each geographic region
2	Public response to recycling is sporadically assessed and/or does not take into account the aspects described above.
1 (worst)	No mechanism for evaluation of public response to recycling is in place.

4.8 Conclusion

This chapter provides a structured approach for identifying stakeholder objectives and performance measures for recycling systems in the context of the lead-acid battery recycling system in British Columbia. Based on this experience, we identify several advantages for incorporating the use of value focused thinking in decision-making to improve recycling policies. These are:

1. Improving Stakeholder involvement in decision framing
2. Assisting in identifying information needs
3. Framing evaluation and monitoring and
4. Aiding the Formation of more attractive alternatives.

Each of these is discussed in the following sections.

4.8.1 Improving stakeholder involvement in decision framing

By integrating the values of those most directly involved in the different phases of the recycling system, decision makers are able to reach outcomes that are more desirable and acceptable to society at large. Recycling systems usually involve conflicting objectives, because the process of recycling, although considered an exercise for waste management, also results in environmental, health and social impacts at the local and international levels. Satterfield and Levin (2003) argue that conflicts may be exacerbated if values are not explicitly articulated before formulating alternatives and the debate concentrates on technical and scientific discussions. Several approaches for evaluating recycling schemes, such as LCA, try to accommodate public values in an a priori model of impact categories pre-defined by experts. These approaches typically fail to effectively address public concerns. Bringing stakeholder values into a structured value focused thinking process helps eliminate the adversarial dynamic that is very common in policy deliberations and instead focuses the discussion on ways to maximize a series of objectives which incorporate all key stakeholder values. Keeney (2002) illustrated how value focused thinking can provide a basis for agreement among stakeholders and evaluation of value trade-offs, in an air pollution study conducted in South California, in which the explicit elicitation of values contributed to a reasoned agreement among stakeholders (Keeney 2004). Similarly, McDaniels and others (2004) discuss a successful public involvement effort for a controversial water management issue in which consensus agreement was achieved among diverse stakeholder groups.

4.8.2 Identification of information needs

Another advantage of value-focused thinking is that it allows the identification of those questions that deserve the most attention from policy makers. That is, objectives identification and performance measures selection guide the data collection and information requirements for conducting the analysis, eliminating unnecessary efforts and facilitating the decision making process. LCA approaches have been widely criticized for their extensive data collection processes and their limited role in addressing public policy concerns over recycling systems. This is because the LCA process makes it difficult to accommodate stakeholder values at the scoping and framing stage (Craighill and Powell 1996; McDaniels et al. 1999) and because its results fail to attend to public policy objectives. However, as we demonstrate in Section 5.5 of this chapter, the results of published LCA studies can still be useful for the purpose of providing a more "objective focused" analysis. In fact, the task of LCA and other impact assessment studies was to provide the necessary information to assess how objectives are met when evaluating alternatives (McDaniels 2000). With this in mind, the results expressed as objectives and attributes in this chapter provided valuable information on effective performance measures for environmental and occupational health impacts of lead-acid batteries. The overall framework also offers an applied guide for the identification of information deficits and alternative proxy attributes that could be used when natural attributes are not available or would unreasonably costly to collect.

4.8.3 Evaluation and monitoring

Currently, there is no mechanism for evaluation of the lead-acid battery recycling program in British Columbia or in Canada. The provincial Ministry of the Environment does not collect statistics on the recycling rate and its environmental, social and economic objectives had not been established prior to this study. Several studies have identified the need for adopting a more integrated approach towards monitoring the efficiency of recycling performance (Craighill and Powell 1996; Spengler and Schroter 2003; Shih et al. 2006; Tam and Tam 2006). However, the vast majority of evaluations still focus only on recycling percentage targets. This study provides a valuable methodological framework for building comprehensive evaluation criteria for recycling schemes taking into account societal objectives. Since policy analysis is an iterative process, evaluation criteria specified when a project is initiated allow the process to be modified and adapted as new information is included or learned. In fact, we have explicitly included learning as a fundamental objective in this case, in order to maximize opportunities for creating new scenarios and to improve decision making over time (Coggins 2001). An objectives-focused approach supports performance management and also facilitates transparency and accountability in policy formulation.

4.8.4 Formulation of more attractive alternatives

Definitely the most notable use of value focused thinking is to provide the foundation for creating innovative alternatives that will ultimately achieve higher public support (McDaniels and Gregory 2004). The methodology allows different groups to express their opinions and focus on the objectives that matter to them while, at the same time, providing a better understanding of the source of disagreements. For instance, local resistance to recycling might be related to the fear of occupational and health impacts due to lead exposure during breaking and processing. Such concerns may drive the need for investigating strategies that could, for instance, employ cleaner technologies or alter the locations of the recycling plants. Also, the fact that local recycling minimizes landfill disposal, provides economic opportunities to communities and reduces the risk of offshore dumping may provide a more nuanced perspective on the overall impacts of recycling on concerned stakeholders. Therefore, these objectives and performance measures provide some indication of the types of elements which might be considered for a more effective recycling strategy. In the next chapter (Chapter 5) we evaluate the current lead-acid battery program using these measures and assess how different potential future recycling strategies perform according these objectives.

4.9 References

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Chapter 5 Multi-criteria Decision Analysis[16]

5.1 Introduction

Recent years have seen a change in the environmental policy towards integrated resource management, an approach which takes into account societal concerns in the decision making process. Stakeholder involvement in environmental decisions is an important strategy for defining these societal concerns and provides a better understanding of the drivers of controversy involving public decisions. Hobbs and Horn (2000) explain that public involvement is important to ensure that public values are reflected in decisions, to guide data collection on impacts that might be overlooked and to provide a due and fair decision process more likely to be supported by the general public.

As a result of the focus on integrated planning, increasing attention has been paid to participatory planning and inclusion of societal values in the decision making. Most of this axiomatic work for identifying environmental values (i.e. preference/opinion surveys and constructive approaches) rejects willingness to pay approaches and cost benefit analysis and seeks alternative valuation methods to capture the full range of social values and interdependencies between ecological and economic systems (Hobbs and Horn 1997). Contribution to these methods came primarily from disciplinary approaches from environmental ethics and ecological economics which focus on the investigation of the values associated with environmental goods and services, ecosystem functions, and natural capital.

Constructive approaches such as multi-criteria decision analysis (MCDA) have been recognized as effective tools to assess the non-monetary impacts of environmental policies in a way that is more acceptable to stakeholders (Gregory and Slovic 1997; McDaniels et al. 1999; Satterfield and Kalof 2005). Gregory (1988) explains that people need an analytical method such as the multiatribute approach to help them articulate values for the elemental aspects of the decision since it "provides access to relevant information (to remind respondents of values they might otherwise overlook), asks for

[16] A version of this chapter will be submitted for publication.

responses to parts of the problem (to avoid cognitive overload), uses natural metrics (instead of dollars, except for naturally monetary aspects), and helps respondents to combine the parts into a single whole (to facilitate the overall assessment of expressed value)." The multi-criteria approach typically involves a series of steps, which provides a systematic approach to decision making and promotes more transparency in the elicitation process (Gregory 2000).

Recycling is an important issue of concern for government agencies and stakeholders as society confronts the challenges of increasing solid waste generation and disposal costs, combined with limited landfill capacity and environmental and health concerns. Although multi-criteria decision analysis has recently been identified as an effective methodology for evaluation of waste management policies (Gomes 2008; Tillman 2000; Rahimi and Weidner 2004), there has been few examples of its application (Spengler et al. 1998; Bonano et al. 2000; Tillman 2000; Chambal et al. 2003). This chapter attempts to address this gap. It focuses on structuring public values and concerns to evaluate policy scenarios for lead-acid battery recycling in British Columbia, Canada.

This chapter uses the list of objectives and performance measures identified in the Chapter 4 and the factors that influence the performance of recycling systems identified in Chapter 3 in order to develop and assess strategies to improve performance of the current lead-acid battery recycling system. The chapter is organized as follows. Following on from the introduction, section 5.2 presents a brief background on multi-criteria decision analysis using value focused thinking. Section 5.3 discusses the characterization of objectives and performance measures based, section 5.4 describes the formulation of recycling alternatives using strategy tables and section 5.5 presents the utility function used to evaluate the desirability of different alternatives. Section 5.6 presents the impacts and consequences of each alternative given the suggested scenarios, section 5.7 evaluates the preference for consequences by assessing weights and trade-offs among objectives and section 5.8 discusses the identification of the preferred alternative and the use of sensitivity analysis. Section 5.9 and 5.10 discuss final recommendations and conclusions.

5.2 Multi-criteria decision analysis using value-focused thinking

Value-focused thinking can be very important in decision making involving multiple stakeholders and conflicting objectives. In Chapter 4 we discussed how value-focused thinking was useful in structuring stakeholder values and objectives for better policy alternatives for lead-acid batteries. Keeney (1998) further explains that value-focused thinking essentially consists of two activities: 1) defining what you want and the possible ways of achieving this and 2) figuring out which alternatives are feasible and then choosing the best choice.

Value-focused thinking is drawn from the field of decision analysis (Keeney 1992) and more specifically from multi-criteria decision analysis (MCDA). Decision analysis is an intentionally logical process for making decisions, often performed when there are multiple, conflicting objectives among stakeholders (Clemen and Reilly 2002). MCDA is a structured approach to making decisions in the face of multiple objectives, allowing the construction of a model for assessing trade-offs and preferences. Such a model has been successfully applied to environmental impact assessment in watershed management (McDaniels et al. 1999), siting nuclear facilities (Merrick and Garcia 2004), energy planning (Keeney and Gregory 2005) and fisheries management (Hobbs and Horn 1997). More specifically in the waste management arena, MCDA has been found to be useful for selecting the best systems for waste management techniques, technologies and waste management programs (McDaniels 1995; Chambal et al. 2003).

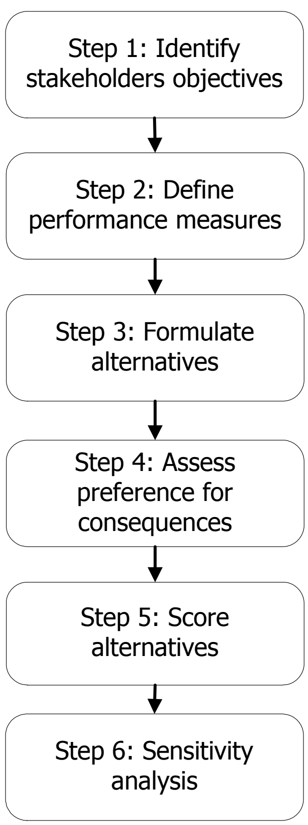


Figure 5-1: Steps of MCDA

Traditional decision making starts by identifying alternatives or strategies before identifying objectives. Keeney (2008) calls this alternative-focused thinking, which is considered reactive and ineffective because it anchors the thought processes by focusing on a limited set of initially available alternatives. Instead he proposes that we start by considering our values, concerns and objectives and then move to determining how we can construct alternatives. In this manner, the process of applying value-focused-thinking principles in a MCDA process can have many benefits, including that of creating better alternatives. Other benefits include improving communication among stakeholder groups and providing a systematic and transparent approach that often leads to uncovering hidden objectives (Keeney 1992).

Several steps should be followed to structure a MCDA model (Figure 5-1). These steps have been derived from the work of Keeney (1999) and Clemen and Reilly (1992) who discuss the use of value-focused thinking methodology for structuring complex decisions with multiple objectives. Step 1 is to identify and structure the problem by eliciting values and objectives from stakeholders. Step 2 is to define performance measures for the relevant objectives and their potential ranges of performance, from best to worst. Step 3 is to formulate alternatives or strategies that will later be assessed based on the list of objectives previously identified by stakeholders. Step 4 is to assess the preference for consequences (from the viewpoint of the decision maker) given different value-tradeoffs and the relative desirability of different levels of an attribute. Step 5 is to score the alternatives using the utility function which mathematically integrates the judgments across the various objectives into one overall index. Step 6 is to perform sensitivity analysis to assess the robustness of the results over a range of key assumptions.

According to proponents of the approach, such a procedure should be followed for structuring objectives and eliciting utility function in any problem involving multiple objectives (Keeney 1992; Clemen and Reilly 2002). In the next sections we discuss the application of this procedure, oriented here towards assessing the lead-acid battery recycling system in British Columbia.

5.3 Structuring objectives and defining measures of performance

Objectives were compiled during a series of interviews with stakeholders involved in the recycling system from July to December 2005, including auto wreckers, recycling depots, distributors, retailers, manufacturers, transporters and recycling plants. Chapter 2 discussed at length the importance of identifying fundamental objectives; the essential issues of importance in a given decision context. It also presented the notion of means objectives, which directly or indirectly contribute to accomplish the fundamental objectives. Distinguishing means and fundamental objectives allows us to measure the available alternatives relative to the fundamental objectives, the values and concerns we really care about, rather than the intermediate points that contribute to these values and concerns. With this in mind, fundamental and means objectives were organized into a means-end objectives framework (Chapter 4) to avoid misclassification and to uncover the list of fundamental objectives. These objectives were then verified by a sub-set of 8 participants representing different stages of the recycling system to ensure that their values were represented either implicitly or explicitly and to provide their opinions on appropriate performance measures for each objective. Figure 5-2 illustrates each sub-objective of a fundamental objective hierarchy which specifies the aspects included in the definition of a fundamental objective identified by the stakeholders involved in the recycling system.

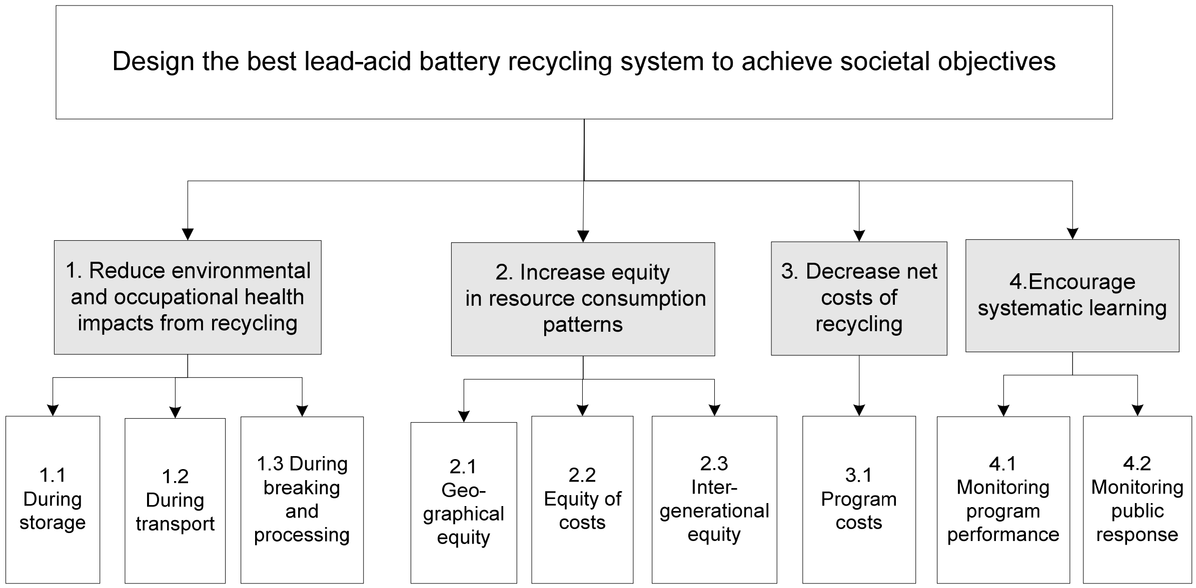


Figure 5-2: Simplified objectives hierarchy for lead-acid battery recycling

Having developed the objectives hierarchy, the next step is to create performance measures for each sub-objective associated with a fundamental objective. The discussion in Chapter 4 also introduced attribute scales, which provide the means for accomplishing fundamental objectives. Table 5-1 provides a summary of performance measures created for each of the sub-objectives identified in the objectives hierarchy. Such measures may be natural, proxy or constructed scales. A natural scale is one that is in general use with an interpretation common to everyone. Natural scales are usually expressed quantitatively (e.g. dollars, % recycling rate) and directly measure the attainment of an objective.

A proxy reflects the degree of attainment of an associated objective (frequently a means objective), but does not directly measure the fundamental objective. Proxy attributes are constructed when data for creating a direct attribute is not readily available or is extremely difficult to obtain. For instance, a proxy attribute named *compliance to permits* was built to measure occupational health and environmental impacts during breaking and processing. This attribute uses an index to measure the level of compliance of the three plants breaking and processing lead-acid batteries in the province. This approach was selected because data on occupational health exposure, environmental emissions and discharges of these plants were not readily available for this study and therefore, compliance to permits was identified as an adequate indirect measure or proxy for this objective. This method simplified our analysis and permitted us to group the occupational health and the environmental impacts objectives into one fundamental objective.

Similarly, the objective created to measure *costs of recycling* has a single measure attached to it, identified as "economic costs of recycling". In our analysis, economic costs of recycling only include the costs paid by consumers and stewardship agencies to run the recycling program (administrative costs, transportation incentives, public awareness programs, etc). Processing costs were not included here because the market value of refined lead exceeds costs of processing lead-acid batteries and these are revenues paid directly to collectors. The major challenge is to make sure batteries from remote areas and unpopulated areas are transported to a recycling plant.

Unlike natural attributes, which are relevant in several decision contexts, a constructed attribute is developed specifically for a given context (McDaniels 1996). These attributes are necessary to construct when no numerical representation exist to measure the objective. Keeney explains that "in general, constructed attributes involve the verbal description of several distinct levels of impacts that directly indicate the degree to which the associated objective is achieved". Four constructed scales were developed for this analysis and its construction process was explained in detail in Chapter 4.

Table 5-1 presents the performance measures selected for each of the objectives in the last tier of each branch of the objective hierarchy (i.e. each sub-objective for each fundamental objective).

Table 5-1: Performance measures for the lead-acid battery recycling system

Sub-objective	Performance measure	Measure type	Lower bound	Upper bound
1.1 Occupational health and environmental impacts during storage (x_1)	% batteries in compliance with UN storage guidelines	Proxy	50%	100%
1.2 Occupational health and environmental impacts during transport (x_2)	% batteries in compliance with UN transport guidelines	Proxy	70%	100%
1.3 Occupational health and environmental impacts during breaking and processing	Index (facilities in compliance with permits)	Proxy	4	4
2.1 Geographical equity of recycling impacts (x_3)	Scale 1-4	Constructed scale	1	4
2.2 Equity of costs (x_4)	Scale 1-5	Constructed scale	1	5
2.3 Intergenerational equity (x_5)	Recycling rate	Natural	65%	100%
3.1 Program costs (transportation, administrative costs) (x_6)	dollars	Natural	$CAN 1.5M	$CAN 5M
4.1 Monitoring of recycling performance (x_7)	Scale 1-3	Constructed scale	1	3
4.2 Evaluation of public response (x_8)	Scale 1-3	Constructed scale	1	3

Since performance measures consist of different measurement units and different scales, it is mathematically incorrect to add the individual scores for an alternative into a total score. A range is therefore needed for each attribute scale based on the anticipated scope of impacts (from low to high). These ranges were obtained through traditional data collection methods (interviews, questionnaires, database search) and expert judgements, which will be discussed in more depth in section 5.6. We expect that attribute 1.3 will not vary for different scenarios given that all breaking and processing plant are already complying with occupational health guidelines and environmental permits. We assume that such level of compliance will remain the same for all scenarios; therefore this attribute can be removed from the analysis, without affecting the results. Single utility functions will later be developed for all other attributes to convert the units of each performance measure into “value units”, which range from 0 to 1 (Keeney 1992; Hobbs and Horn 1997). Once this conversion has been established, the value units for each individual measure will be added into a total score for the alternative. This process will be addressed in section 5.7.

5.4 Formulating alternatives for better recycling schemes

Because of the nature of the policy questions, elements of the alternatives are combined into strategies for improving recycling outcomes. The list of performance indicators presented in the previous section provided the foundation principals for identifying optimal strategies. Recycling scenarios were identified by an extensive literature review of national and international recycling programs, a comparative analysis among other recycling systems in the province (Chapter 3), direct observation from field visits, personal interviews with participants and key informants (Chapter 2 and 4).

A strategy-generation table offered a useful tool to provide a clear representation of possible combinations of alternatives (Chambal et al. 2003). For instance, the factors identified by managers of recycling programs in Chapter 3 provided particularly important insights on the kind of elements that should be incorporated in the system taking into account the general as well as the specific factors that apply to the lead-acid battery recycling program. A producer responsibility program seems to be an appropriate response to the lead-acid battery program but, as discussed in Chapter 3, producer participation alone is not sufficient to make a program successful. Other components that need to be taken into account include public awareness, transport network, transport incentives, consumer incentives, collection network (return to retail and/or depots), compliance to occupational and health guidelines, operating practice of collection sites and capacity of processing plant. For the design of alternatives, we have focused our analysis on the particular aspects that influence the design of the system (as opposed to its operation): producer responsibility, collection network, public awareness, transport incentives, consumer incentives, consumer access and capacity of processing plant. In addition, mechanisms for system evaluation and adaptive were also included in the components of the strategy generation table under consideration.

In the case of a system that incorporates the concept of producer responsibility a different kind of funding mechanism has to be established. Separate financial resources become necessary to cover the cost of battery recycling by manufacturers. The consumers of the product would eventually pay at least part of the cost associated with a product either in the form of recycling fee or as part of the price of the product.

Examples of such mechanisms include 1) internalizing the cost into the price of the products, 2) charging the visible recycling fee on top of the price of a product. Although both options require virtually the same start-up costs, advanced disposal fees have the potential to provide stronger incentives to the manufacturers to promote design for the environment. Manufacturers would strive to incorporate consideration for the reuse and easy recovery of used material at the designing stage with the aim of reducing the visible cost for end-of-life management and of increasing the value from recovered materials. If the cost for end-of-life management of a product is visible, it may help raise consumer awareness about waste management and may also serve to inform consumers how much they are paying for recycling when they purchase products manufactured by different companies. Therefore, we have opted to include advanced disposal fee as the preferred funding mechanisms for all proposed strategies.

Each strategy includes a combination of distinct elements from each column and each row represents the selected combination for the overall scenario. The strategies will be assessed in terms of the performance measures identified in Table 5-1. This approach identifies three short term strategies (immediate implementation with assessment within 2 years) and three long term strategies (immediate implementation with assessment within 6 years), which are represented in Table 5-2. Overall three short term strategies (ST1-ST3) were paired with 5 long term strategies (LT1-LT3B) as shown in Figure 5-3 (below).

The short term strategies (ST) allow us to compare the performance of the current policy (ST1) with two other strategies with distinct consumer incentives (ST2 and ST3). ST2 is a return-to retail program managed by producers, which incorporates advanced disposal fees and a reverse deposit system charged at the point of retail, a transportation subsidy for batteries located in remote areas and a public awareness program. Under this system, consumers pay a deposit when they first buy a battery and later trade in an old battery whenever they purchase a new one. If they do not have a battery to trade in, they pay another deposit. Reverse deposit systems have resulted in high rates of recovery for lead-acid batteries in more than 20 states in the United States (Table 5-3).

Table 5-2: Strategy generation table

	Strategies	**System Mgmt**	**Consumer fees**	**Collection network**	**Transport incentive**	**Public awareness ***	**Plant capacity**	**Evaluation**
Short term	ST1 (current)	Government	None	Voluntary participation of retailers	TIP	No	KC & Metalex	None
	ST2	Producers	Reverse deposit	Return to retail	Freight incentives	Yes	KC & Metalex	Annually
	ST3	Producers	Advanced disposal fee	Return to retail	Freight incentives	Yes	KC & Metalex	Annually
Long term	LT1 (current)	Government	Advanced disposal fee	Voluntary participation of retailers	TIP	No	KC & Metalex	None
	LT2A	Producers	Reverse deposit	Return to retail	Freight incentives	Yes	KC & Metalex (increased capacity)	Annually
	LT2B	Producers	Reverse deposit	Return to retail	Freight incentives	Yes	KC & Metalex with exports	Annually
	LT3B	Producers	Advanced disposal fee	Return to retail	Freight incentives	Yes	KC & Metalex (increased capacity)	Annually
	LT3B	Producers	Advanced disposal fee	Return to retail	Freight incentives	Yes	KC & Metalex with exports	Annually

* Investment on public awareness and communications of $350,000/year

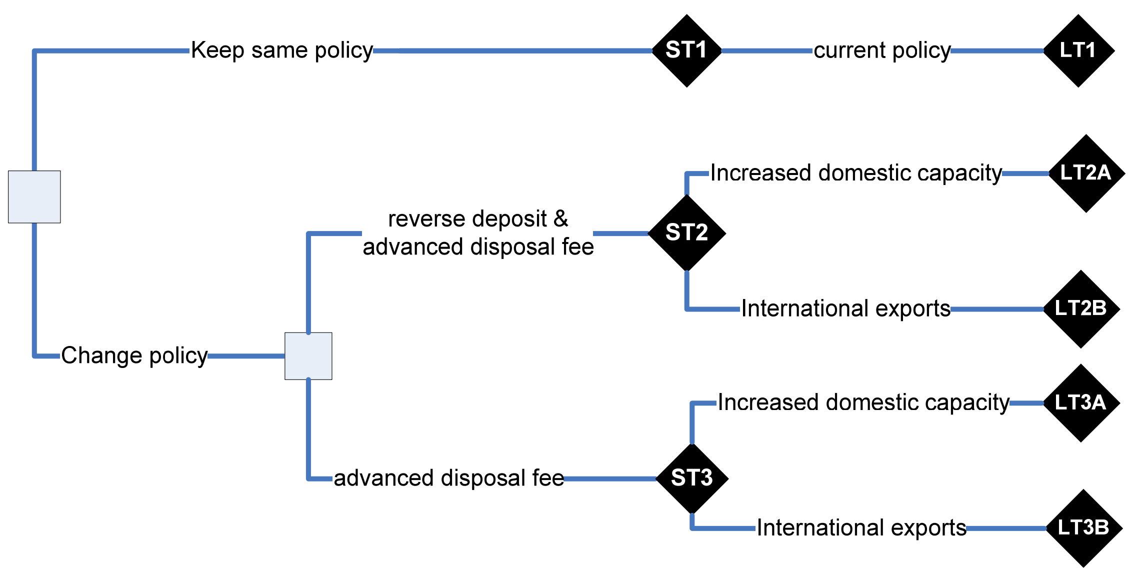


Figure 5-3: Linked decisions for selected short term and long term alternatives

ST3 is a second type of return-to-retail program managed by producers and financed through an advanced disposal fee. There is no redeemable deposit charged at the point of retail but this program also includes a transportation incentive for remote areas and a public awareness program. This system is very similar to the lead-acid battery recycling program implemented in Italy and Sweden (Table 5-3), where specific organizations have been nominated by manufacturers and producers to coordinate the program and fund unprofitable stages of the collection chain. The high degree of effectiveness experienced with these types of programs abroad is shown in Table 5-3 below. This approach has also been used for many waste management programs across Canada, including the post-consumer paint program administered by Product Care[17] and used oil program administered by the BCUOMA (British Columbia Used Oil Management Association).

Table 5-3: Literature review results

Country	Policy Option	Stewardship Agency	Fee paid by	Recycling rate	Source
USA	deposit refund	Battery Council International	Producers and consumers	95% (2005)	(Battery Council International 2005)
Italy	advanced disposal fee	Cobat Battery Association	Consumers	95% (1993)	(Ahmed 1996)
Sweden	advanced disposal fee	Returbatt Battery Association	Consumers	96% (1997)	(Ahmed 1996)
Germany	advanced disposal fee	GRS Batterien Battery Association	Producers	95% (1993)	(International Lead and Zinc Study Group 2001)
France	deposit refund	Fibat/Screlec Battery Association	Producers and consumers	90% (1993)	(Ahmed 1996)

The long term strategies LT2 and LT3 were formulated to address medium-long term issues related to recycling capacity of existing plants in the province. Hammond et al (1996) describe such decisions as *linked decisions,* in which a basic decision must be addressed prior to making a future decision. In this case, key characteristics of system design need to be established before making future decisions regarding the sustained recycling capacity of the recycling program. Therefore, the long term strategies take into account plant capacity constraints in the longer term (6 years from now) assuming that all the other factors examined in the short term strategy will follow the same trend. All

[17] Product Care is a not-for-profit industry sponsored association that manages product stewardship programs for household hazardous and special waste (post consumer paint, flammable liquids, gasoline and pesticides) on behalf of its members in British Columbia and other provinces in Canada. www.productcare.org

strategies were evaluated based on lead prices and fuel prices in November 2007. Although other feasible strategies could have been assembled using this technique, the concept was to derive a manageable list of reasonable strategies which could later be improved and refined.

5.5 Constructing the utility function[18]

After strategies and performance measures were defined, the next issue is to build a value model that algebraically represents views on relative importance among objectives, given the defined ranges of impacts associated with different strategies. The most commonly used value function is the additive utility function (Hammond et al. 2002) because its underlying basis is easily understood and it enables extensive sensitivity analysis (McDaniels 1996). Furthermore, previous studies have shown that the results of additive utility functions are comparable with more complex non-additives (Chambal et al. 2003). As a result, an additive utility function was considered appropriate for a single measure of desirability of each alternative. The additive function is represented in its full form as:

$$U = \sum_i k_i u_i(x_i) + k_2 u_2(x_2) + \ldots + k_i u_i(x_i) \tag{1}$$

where U is overall utility, k is the scaling constant or weight showing the relevant contribution to U of a change in a specific objective (x_i), and the u_i are single attribute utility functions, one for each objective x_i. Under this assumption, the utility function is simply a weighted average of single attribute value functions $u_i(x_i)$. The purpose of the utility function is to rank order alternative results in a manner consistent with the decision maker's preference for those outcomes (Hobbs and Horn 1997).

[18] Acording to Geneletti (2005) "A value function can be defined as a mathematical representation of human judgment (Beinat, 1997). It aims at making a judgment strategy explicit during an evaluation problem by transforming the measurement of an indicator into a value score (Keeney, 1992). This value score, which typically ranges between 0 and 1, represents the degree to which the objective of the evaluation is reached. If the degree of satisfaction of the objective is expressed by more than one indicator, the corresponding model consists of a multi-attribute value function, i.e. a combination of individual value functions (Beinat, 1997)"

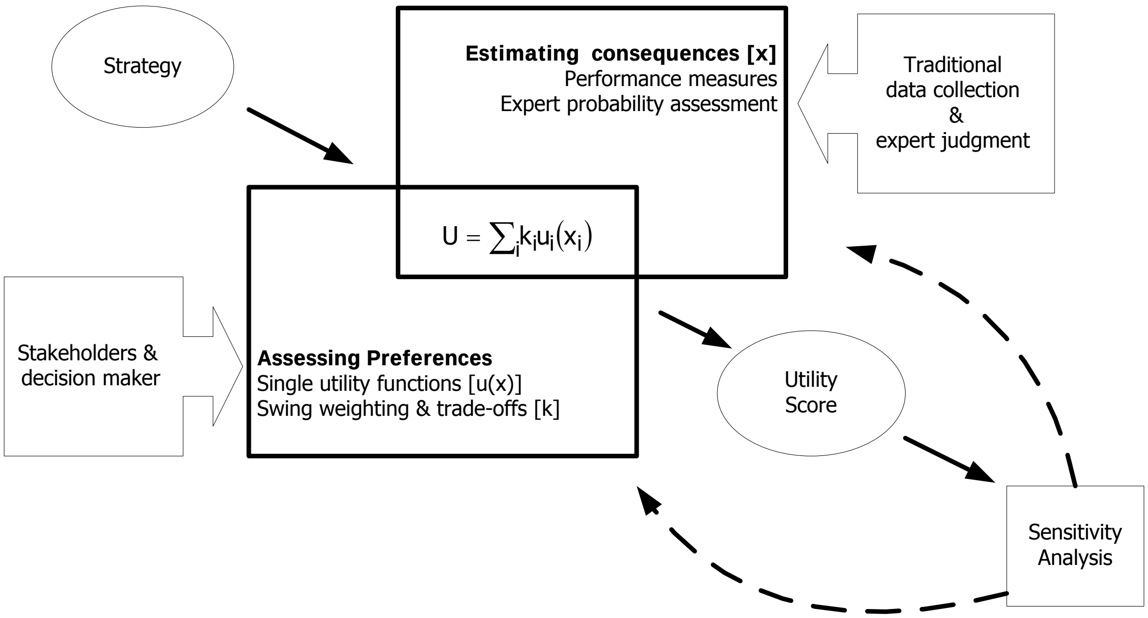


Figure 5-4: Components of the utility function

Once the functional form of the utility function is established, the next steps are to 1) assess the consequences to implement each strategy based on the pre-defined performance measures and 2) assess the scaling constants and the single utility function, which will ultimately reflect the preference for the outcomes. The two data sets were included in a multi-criteria decision support tool called Logical Decisions® to calculate the overall utility of each recycling strategy. A series of sensitivity tests were then performed to evaluate the effect of ranges in input values and assumptions. Failure to perform systematic sensitivity tests leaves both the analysis and the users unable to judge the adequacy of the analysis and the conclusions reached (Chambal et al. 2003).

5.6 Estimating consequences

Most data used to model impacts of alternatives were obtained through database search, interviews, questionnaires and site visits. However, in some cases, data may not be readily available on important uncertain events or conditions. In addition, gathering some data may be too costly or time-consuming to be practical for informing a decision. Because of this, structured interviews were also conducted with experts in order to elicit subjective probability distributions for the outcomes of uncertain variables under each different policy strategy (Morgan 1992). The specific data gaps that we identified suggested that three variables needed to be assessed through expert judgements: the recycling rate, compliance to storage guidelines and compliance to transport guidelines. All the other variables were calculated using published sources and traditional data collection methods conducted over the course of this research. Table 5-4 indicates the data source for estimating the consequences of each variable included in the analysis.

Table 5-4: Data source for estimating consequences of each objective

Occupational Health and Environment	Data Source
Compliance to storage (ST1 & LT1)	Direct observation/site visits (2005)
Compliance to storage (other alternatives)	Direct observation/site visits (2005) Expert judgment (interview)
Equity	
Recycling rate (ST1 and LT1)	Multiple regression model (Chapter 2) & Expert judgment (researcher)
Recycling rate (ST2 & ST3; LT2 & LT3)	Expert judgment (researcher)
Geographical Equity (all alternatives)	Direct assessment (researcher)
Equity of costs (all alternatives)	Direct assessment (researcher)
Program costs	
Environmental levy (ST1 and LT1)	Consumption data (Chapter 2)
Administration costs (ST2 & ST3; LT2 & LT3)	Used Oil Management Association 2005 report
Communication (ST2 & ST3; LT2 & LT3)	Used Oil Management Association 2005 report
Compliance review (ST2 & ST3; LT2 & LT3)	Used Oil Management Association 2005 report
Transportation incentive (ST2 & ST3; LT2 & LT3)	Regional recycling rate (Chapter 2) Quotes from provincial transportation companies
Deposit administration costs (ST2 & LT2)	Interview with USA recycling program
Learning	
Monitoring public response (all alternatives)	Direct assessment (researcher)
Monitoring program objectives (all alternatives)	Direct assessment (researcher)

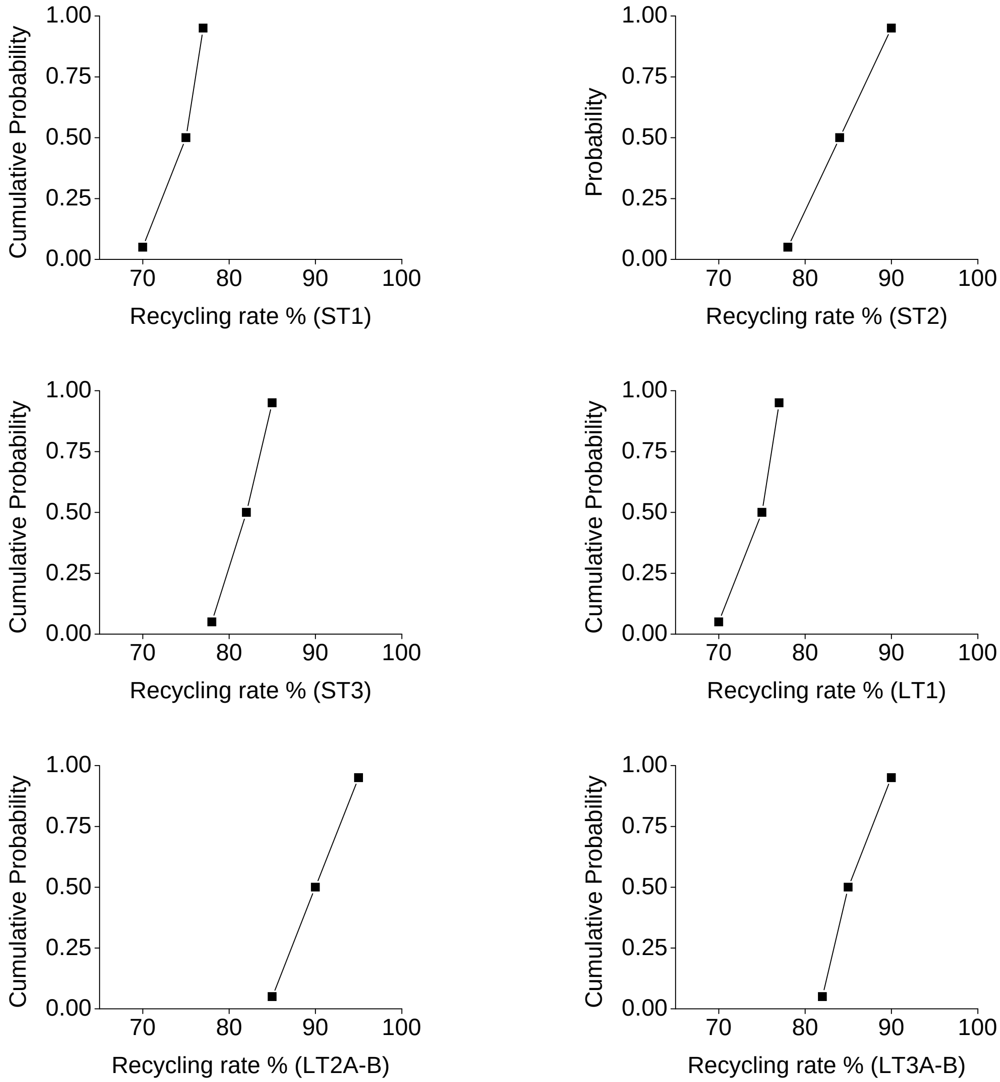
There is a considerable theoretical literature and a number of techniques for dealing with uncertainties in policy analysis. The field of decision analysis prescribes an approach for making good decisions under conditions of complexity and uncertainty (McDaniels 1995). As a result, decision analysis has developed practical techniques for encoding expert judgments about uncertain events in terms of subjective probability distributions elicited from expert judgments (Clemen and Reilly 2002). As complexity increases, professional judgment and experience play a larger role as the percentage of a problem that can be captured by "objective data" naturally decreases (Morgan 1992). Vick (1990) argues that judgment is also an inherent and essential part of engineering practice, despite the common view that judgment is "stop-gap" for objective, quantitative data. Rather than downplaying the important contribution of judgment, as many decision processes do, decision analysis provides theory and procedures for systematically gathering and integrating explicit professional and value judgments (Vick 2002).

Eliciting expert judgments is not a substitute for modeling, experimentation, and data analysis, but is meant to "provide a snapshot of the state of knowledge" based on these traditional means of garnering insights for decision-making (Clemen and Reilly 2002). In this sense it is a cost effective way to create probability distributions for data that would be overly expensive or time consuming demand an amount to derive through modeling, experimentation or data analysis.

Over the past 20 years, several distinct procedures and protocols have been developed for acquiring probability assessments of uncertain events. We adopted the assessment protocols described by Clemen and Reilly (1986) and Mcname and Celona (2002) to elicit expert assessments of probability distributions. In general, every assessment protocol includes the following steps: *background*, *structuring*, *conditioning* and *encoding*. The *background* stage identifies the variables for which expert assessment is needed and the level of expertise required. Once the expert is identified, it is also important to establish rapport with the subject and verify the existence of any pre-conceived bias. The *structuring* stage aims to structure the variable clearly and to elaborate an influence diagram to uncover any hidden assumptions and to identify the relationship among the variables. In the *conditioning* stage, the analyst verifies the expert knowledge by eliciting extreme values and asking for scenarios that would explain this outcome. This process helps counteract the biases associated with the psychological heuristics of anchoring (estimates anchored on initial values) and availability (estimates based on facts available in memory). In the *encoding* step, the expert makes the required probability assessment under the guidance of the analyst. The elicitation process should be repeated for various values, varying the form and the order of the questions to verify inconsistencies in the assessment. This verification process allows us to check if the knowledge base was constructed properly (Turban, 1990).

Expert judgements were particular useful for estimating the recycling rate and the expected levels of compliance with transportation and storage guidelines for the long term strategies. Expert judgments on the recycling rate were elicited from the researcher by her supervisor, Dr. Tim McDaniels in November 2007. First, the recycling rate for current strategy (ST1 and LT1) was estimated based on the multiple regression model presented in Chapter 2. The results of the multiple regression models were revisited and probability distributions were elicited from the researcher for all other strategies based on the specific factors shaping each alternative illustrated in Table 5-2. We also took into account data from different countries with similar recycling policies (Table 5-3) adapted to the specific geographic characteristics of British Columbia. These were calculated and used as background data during the expert judgment elicitation process.

The primary output of the elicitation process is the probability distribution on value. Since the cumulative probability plot is the most efficient means of presenting information for decision analysis (Clemen and Reilly 1990), we opted for the three point estimate option which describes the level for a measure by defining the 5^{th}, 95^{th}, and 50^{th} percentiles of its cumulative probability distribution function. Because it is often difficult to think in terms of probabilities of 0 or 1 (Mcnamee and Celona 1990), we first take 5^{th} and 95^{th} percentile. In the example below, the 5^{th} percentile is a value *x* such that there is only a 5% chance that the recycling rate would be less than or equal to *x*. Likewise, the 95^{th} percentile is a value *x* such that there is a 95% chance that the recycling rate would be less than or equal to *x*. Informally, we might think of these as the smallest and largest values that the uncertain values could reasonably assume. After assessing the extreme values, the medium must be assessed. The task here is to find a recycling rate that "split the probability interval above and below the median"(Clemen and Reilly 2002). For example, the 50^{th} percentile is the value *x* such that the uncertainty quantity is just as likely to fall below or above *x*. This information can be represented by a series of cumulative probability distribution graphs illustrated below:



Source: see text

Figure 5-5: Cumulative probability distributions for recycling rates

A similar approach was taken to estimate the level of compliance to storage and transportation guidelines, in which results for the current policy were estimated based on site visits at 49 collection sites and 7 transportation facilities, which are responsible for handling respectively 52% and 45% of the total batteries collected in the province in the year 2005. Then, expert judgments were elicited on the performance of these variables given different alternatives based on an interview with the management of one of the recycling programs in the province. The interviews were conducted by the researcher and the results are presented in Appendix I and J.

For all other variables, data were extrapolated from other recycling programs. Deposit refund administration costs were estimated based on figures provided by the Battery Council International in the United States, which operates a deposit-refund system for more than 20 states in this country. Other administration costs (management, communication, compliance review) were estimated based on the reported costs of the automotive used oil program in British Columbia because of its similarities in distribution and chain of custody. Transportation costs and infrastructure were calculated based on quotes from the two transportation companies licensed to transport lead-acid batteries in the province. The impacts of the attributes measured through constructed scales (*geographical equity*, *equity of costs, monitoring public response* and *monitoring program objectives)* were, in comparison, relatively easy to assign since they depended on pre-defined constructed scales presented in Chapter 4 which directly match the impacts of each alternative. These constructed scales have been reproduced in Table 5-5 and Table 5-6 for easy reference.

Table 5-5: Constructed scales for equity in resource consumption patterns

Attribute for geographical equity *(x3)*

Level	**Description of attribute level**
4 (best)	Products are transported and recycled within Canada and USA. Breaking and smelting facilities meet international UN guidelines.
3	Product are transported to and recycled to facilities in OECD countries or countries which ratified the Basel Ban Convention with no allowance for onward export. Breaking and smelting facility meet international UN guidelines.
2	Products are transported to and recycled to facilities located in non-OECD countries or countries which have not ratified the Basel Ban Convention. Breaking and smelting facilities are certified according UN guidelines.
1 (worst)	Products are transported to and recycled to facilities located in non-OECD countries. Breaking and smelting facilities are not certified according to UN guidelines.

Attribute for equity of costs *(x4)*

Level	**Description of attribute level**
5 (best)	Shared responsibility between producers and users – Producers are responsible for managing waste products covered by the recycling plan according to the pollution prevention hierarchy. Recycling costs are shared equally between producers and consumers.
4	Producer & user responsibility – Producer is responsible for managing waste products covered by the recycling plan and recycling costs are totally financed by consumers.
3	Government & user responsibility – Government is responsible for managing the recycling program and recycling costs are totally financed by consumers.
2	Fully government responsibility - Government is entirely responsible for managing and recycling costs are financed by general taxpayers.
1 (worst)	No formal program – program relies solely on informal collection and domestic market forces.

Table 5-6: Constructed scales for systematic learning

Attribute for monitoring recycling performance *(x7)*	
Level	**Description of attribute level**
3 (best)	Program performance is consistently monitored according to economic, social and environmental objectives, including recovery/recycling rate.
2	Program performance is consistently monitored primarily based on the recovery rate/recycling rate
1 (worst)	No mechanism for systematic monitoring of program performance in place

Attribute for monitoring public response *(x8)*	
Level	**Description of attribute level**
3 (best)	Public response to recycling is annually assessed and revised taking into account: 1) level of public awareness by geographic region (% of population knowledgeable about the program); 2) rate of return or recycling rate by geographic region
2	Public response to recycling is sporadically assessed and/or does not take into account the aspects describe above.
1 (worst)	No mechanism for evaluation of public response to recycling is in place.

The compiled results are presented in Table 5-7, which describes the degree to which the different strategies meet the various sub-objectives of the analysis. The results presented here depend almost exclusively on the combination of strategies attached to each alternative and do not reflect trade-offs between different combinations of consequences. Such trade-offs are crucial for clarifying the many complex and intertwined issues integrated in the decision. Normally, it is not possible to achieve the best level with respect to all objectives in a given decision situation. For instance, by comparing ST2 and ST3 from Table 5-7, we notice that ST2 scored higher in the sub-objective "intergenerational equity" but has higher costs than ST3. The key question here is, "how much should be given up with regard to one objective to achieve a specified improvement in another?" This issue is one of value trade-offs and preference for a particular consequence in detriment of another. Since not all objectives have the same level of importance to the decision maker, these judgments are integral part of the decision making process. In the next section, we discuss how a systematic development of a preference model makes it possible to explicitly include the implications of different value judgments in the analysis.

Table 5-7: Estimated consequences of each attribute included in the analysis

Alternatives	Occ. & Env. impacts		Equity in resource consumption			Economic costs	Learning	
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
ST1(current)	54	77	4	2	74	5.0 M	1	1
ST2	65	80	4	5	84	1.7 M	3	3
ST3	65	80	4	5	81	1.6 M	3	3
LT1 (current)	54	77	4	2	74	5.7 M	1	1
LT2A	75	84	4	5	90	2.3M	3	3
LT2B	75	84	2	5	90	2.0 M	3	3
LT3A	75	84	4	5	85	2.2 M	3	3
LT3B	75	84	2	5	85	1.9 M	3	3

X_1= *Compliance to storage:* % of batteries in compliance with UN storage guidelines

X_2=*Compliance to transport:* % of batteries in compliance with UN transport guidelines

X_3= *Geographical equity:* Scale 1-4 (table 5-5)

X_4= *Equity of costs:* Scale 1-5 (table 5-5)

X_5= *Intergenerational equity:* % recycling rate

X_6= *Program costs:* $Can dollars (please see Appendix K)

X_7= *Monitoring of recycling performance:* Scale 1-3 (table 5-6)

X_8=*Evaluation of public response:* Scale 1-3 (table 5-6)

5.7 Assessing preference for consequences

This step consists of eliciting two types of judgements to complete the analysis. First are judgements of the relative desirability of different levels of a single attribute utility function, represented as $u_i(x_i)$ in Equation 1. Second are value tradeoffs between attributes, represented as the attribute weight or scaling constant (k) in the same equation.

The relative desirability of different levels of each variable, that is the single utility functions $u_i(x_i)$ of this study were developed using a direct assessment technique. For each variable x_i upper and the lower bound were assigned. These extremes were based on the range of possible values for each attribute reflected in the set of alternatives under consideration (Clemen and Reilly 2002). These values were estimated by the researcher based on previous research, interviews and questionnaires with various organizations involved with the recycling systems in British Columbia and are discussed below. From the ranges of x_i the scaling constants u_i were determined so that the highest possible value for each single utility function (u_i (x_i) was 1.

The eight measures illustrated in Figure 5-6 are discussed below to explain the shape and the single utility function selected for each attribute. For all measures developed using a constructed scale (*geographical equity(x_3), equity of costs (x_4), monitoring of public response (x_7) and monitoring of recycling performance (x_8))* a linear relationship between the given measure and its associated value score was established. Any change in the x-axis is captured by an equivalent change in the y-axis. The single utility function for *Program costs (x_6)* is also linear and is driven by the estimated costs of the various recycling scenarios presented in Table 5-2. The estimated costs for managing each scenario (based on annual reports of current recycling programs under operation) is presented in Appendix K.

Compliance to storage (x_1) was assessed based on an interview with the manager of a recycling program in the province. Results were estimated to fall between 50% and 100% and a higher value was given to compliance levels over 70% because approximately 30% of the batteries in the province are collected by small business, including small retailers, auto wreckers and scrap dealers which, according to interviews and site visits, have demonstrated poor compliance to storage guidelines. For instance, 83% of all small businesses, auto wreckers and scrap dealers visited, stored batteries in uncovered areas and/or stored them with other hazardous materials (as opposed to 10% non compliance among large businesses and 15% among medium size businesses). These facilities usually have inappropriate storage facilities and enforcement of existing guidelines is extremely difficult to accomplish due to the substantial number of businesses that fit into this category. Therefore, a modified straight line function was produced to give a higher value for compliance levels over 70%.

Compliance to transportation (x_2) was also assessed based on an interview with the manager of a recycling program in the province. Results ranged between 70% and 100% and a higher value was also assigned to compliance over 90% given the difficulty to assess the compliance of small transportation companies, responsible for 20% of the batteries transported in the province. These companies are mostly responsible to transport batteries from remote and unpopulated areas.

Intergenerational equity (x_5) was measured by the recycling rate and was assessed by the researcher. Given that the overall provincial recycling rate has been fluctuating between 64% and 88% for the past 12 years (Chapter 2), a range between 65% and 100% was considered reasonable for the model. A recycling rate higher than 85% demands a larger investment of resources because exceeding this level implies recycling from the 15% of communities with lower transportation capacity and more distant from the recycling plants. This led to using a modified straight line function as seen in Figure 5-6.

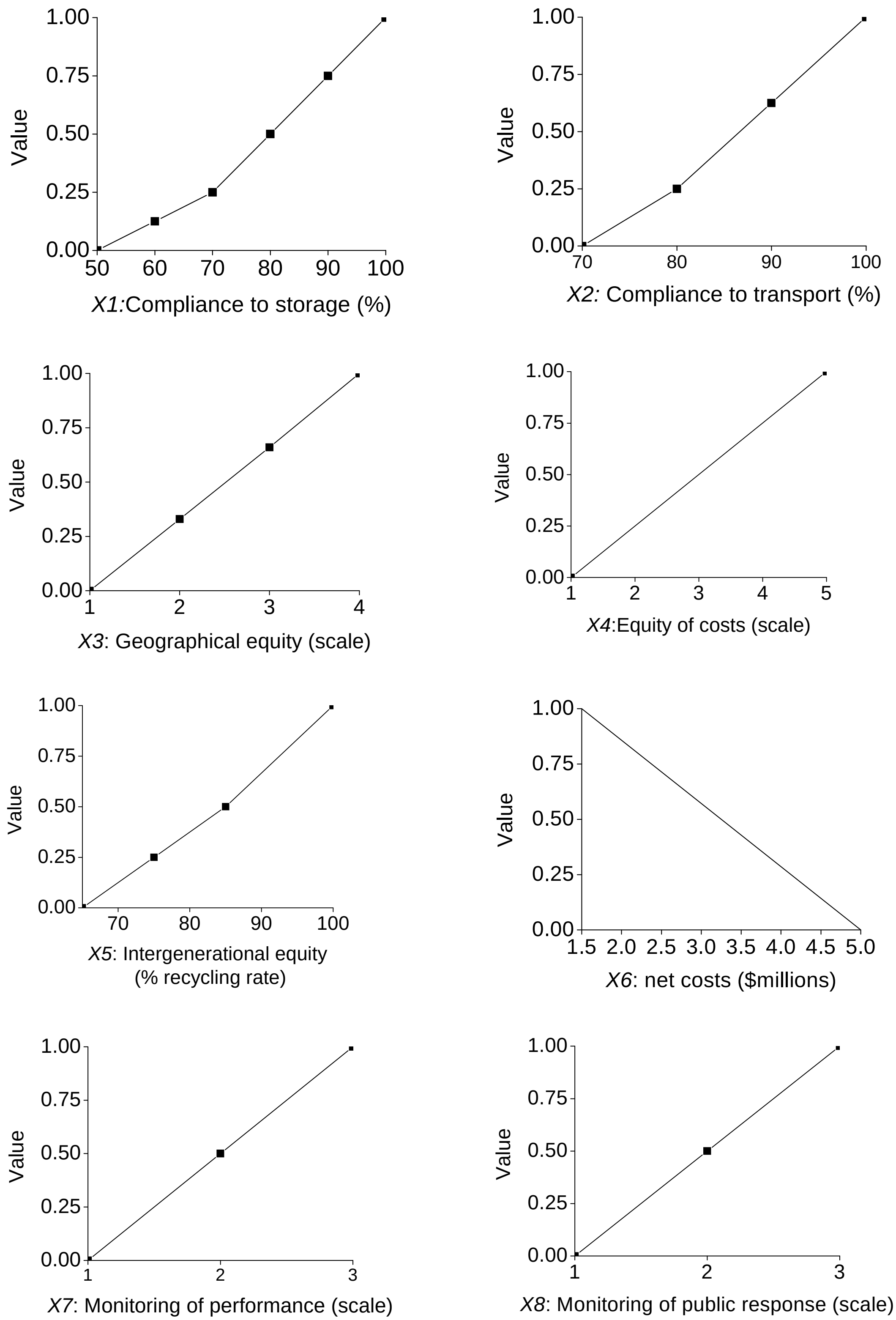


Figure 5-6: Single utility functions for sub-objectives

The next step consists of weighing the objectives hierarchy comprised by the multiple objectives of the decision. Obviously, each of the objectives is not equally important to the decision maker. In order to account for this varying degree of importance, weights must be assigned to the objectives. Two weighting techniques were used in this phase: swing weights and trade-offs. Swing weights and trade-offs are two different methods used to understand how experts weigh their relative preferences for different levels of outcome of different variables.

The swing weights method determines relative preference for different outcomes by comparing the results of 'swinging' the value of variables from the lowest feasible value to the highest feasible value in pairs. So for example the analysis might ask if an increase in cost from $1.5 to $5million would be justifiable for an improvement in recycling rate from 74 to 100%. If the answer is yes then recycling rate ranks higher than cost in the analysis and if it is no then it ranks lower. The next question asked is how much more or less important it is. So if an expert determined that increasing the recycling rate from 74 to 100% would be twice as important as increasing the cost from $1.5 to $3 million then cost would be adjudicated an importance half that of recycling rate. By successive pair-wise comparison an overall ranking of all 8 variables can be achieved and their relative importance can be scaled using weights k_i to produce preference ratings for all variables ($k_i\ u_i\ (x_i)$) which sum to 1 (i.e. as $u_i(x_i)$ have already been calculated to have a maximum value of 1 for each variable $\sum k_i \ldots k_n = 1$).

The trade-offs method takes a slightly different approach to determining the relative preference for increments in the variables and hence serves to triangulate (and hence validate or refine) the k_i values produced by the swing weighting method. The trade-offs method compares the calculated results of different scenarios pairs of variables for relative importance. Rather than consider the entire range of possible values it compares specific increments resulting from specific scenarios. This means that if one scenario costs $1.5 million and achieves a 74% recycling rate and another scenario costs $2 million and achieves a recycling rate of 80% the expert has to determine which scenario is preferable. If neither is preferred we can determine that a 6% increase in recycling rate is valued at $0.5 million. If one is considered more important then the expert can determine how much a 6% increase in recycling would be worth. Again this method can be used to calculate values of k_i which describe the relative importance of each variable and sum to 1.

The application of more than one weighing method follows the approach suggested by Hobbs and Horn (2000), which has been proven to provide a more reliable assessment of judgments since it gives the opportunity to adjust and improve our assessment during the analysis. These two weighting methods also represent a good combination of reliability and ease of use, thus providing a useful check for consistency in the analysis. They are described in more detail in the following section.

5.7.1 The swing weight method

Swing weights describe the relative importance of "swinging" an objective from its least preferred to its most preferred level. A swing weight of 100 is assigned to the attribute which is viewed as having the most important impact on the decision context as it changes through this range. Lower weights are assigned to the attributes which are deemed to be less important based on the relative importance of swinging them through their entire feasible range compared to the importance of swinging the most important variable through its entire feasible range. The question is not, "Is the recycling rate (used to measure intergenerational equity) more or less important than equity of costs?" Instead, it is crucial to carefully consider the actual criteria ranges when performing this assessment. The question is, "is a *specific improvement* from 74% to 90% in the recycling rate more or less important than a *specific improvement* from 3 to 5 in the equity of costs' scale?" Questions of relative importance are pointless without considering the performance ranges of each objective. The swing weights therefore define the ratios of the weights of potential outcomes for each objective.

With this in mind, the fundamental objectives were first compared as a group and then, once relative weights for each fundamental objective were determined the relative importance of the sub-objectives contributing to each fundamental objective was determined. In more detail, the *most desirable* fundamental objective (in this case, objective 2) was assigned a 100 score. The next step was to indicate how many times more important a move from worst to best on the most desirable fundamental objective is than a worst to best on other fundamental objectives. For instance, objective 2 was found to be 2 times more important than objective 1, so objective 2 was assigned a score of 50. The same procedure was then repeated within each group of sub-objectives under the fundamental objectives. In the end, all the weights were computed by adjusting the swing weights so they sum to one. Table 5-8 illustrates the process of swing weighting for developing the weights for the fundamental objectives.

Table 5-8: Results of swing weight method for fundamental objectives

Fundamental Objectives	Rank	Score	Adjusted weight
1. Reduce environmental and occupational health impacts of recycling	3	50	0.206
2. Increase equity of resource consumption patterns	1	100	0.413
3. Increase economic benefits from recycling	2	65	0.272
4. Encourage systematic learning	4	25	0.107

The process was then repeated for each set of sub-objectives. The results of the swing weighting exercise are illustrated in Figure 5-7, which shows how much weight each fundamental objective (shown in parenthesis) and associated sub-objective contribute to the overall objective at the top of the hierarchy.

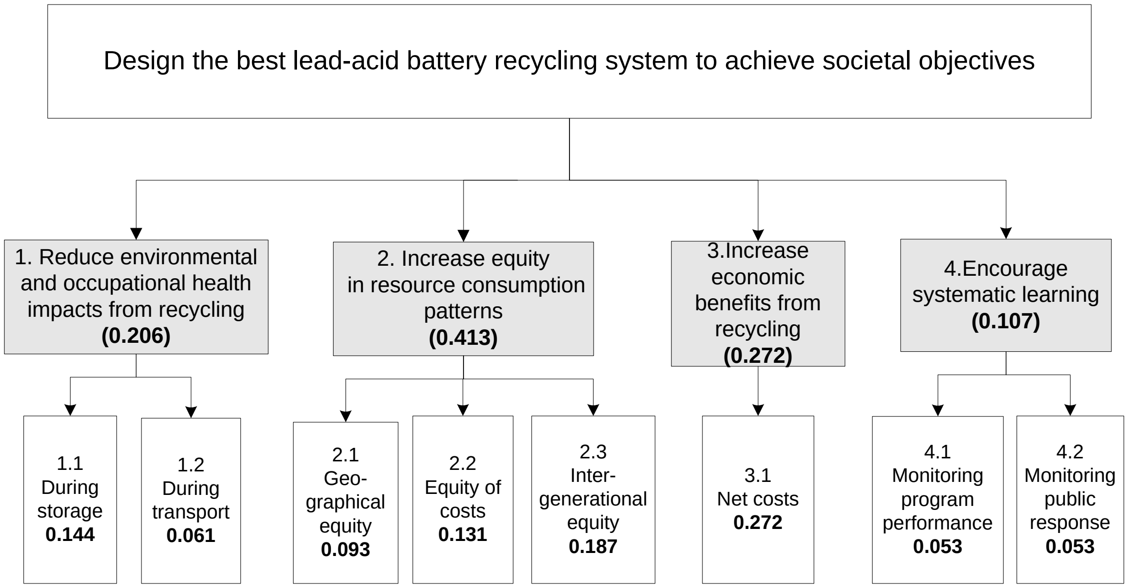


Figure 5-7: Weights of the objectives hierarchy

The purpose of the swing weight method is to force the decision maker to explicitly consider the **range** of the possible values for each performance measure when weighing it, which is a precondition for a valid assessment (Hobbs and Horn 1997). Other methods ask experts for direct weights between different criteria, without considering the feasible range of values, such as analytical hierarchy or rating from 0-100, fail to address this important issue. As a result, the weights may reflect some general sense of importance but fail to take into account the significance of the objective's ranges with respect to one another (Von Winterfeldt and Edwards 1986).

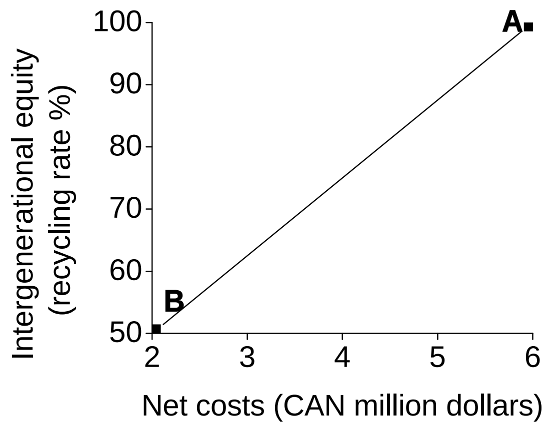
Figure 5-7 shows the objectives hierarchy along with the local weights assigned to each alternative (global weights are show in parenthesis). Local weight refers to how much weight a sub-objective contributes to the overall objective; global weight refers to how much weight each of the fundamental objectives contributes to the overall objective at the top of the hierarchy.

5.7.2 Trade-off method

The trade-off method requires a somewhat different thought process compared with the previous method. With the swing weight method, we assess relative importance, whereas with the trade-off method we determine a specific amount of one sub-objective that we would be willing to give up to obtain a fixed improvement in another sub-objective (Hobbs and Horn 1997).

In the end, both methods serve to calculate values of preference for the expert for different outcomes and hence the trade-offs method serves to test the consistency of the swing weights assigned for the sub-objectives. It does this by assessing pairs of simple hypothetical alternatives that differ in two sub-objectives but that are equally preferred. For instance, in Figure 5-8 one is asked to compare two hypothetical alternatives, labelled A and B. Alternative A is a strategy with 100% recycling rate that costs $CAN 4.75M. Alternative B has a recycling rate of 65% and costs $2.75M. In this case, we assume that all other sub-objectives that are not included here have the most preferred level for both alternatives A and B.

If A and B are preferred equally it means that the decrease in recycling rate for B compared with A is just compensated for by the decrease in program costs. This implies that the program costs and intergenerational equity measures should have equal weights given their ranges in this example, which is a reasonable trade-off from our viewpoint.



	A	B	A-B
Program costs ($CAN million dollars)	4.75	2	2.75
Intergenerational equity (recycling rate %)	100	65	35

Figure 5-8: Trade-off between program costs and intergenerational equity

The same exercise was repeated for each one of the sub-objectives in order to verify the consistency in the swing weights assessment. Once all the appropriate adjustments were made, the implication of our judgement using both weighting methods was carefully examined in the sensitivity analysis described in the next section.

5.8 Preferred alternative and sensitivity analysis

The utility function allows us to combine the collected data on consequences and trade-offs to estimate the performance of the objectives for each of the recycling scenarios (Table 5-2). The data collected is included in a spreadsheet decision model to calculate an overall utility function which reflects the policy maker preference for a given recycling scenario. The alternative score is calculated using the linear additive utility model presented in section 5.7.

Table 5-9 presents the deterministic results of the decision model for the selected short term and long term strategies for lead-acid battery recycling in British Columbia, which includes the overall utility and respective ranking of each alternative. The estimated short term and long term scenario for the current policy (ST1 and LT1) have the lowest score overall. ST3 is best among the short term strategies, having achieved a slightly higher score than ST2. On the other hand, LT2A is best among the long term strategies, followed by LT3A, LT2B and LT3B and LT1. The strategies based on the current policy (ST1 and LT1) significantly underperformed in both analyses.

Table 5-9: Overall utility of alternatives based on swing weight method

Rank	Short term alternatives	Utility
1	ST3	0.82
2	ST2	0.81
3	ST1 (current)	0.30
Rank	Long term alternatives	Utility
1	LT2A	0.82
2	LT3A	0.80
3	LT2B	0.78
4	LT3B	0.75
5	LT1 (current)	0.26

The sensitivity analyses that follow (Table 5-10 and Table 5-11) were performed to examine the robustness of our results over a range of key assumptions (McDaniels, 1995). The purpose of the sensitivity analysis is to identify the most influential weights that have impact on the results or contain the main source of variance, so that the impact of changes in these weights can be assessed.

Table 5-10 examines the change on value trade-offs and their effects on ordering the short term strategies. Sensitivity analysis demonstrated that *intergenerational equity* and *program costs* are the major contributors to differences in the overall utility of short term strategies. For instance, a 50% increase in the trade-off value of *intergenerational equity* (measured by the recycling rate) contributes to a higher overall utility of ST2. Similarly, a 20% decrease in the trade-off value of *program costs* would also raise the utility of ST2 to the first rank. These results are due to our estimates that ST2 and ST3 would achieve 84% and 81.8% recycling rate respectively and that ST2 would cost 13% more to be implemented (Table 8). Such small differences among the estimates are attributed to the relatively short time frame (two years after implementation) in which all the short term strategies were assessed. Deposit refund systems, which may have the potential to yield higher recycling rates, usually require higher capital and operational costs and within this limited time frame is difficult to assess the possible benefits of one strategy over the others. Nonetheless, the current strategy (ST1) persistently underperformed in all sensitivity tests performed, which was expected due to its low score in all sub-objectives (Table 5-7).

Table 5-10: Input changes and their effects on the ordering of short term strategies

Value trade-offs Short term strategy	Changes in input	Effect
1.1 Compliance to storage	Any reasonable changes	Same order
1.2 Compliance to transport	Any reasonable changes	Same order
2.1 Geographical equity	Any reasonable changes	Same order
2.2 Equity of costs	Any reasonable changes	Same order
2.4 Intergenerational equity	Any reasonable decreases	Same order
2.3 Intergenerational equity	Increase value by 20%	Same order
2.3 Intergenerational equity	Increase value by 50%	ST2 wins
3. Program costs	Decrease value by 20%	ST2 wins
3. Program costs	Decrease value by 50%	ST2 wins
3. Program costs	Any reasonable increases	Same order
4.1 Monitoring program performance	Any reasonable changes	Same order
4.2 Monitoring public response	Any reasonable changes	Same order

As discussed, the long term strategies include options to address recycling capacity constraints, in addition to all other elements originally incorporated in the short term strategies. Our original results (table 9) indicate that LT2A (achieved the highest utility level among all other scenarios. LT2A represents a return-to retail program managed by producers, financed through industry levies incorporated in a deposit fee or "core charge" charged at the point of retail, a transportation subsidy for batteries located in remote areas and a public awareness program. LT2A also required increased domestic recycling capacity and preference for scrap batteries to be recycled in Canada and/or USA as opposed to non-OECD countries with less environmentally sound technology.

Sensitivity analysis demonstrated that specific changes in trade off values of *geographical equity*, *intergenerational equity* and *program costs* have affected the overall ranking of long term strategies. For example, a decrease of 50% in the value trade-offs of *geographical equity* has raised the rank of LT2B strategy from third to second place but ST2A remained as the highest utility. It was necessary a decrease of 75% in this value trade-off or almost its complete elimination for the LT2B strategy to be ranked as the highest utility level among all long term strategies. Conversely, only an increment of 75% in the value trade-off of *intergenerational equity* had an effect on the ranking of the long term strategies. Similarly, reasonable changes in the value trade-offs of *program costs* did not produce any change in the order of the strategies. This suggests that *program costs* have a relatively low percent contribution to the difference in utility given the current judgment on preferences.

Table 5-11: Input changes and their effects on the ordering of long term strategies

Value trade-offs Long term strategy	Changes in input	Effect
1.1 Compliance to storage	Any reasonable changes	Same order
1.2 Compliance to transport	Any reasonable changes	Same order
2.1 Geographical equity	Decrease value by 20%	Same order
2.1 Geographical equity	Decrease value by 50%	LT2B second, LT3A third
2.1 Geographical equity	Decrease value by 75%	LT2B wins, LT2A second, LT3B third
2.1 Geographical equity	Any reasonable increases	Same order
2.2 Equity of costs	Any reasonable changes	Same order
2.4 Intergenerational equity	Any reasonable decreases	Same order
2.3 Intergenerational equity	Increase value by 20%	Same order
2.3 Intergenerational equity	Increase value by 50%	Same order
2.3 Intergenerational equity	Increase value by 75%	LT2B second, LT3A third
3. Program costs	Any reasonable decreases	Same order
3. Program costs	Increase value by 20%	Same order
3. Program costs	Increase value by 50%	Same order
3. Program costs	Increase value by 75%	Same order
3. Program costs	Increase value by 100%	LT2B wins, LT3A second, LT2A third
4.1 Monitoring program performance	Any reasonable changes	Same order
4.2 Monitoring public response	Any reasonable changes	Same order

The long term strategies have achieved a higher level of robustness compared to the short term strategies. In other words, it requires greater changes (50% and over) on assigned value trade-offs to change the ordering of the overall utility. The time frame of the long term strategies allowed for better adjustment to the various interventions incorporated in each alternative. Therefore, differences among the long term strategies became more apparent as compared to the short term strategies. For instance, strategy ST2 and ST3 achieved a 2.2% difference recycling rate although ST2 incorporates deposit refunds and ST3 does not include any consumer incentive instrument. When evaluating the recycling rate performance in the long term strategies, we verify that this difference has increased to 5%. It is also important to use sensitivity analysis to examine the implications of possible changes in judgments related to time frame, which was observed when comparing the short term and the long term strategies. The overall conclusion of the sensitivity analysis is that there were no changes in input information about any parameters that would make the current policy (both short term and long term) a winner.

Other sensitivity tests examined how changes in the single value function affected the overall utility. More specifically, we have modified all single utility functions represented in figure 1 fit a straight line. In all cases, no effect on the ranking of the strategies was observed. In fact, the results of this exercise is analogous with previous experiments (Hobbs and Horn 1997) which have shown that variations in weights and value tradeoffs affect results more than variations in single utility functions.

5.9 Case study recommendation and conclusion

The decision analysis model uses the decision maker's weights and single utility functions to determine the ability of each alternative to meet the fundamental objectives. A total of 3 short term strategies and 5 long term strategies were developed according to a literature review on other recycling programs and the regional experience with other recycling systems. Based on the overall value to the decision-maker, the model results suggest that LT2B is the best long term strategy for the lead-acid battery recycling program. This strategy incorporates a return-to retail program managed by producers, financed through advanced disposal fee and includes a reverse deposit refund charged at the point of retail, a transportation subsidy for batteries located in remote areas and a public awareness program. This alternative also includes capital costs for expansion of the current plant capacity domestically, without allowance for onward exports to non-OECD countries.

The longer time frame of the long term strategies allowed for better adjustment to the various interventions incorporated in such alternative. As a result, sensitivity analysis showed that the long term strategies are less sensitive to moderate changes in the model objective weights and key model parameters, which strengthen the argument that for the implementation of this alternative.

This alternative has several advantages to it. First, it has the highest recycling rate and therefore has the potential for diverting more batteries out of the waste stream. Second, it includes a reverse deposit refund system that is relatively easy to manage compared to other traditional deposit systems and has the potential to yield high rates of returns from consumers (Hobbs and Horn 1997). Third, it reflects the importance of establishing domestic recycling schemes in order to avoid export of hazardous waste to environmentally unsound destinations abroad. Fourth, it incorporates *shared responsibility* between producers and users, which means that producers are responsible for managing waste products covered by the recycling plan and recycling costs are shared between producers and consumers. As discussed in Chapter 3, producer responsibility alone does not necessarily promote design for the environment unless both producers and stewardship agencies are working collaboratively to evaluate waste management strategies taking into account the pollution prevention hierarchy. In this context, *shared responsibility* also means that producers are accountable for incorporating changes in product design to reduce the overall footprint of products.

5.10 Discussion

The methodological framework described in this chapter contributes to the development of effective methods to assess performance of recycling systems. This analysis provides a relevant contribution on how to assemble and assess strategies for complex recycling systems using decision analytical tools informed by values and preferences. This chapter evolves from the data gathered in Chapters 2, 3 and 4 which consisted in collecting information about the current recycling program and in developing objectives and performance measures by consulting stakeholders involved with the recycling system.

A significant strength of this research is the interdisciplinary approach to policy analysis, bringing together expertise in decision analysis, environmental management, mining engineering, community consultation, recycling policies and risk communication. In addition the approach employs a tested methodology for eliciting the values and concerns of stakeholders and for weighing these values which maximize transparency in the decision making. The methodology also makes use of expert technical knowledge so that consequences can be ascertained as accurately as possible using existing knowledge and availability of data. Overall the approach combines both technical judgements and stakeholder values into an integrated framework, which is essential for producing policy options that are technically feasible and effective while being capable of widespread support. The research responds directly to the identified need to improve the current lead-acid battery recycling system, building on a solid characterization of the current system carried over the previous chapters. This should also enable more politically viable solutions to be identified.

We recognize that the application in this chapter present some limitations as only a few individuals were interviewed to construct the utility function. However, considerable time was dedicated to structuring stakeholder objectives, separating fundamental and means objectives and developing performance measures. This analysis draws on an extensive literature review, interviews, questionnaires, database search and our judgments about it. The current model is designed so that interested parties can evaluate strategies using their own input parameters and reduce the set up time to implement this approach in the future (Battery Council International 2005). Since the Ministry of Environment is currently considering options to revamp the existing battery recycling program into an extended producer responsibility program (MWLAP 2004), this research provides timely information for informed decision making.

5.11 References

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Chapter 6 General Conclusions

For the minerals sector to contribute to sustainable development, the use of its products must be considered as part of mining and mineral processing activities (MMSD, 2001). Effective recycling schemes which make use of fewer resources and minimize waste have long been identified as a prominent strategy for improving materials efficiency, reduce landfill disposal and promote equitable resource consumption patterns (Technical Working Group of the Basel Convention (2002). With this in mind, this research uses a system thinking approach to describe and evaluate the current lead-acid battery recycling program in British Columbia. Four different system analysis perspectives have guided this research: multiple regression analysis, value-focused thinking, influence diagrams and multiple criteria decision analysis.

6.1 Key findings:

- The multiple regression analysis paralleled the results obtained from initial interviews in which main factors influencing the recycling rate from 1995 to 2005 were: fuel prices, *transportation capacity*, *presence of auto-wreckers, scrap dealers and recycling depots* and *participation of manufacturers, distributors and retailers*. The factors that did not significantly contributed to the recycling rate were *LME lead prices* and *Transportation Incentive Payments (TIPs)*.

- The regression model results revealed that *LME lead price* was not a statistically significant predictor of the recycling rate. In fact, dropping LME lead price from the regression analysis did not compromise the overall performance of the other parameters. This apparent discrepancy is particularly explained by the strong buying power and limited recycling capacity of the two recycling plants in the province, which control the price of scrap lead below LME lead prices and poses challenges to the transportation of scrap batteries within British Columbia.

- TIPs failed to provide adequate incentives for collection and transportation of lead-acid batteries in 12 out of 14 transportation regions. In fact, when TIPs are removed from the initial model, no appreciable changes in other coefficients or in the overall reliability of R^2 relative to the previous models have been observed. These results reinforces the fact that TIPs and LME lead prices have posed limited contribution to the overall recycling rate in the province during the given period because of the strong market power of recycling plants.

- The number of batteries collected as well as the recycling rate had not been established prior to this study. Our results revealed that the provincial recycling rates have achieved an average of 75% during the operation of the recycling program in British Columbia (with high fluctuations within transportation zones). The above data indicate that the current program performs below average compared to other recycling program implemented in the USA, Europe and Japan which have accomplished national recycling rates of over 90% for lead-acid batteries.

- Over the past 12 years, TIPs payments to collectors have ranged from $803 to $1,486,829 annually and the provincial government has collected an average of $4Million/year from the environmental levy alone . Since TIPs are inversely proportional to LME lead prices, they are practically non-existent for most zones given the high lead prices we are currently experiencing. The difference between the money collected and the subsidy paid has been directed to the Sustainable Environment Fund to fund other environmental protection activities not necessarily related to lead-acid batteries and this is not appreciated by those involved in Lead-Acid Battery recycling.

- Managers of stewardship programs in British Columbia have identified two categories of factors influencing varied recycling systems in the province: *consensus* factors and distinguishing (or context specific) factors. *Revenue direction, public awareness, producer responsibility, consumer access, operating practice, transport network* were considered *important* or *very important* aspects that positively influence the performance of all stewardship programs. These aspects were classified as consensus factors as they were considered essential to the success of all stewardship programs in British Columbia and should be taken into account when designing and evaluating the success of all recycling programs. *Environmental and health impacts, ease of siting, consumer incentives, transport incentives and capacity of processing plant* have been classified by managers as distinguishing or context specific factors since their level of importance varied according to the type of material and its associated collection network.

- The extent to which stewardship programs lead to *design for the environment* is questionable. Participants have not considered this a *very important* aspect because *"it is not under their control"*. Results indicate there is a lack of understanding regarding the roles and responsibilities of stewardship agencies (responsible for recycling) and producers (responsible for manufacturing). Although producers are beginning to assume responsibility for how materials and natural resources are used, to be environmentally more sensitive, the pollution prevention hierarchy must be infused throughout the entire product life cycle.

- The results of the multi-stakeholder consultation guided by value-focused thinking interviews revealed five fundamental objectives that reflect what society in general would like to achieve an lead-acid battery recycling program in British Columbia: reduce environmental impacts of recycling, reduce occupational health and safety impacts of recycling, reduce economic costs of recycling, increase adaptive learning and increase equity in resource consumption patterns. The list of performance indicators associated with these fundamental objectives provided comprehensive evaluation criteria for guiding data collection and evaluating the performance of lead-acid battery recycling programs in British Columbia.

- Among all short term and long term recycling strategies assessed by the performance indicators, the strategy based on the current lead-acid battery program (ST1 and LT1) had the lowest score overall. ST3[19] is best among the

[19] ST3 is a return-to-retail program managed by producers and financed through an advanced disposal fee. There is no redeemable deposit charged at the point of retail but this program also includes a transportation incentive for remote areas and a public awareness program.

short term strategies, having achieved a slightly higher score than ST2[20]. On the other hand, LT2A is best among the long term strategies, followed by LT3A[21], LT2B[22] and LT3B[23] and LT1. LT2A was found to be the preferred strategy which includes a return-to retail program managed by producers, financed through an advanced disposal fee and managed through a reverse deposit refund charged at the point of retail, a transportation subsidy for batteries located in remote areas and a public awareness program. LT2A also involves expansion of the current plant capacity domestically, without allowance for onward exports to non-OECD countries.

- The overall utility results of the short term strategies are sensitive to specific changes in trade-off values of *intergenerational equity* (recycling rate) and *net costs*. The current strategy (ST1) persistently underperformed in all sensitivity tests, which was expected due to its low score in all sub-objectives.

- The overall utility results of the long term strategies are sensitive to specific changes in trade off values of *geographical equity* (geographical distribution of environmental and social impacts of recycling), *intergenerational equity* (recycling rate) and *net costs*. However, the long term strategies have achieved a higher level of robustness compared to the short term strategies. It requires greater changes (50% and over) on assigned value trade-offs to change the ordering of the overall utility. The time frame of the long term strategies allowed for better adjustment to the various interventions incorporated in each alternative.

- Other sensitivity tests on changes to the single value functions resulted in no effect on the overall ranking of the short and long term strategies. In fact, the

[20] ST2 is a return-to retail program managed by producers, financed through an advanced disposal fee and including a deposit refund charged at the point of retail, a transportation subsidy for batteries located in remote areas and a public awareness program.
[21] LT3A is one of the long term strategies for ST3 in which also includes expansion of the current plant capacity domestically, without allowance for onward exports to non-OECD countries.
[22] LT2B is one of the long term strategies for ST2 in which also includes expansion of current recycling capacity with allowance for onward exports to non-OECD countries.
[23] LT3B is one of the long term strategies for ST3 in which also includes expansion of current recycling capacity with allowance for onward exports to non-OECD countries.

results of this exercise confirm that variations in weights and value tradeoffs affect results more than variations in single utility functions.

6.2 Methodological contributions:

- **Multiple regression analysis** provided a retrospective assessment of the recycling rates of 12 transportation zones from 1995 to 2005 based on nine explanatory variables (participation of manufacturers, distributors and retailers, participation of *recyclers*, Transportation Incentive Payments, London Metal Exchange price of lead, fuel costs, and *transportation capacity*. The model structure was carefully designed to accommodate the general and zone specific characteristics associated with the transportation zones and demanded extensive data collection from multiple sources. The **data collection process** can be easily reproduced and provide a relevant guide for continuing documentation and assessment of the outcome variable (recycling rate). In addition, **the final form of the regression model**, determined through a backward stepwise method, provides a powerful tool to examine the effect of many different explanatory on the recycling rate and, at the same time, allows predictions about future.

- **Mental model interviews** with management of stewardship agencies provided a valuable contribution on the factors that, according to participants' perceptions and experiences, shape the nature of recycling systems in the province and which interventions are more likely to contribute to better performance in recycling system in British Columbia. An **influence diagram** summarizes the major features of the system, pooling the beliefs of appropriate experts. Considered qualitatively, such a diagram specifies what issues are worth raising when designing policy decisions. Considered quantitatively, it provides a basis for determining the relative importance of those issues taking into account the similarities and differences across recycling systems.

- The results of the interviews with the stewardship agencies provided particularly important insights on the kind of elements that should be incorporated in the recycling system taking into account the general as well as the specific factors that apply to the lead-acid battery recycling program. The following aspects that influence the design of the system (as opposed to its operation) were included in the **strategy generation table**: producer responsibility, consumer access, public awareness, transport incentives, consumer incentives, consumer access and capacity of processing plant. These elements formed the components of each recycling strategy which were later assessed by the performance indicators elicited from stakeholders. The strategy generation table also provided a functional example on how to combine individual aspects of recycling systems into recycling strategies.

- **Value-focused thinking interviews** were used to assess objectives and performance measures based on stakeholder's values and concerns. It was particular difficult to assess stakeholders objectives without first articulating the main challenges and concerns faced by stakeholders in the recycling system. Thus, stakeholders were first asked to consider problems experienced with the recycling system, and then their initial list of concerns were used to articulate their underlining reasons for such concerns. This approach proved to be very effective and minimized any difficulties we might have encountered when asking stakeholders to articulate values and objectives up front.

- Following this stage of the interview, participants were asked to answer a series of questions to elicit their objectives regarding the recycling system. Their responses were later combined into a **means-objective framework,** which offers a big picture of different stakeholder values and the causal relationships among means and fundamental objectives. The set of fundamental objectives guided the identification of attributes or performance measures, which were classified into three categories: **natural, proxy and constructed attributes**. Such process avoided misclassification and duplicity, allowing for identification of effective measure of performance. The results reflect the current state of knowledge in the literature and alternative measures for assessment of impacts of lead-acid battery recycling.

- Overall, this study provided a valuable methodological framework for building **comprehensive evaluation criteria** for recycling schemes taking into account societal objectives. It also provided useful insights on the questions deserving the most attention and also provided an applied guide for identifying effective measures for recycling systems in general given availability of data and time constraints.

- The **utility function** allowed us to rank order alternative results in a manner consistent with the decision maker's preference for those outcomes. Two weighting techniques were used to evaluate trade-offs among the objectives: swing weights and trade-offs. The application of more than one weighing method proved to be a reliable assessment of judgments, providing the opportunity to adjust and improve our assessment during the analysis. These two weighting methods also represent a good combination of reliability and ease of use, thus providing a useful check for consistency in the analysis. The current model is designed so that interested parties can evaluate strategies using their own input parameters and reduce the set up time to implement this approach in the future.

6.3 Claims to original research

I claim the following contributions of this work are original:

1. This study uses a systems approach to examine the recycling efficiency of the provincial lead-acid battery collection program and to investigate how a series of variables elicited from informed stakeholders have contributed to the collection and transportation of batteries in each of the transportation zones. This approach informed the construction of a multiple regression analysis to assess how these factors influenced the recycling rate performance from 1995 to 2005.

2. This is the first time a qualitative systems analysis approach (use of influence diagrams informed by expert interviews) is developed to identify and compare key factors contributing to the overall performance of varied waste management systems. This comparative study provides essential information on the dynamics of existing waste management systems and especially on the incentives and policy

instruments that influence organizational behaviour and drive system performance in British Columbia.

3. This work contains an original methodological framework for establishing comprehensive evaluation criteria for recycling schemes taking into account societal objectives. Currently, there is no mechanism for evaluation of the lead-acid battery recycling program in British Columbia or in Canada. The provincial Ministry of the Environment does not collect statistics on the recycling rate and its environmental, social and economic objectives had not been established prior to this study. This applied guide also reflects the current state of knowledge in the literature and provides alternative measures for assessment of impacts of lead-acid battery recycling.

4. This is the first time a system analysis process is applied to assess recycling systems with wide stakeholder involvement and verification. The analysis presented here provides a relevant contribution on how to effectively assemble and assess strategies for complex recycling systems informed by values and preferences.

5. This work reveals that the current lead-acid battery recycling program fails to meet societal objectives and persistently underperforms compared to other domestic and international recycling programs. The chief complaint raised by stakeholders was the lack of transparency and accountability related to the revenue obtained from the CAN$5 environmental levy charged on new batteries. During the last 3 years, nearly all environmental levies collected was directed to fund other activities not linked with the lead-acid battery program. Clearly, the Lead-Acid Battery Recycling Program has to be restructured and transferred to an industry-led stewardship agency accountable to consumers and taxpayers.

6.4 References

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Appendices

Appendix A: Transportation incentive payment algorithm

British Columbia Ministry of Environment
Lead Acid Battery Collection Program
TRANSPORTATION INCENTIVE PAYMENTS (TIPs)
EXAMPLES OF DIFFERENTIALS & RESULTANT INCENTIVE for LME lead price at CAN$551.146/tonne pb (CAN$0.250/lb pb)[1]

		A	B	C	D	E	F0	F1	G1	G2	G3	G4	G5	H0	H1	I0
		$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes	$/tonnes
Plant revenues																
(A) LME Lead price[2]		551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146	551.146
(B) LME OFFSET	**A+44.092**	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092	44.092
(C) Total revenue from finished pb	**A+B**	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238	595.238
Plant costs - Breaking and Smelting ($/tonne Pb)																
(D) Smelter costs		394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621	394.621
(E) Breakers costs		90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388	90.388
(F) Profit factor	**(D+E)*0.10**	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501	48.501
(G) Total Costs	**D+E+F**	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510	533.510
(H) NET SCRAP VALUE/tonne Pb	**C-G**	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728	61.728
(I) NET SCRAP VALUE/tonne Battery[3]	**(C-G)*0.50**	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642	30.8642
Costs for collectors - Collection and Assembly ($/Battery)																
(J) Battery purchase		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
(K) Handling Costs		1.036	0.600	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036	1.036
(L) Battery assembly		0.277	0.107	0.104	0.321	0.603	0.578	0.621	0.725	0.323	0.621	0.648	0.648	0.721	0.648	0.321
(M) Long haul		0.925	0.689	0.300	0.079	0.408	0.918	1.286	1.472	1.074	3.183	2.695	3.173	1.869	2.007	0.324
(N) Profit factor	**(J+K+L+M)*0.10**	0.324	0.240	0.244	0.244	0.305	0.353	0.394	0.423	0.343	0.584	0.538	0.586	0.463	0.469	0.268
(O) TOTAL COSTS / battery	**(J+K+L+M+N)**	3.562	2.636	2.684	2.679	3.352	3.886	4.337	4.657	3.776	6.423	5.917	6.443	5.088	5.161	2.949
(P) TOTAL COSTS / tonne[4]		206.6554	152.9173	155.7095	155.4382	194.4447	225.4464	251.6316	270.1513	219.0697	372.6536	343.28	373.8068	295.1833	299.3892	171.1086
(Q) RESULTANT TIP per tonne of battery	**(P-I)**	175.791	122.053	124.845	124.574	163.580	194.582	220.767	239.287	188.205	341.789	312.416	342.943	264.319	268.525	140.244

Notes
1- Algorithm obtained from archival search at Novatec Consults Inc in July 2006. All estimates have been converted to metric tonnes for easy reference
2- Estimated based on the previous month's minimum LME lead price, in Cdn/tonne lead
3- Assumption that 50% of a typical lead-acid battery contains lead
4- Assumption that a standard battery weights 38lb or 17.23kg

Appendix B: Analysis of the multiple regression model of equation 8

(All factors)

Zone	Factor	ß coefficients	Std. Error	Std. ß coefficients	t-score	*p*-value
A	Z_A	1.747	1.185	0.495	1.474	0.141
A	Tip_A	-0.001	0.001	-0.019	-1.244	0.214
A	MDR_A	-0.008	0.012	-0.146	-0.708	0.479
A	Rec_A	-0.008	0.012	-0.110	-0.700	0.484
B	Z_B	0.923	0.592	0.261	1.559	0.119
B	Tip_B	0.000	0.001	0.005	0.387	0.699
B	Rec_B	-0.001	0.007	-0.010	-0.209	0.835
B	MDR_B	0.001	0.007	0.015	0.119	0.905
C	Z_C	0.616	0.282	0.174	2.181	0.029 *
C	MDR_C	0.006	0.003	0.126	2.054	0.040 *
C	Rec_C	0.006	0.003	0.045	1.861	0.063 +
C	Tip_C	-0.001	0.001	-0.012	-0.948	0.343
D	Z_D	0.254	0.107	0.072	2.368	0.018 *
D	MDR_D	0.001	0.001	0.026	1.853	0.064 +
D	Rec_D	0.001	0.001	0.010	1.013	0.311
D	Tip_D	-0.001	0.001	-0.009	-0.649	0.516
E	Rec_E	0.007	0.001	0.137	9.962	0.000 ***
E	MDR_E	0.005	0.001	0.049	4.710	0.000 ***
E	Z_E	0.161	0.116	0.046	1.382	0.167
E	Tip_E	0.000	0.001	-0.005	-0.337	0.736
F0	MDR_F0	0.014	0.001	0.143	13.394	0.000 ***
F0	Rec_F0	0.009	0.001	0.096	9.485	0.000 ***
F0	Z_F0	0.210	0.113	0.059	1.861	0.063 +
F0	Tip_F0	0.000	0.001	0.005	0.327	0.743
F1	MDR_F1	0.050	0.004	0.132	13.013	0.000 ***
F1	Z_F1	0.721	0.127	0.204	5.668	0.000 ***
F1	Rec_F1	0.003	0.001	0.039	3.133	0.002 **
F1	Tip_F1	0.001	0.001	0.021	1.165	0.244
G1	Rec_G1	0.011	0.001	0.122	11.209	0.000 ***
G1	MDR_G1	0.009	0.002	0.054	5.640	0.000 ***
G1	Z_G1	0.735	0.132	0.208	5.550	0.000 ***
G1	Tip_G1	0.000	0.000	-0.002	-0.107	0.915
G2	Z_G2	1.875	0.118	0.531	15.951	0.000 ***
G2	Tip_G2	-0.003	0.001	-0.076	-4.760	0.000 ***
G2	Rec_G2	0.004	0.001	0.035	3.225	0.001 ***
G2	MDR_G2	0.003	0.001	0.043	2.978	0.003 **
G3	Z_G3	1.165	0.139	0.330	8.406	0.000 ***
G3	Tip_G3	0.000	0.000	-0.007	-0.296	0.767
H0	Rec_H0	0.010	0.001	0.166	14.044	0.000 ***
H0	MDR_H0	0.011	0.001	0.081	7.971	0.000 ***
H0	Z_H0	0.381	0.131	0.108	2.897	0.004 **
H0	Tip_H0	0.000	0.000	0.021	1.108	0.268
H1	Z_H1	0.994	0.168	0.282	5.935	0.000 ***
H1	Rec_H1	0.005	0.001	0.112	5.288	0.000 ***
H1	Tip_H1	-0.002	0.001	-0.065	-2.908	0.004 **
Z_	Rec_I	0.010	0.001	0.201	15.184	0.000 ***
I	MDR_I	0.002	0.002	0.010	1.129	0.259
I	Z_I	0.115	0.111	0.032	1.034	0.301
I	Tip_I	0.000	0.001	-0.005	-0.373	0.709
All	Transp	0.020	0.002	0.141	10.743	0.000 ***
All	Fuel	0.000	0.000	-0.161	-3.487	0.001 ***
All	LME	0.000	0.000	-0.057	-0.670	0.503

R = .940; R^2 =.883; Adjusted R^2 = .879
MDR_H1; MDR_I and Rec_G3 are constant and were deleted from the analysis
Z refers to the zone specific intercepts

Appendix C: Analysis of the multiple regression model of equation 9

(LME lead removed)

Zone	Factor	ß coefficients	Std. Error	Std. ß coefficients	t-score	p-value
A	Z_A	1.681	1.181	0.476	1.424	0.155
A	TIP_A	-0.001	0.001	-0.015	-1.064	0.287
A	MDR_A	-0.008	0.012	-0.146	-0.710	0.478
A	Rec_A	-0.008	0.012	-0.109	-0.691	0.489
B	Z_B	0.867	0.586	0.246	1.480	0.139
B	TIP_B	0.001	0.001	0.008	0.669	0.504
B	Rec_B	-0.001	0.007	-0.009	-0.174	0.862
B	MDR_B	0.001	0.007	0.013	0.100	0.920
C	Z_C	0.553	0.266	0.157	2.077	0.038 *
C	MDR_C	0.006	0.003	0.127	2.058	0.040 *
C	Rec_C	0.006	0.003	0.045	1.879	0.060 +
C	TIP_C	-0.001	0.001	-0.009	-0.738	0.461
D	Z_D	0.194	0.058	0.055	3.316	0.001 ***
D	MDR_D	0.001	0.001	0.026	1.805	0.071 +
D	Rec_D	0.001	0.001	0.010	0.995	0.320
D	TIP_D	0.000	0.001	-0.005	-0.405	0.686
E	Rec_E	0.007	0.001	0.137	9.991	0.000 ***
E	MDR_E	0.005	0.001	0.049	4.745	0.000 ***
E	Z_E	0.095	0.063	0.027	1.510	0.131
E	TIP_E	0.000	0.001	0.000	-0.032	0.974
F0	MDR_F0	0.014	0.001	0.143	13.442	0.000 ***
F0	Rec_F0	0.009	0.001	0.096	9.479	0.000 ***
F0	Z_F0	0.147	0.062	0.042	2.362	0.018 *
F0	TIP_F0	0.000	0.001	0.010	0.699	0.484
F1	MDR_F1	0.050	0.004	0.132	13.002	0.000 ***
F1	Z_F1	0.665	0.095	0.188	6.976	0.000 ***
F1	Rec_F1	0.003	0.001	0.040	3.145	0.002 **
F1	TIP_F1	0.001	0.001	0.026	1.615	0.106
G1	Rec_G1	0.011	0.001	0.122	11.229	0.000 ***
G1	Z_G1	0.679	0.103	0.192	6.587	0.000 ***
G1	MDR_G1	0.009	0.002	0.054	5.622	0.000 ***
G1	TIP_G1	0.000	0.000	0.003	0.199	0.842
G2	Z_G2	1.815	0.075	0.514	24.076	0.000 ***
G2	TIP_G2	-0.003	0.001	-0.072	-4.983	0.000 ***
G2	Rec_G2	0.004	0.001	0.035	3.224	0.001 ***
G2	MDR_G2	0.003	0.001	0.043	2.980	0.003 **
G3	Z_G3	1.102	0.102	0.312	10.787	0.000 ***
G3	TIP_G3	0.000	0.000	0.000	-0.011	0.991
H0	Rec_H0	0.010	0.001	0.166	14.043	0.000 ***
H0	MDR_H0	0.011	0.001	0.081	7.972	0.000 ***
H0	Z_H0	0.320	0.095	0.091	3.356	0.001 ***
H0	TIP_H0	0.001	0.000	0.026	1.591	0.112
H1	Z_H1	0.938	0.144	0.266	6.492	0.000 ***
H1	Rec_H1	0.005	0.001	0.112	5.269	0.000 ***
H1	TIP_H1	-0.001	0.000	-0.060	-2.853	0.004 **
I	Rec_I	0.010	0.001	0.201	15.194	0.000 ***
I	MDR_I	0.002	0.002	0.010	1.075	0.283
I	Z_I	0.052	0.060	0.015	0.867	0.386
I	TIP_I	0.000	0.001	-0.001	-0.098	0.922
All	Transp	0.020	0.002	0.141	10.734	0.000 ***
All	Fuel	0.000	0.000	-0.170	-3.817	0.000 ***

R = .938; R2 =.883; Adjusted R2 = .879
MDR_H1; MDR_G3 and Rec__G3 are constant and were deleted from the analysis
Z refers to the zone specific intercepts

Appendix D: Analysis of a multiple regression model of equation 10

(LME and TIPs removed)

Zone	Factor	ß coefficients	Std. Error	Std. ß coefficients	t-score	*p*-value
A	Z_A	1.498	1.176	0.424	1.274	0.203
A	MDR_A	-0.007	0.012	-0.122	-0.594	0.553
A	Rec_A	-0.007	0.012	-0.093	-0.593	0.553
B	Z_B	0.778	0.578	0.220	1.346	0.179
B	MDR_B	0.002	0.006	0.030	0.235	0.814
B	Rec_B	0.000	0.006	0.003	0.057	0.955
C	Z_C	0.548	0.269	0.155	2.039	0.042 *
C	MDR_C	0.005	0.003	0.120	1.959	0.050 *
C	Rec_C	0.006	0.003	0.044	1.832	0.067 +
D	Z_D	0.187	0.057	0.053	3.309	0.001 ***
D	MDR_D	0.001	0.001	0.024	1.744	0.081 +
D	Rec_D	0.001	0.001	0.010	0.932	0.351
E	Rec_E	0.007	0.001	0.137	9.930	0.000 ***
E	MDR_E	0.005	0.001	0.049	4.689	0.000 ***
E	Z_E	0.085	0.055	0.024	1.537	0.124
F0	MDR_F0	0.015	0.001	0.146	14.035	0.000 ***
F0	Rec_F0	0.009	0.001	0.096	9.414	0.000 ***
F0	Z_F0	0.146	0.049	0.041	3.002	0.003 **
F1	MDR_F1	0.050	0.004	0.132	13.072	0.000 ***
F1	Z_F1	0.704	0.069	0.199	10.132	0.000 ***
F1	Rec_F1	0.002	0.001	0.028	2.427	0.015 *
G1	Rec_G1	0.011	0.001	0.124	11.401	0.000 ***
G1	Z_G1	0.623	0.079	0.176	7.889	0.000 ***
G1	MDR_G1	0.009	0.002	0.055	5.706	0.000 ***
G2	Z_G2	1.649	0.067	0.467	24.506	0.000 ***
G2	Rec_G2	0.003	0.001	0.024	2.271	0.023 *
G2	MDR_G2	0.002	0.001	0.028	1.940	0.052 +
G3	Z_G3	1.049	0.063	0.297	16.698	0.000 ***
H0	Rec_H0	0.010	0.001	0.166	13.923	0.000 ***
H0	MDR_H0	0.011	0.001	0.083	8.128	0.000 ***
H0	Z_H0	0.347	0.071	0.098	4.893	0.000 ***
H1	Rec_H1	0.006	0.001	0.147	8.545	0.000 ***
H1	Z_H1	0.597	0.080	0.169	7.469	0.000 ***
I	Rec_I	0.010	0.001	0.201	15.324	0.000 ***
I	MDR_I	0.002	0.002	0.010	1.064	0.287
I	Z_I	0.042	0.048	0.012	0.874	0.382
All	Transp	0.019	0.002	0.140	10.632	0.000 ***
All	Fuel	0.000	0.000	-0.131	-3.303	0.001 ***

R = .938; R^2 =.880; Adjusted R^2 = .877
MDR_H1; MDR_G3 and Rec_G3 have constant zero values and were deleted from the analysis
Z refers to the zone specific intercepts

Appendix E: UBC ethics approval letter

The University of British Columbia
Office of Research Services and Administration
Behavioural Research Ethics Board

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	NUMBER
McDaniels, T.L.	Resources, Envir & Sustain	B06-0474

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT

UBC Campus ,

CO-INVESTIGATORS

Silva, Ana Carolina, Mining & Mineral Engineering

SPONSORING AGENCIES

TITLE:

Evaluation of the Lead-acid Battery Recycling System in British Columbia

APPROVAL DATE	TERM (YEARS)	DOCUMENTS INCLUDED IN THIS APPROVAL:
JUL - 6 2006	1	June 28, 2006, Consent form / Contact letters / Questionnaires

CERTIFICATION

The application for ethical review of the above-named project has been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approved on behalf of the Behavioural Research Ethics Board
by one of the following:
Dr. Peter Suedfeld, Chair,
Dr. Susan Rowley, Associate Chair
Dr. Jim Rupert, Associate Chair
Dr. Arminee Kazanjian, Associate Chair

This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures

Appendix F: Participant letter of initial contact

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

UBC

www.bridge.ubc.ca

(Company name here)
(Company address here)
May 2006

Dear Manager:

I am a doctorate student from the University of British Columbia working on research project entitled: *Evaluation of the lead-acid battery recycling system in British Columbia.* The purpose of this research is to evaluate the performance of the current lead-acid battery recycling program. During the development of my research I would like to conduct interview with collectors, transporters, recyclers and smelters of lead-acid batteries within the province. Your company was selected from the list of waste generators provided by the Ministry of Environment and I would like to conduct individual interviews with you in order to gather your experience regarding the lead-acid battery recycling system. These experiences will serve as a basis to develop a set of criteria to evaluate the current recycling system and identify strategies on how it could be improved.

This research consists of two parts: an initial interview and a follow-up. During the initial interview I will ask you to share your perceptions of the current recycling program. This interview will last for approximately 1.5 hour. I will contact you in one week's time by telephone to determine if you are willing to participate in this initial interview. If you agree to take part in this initial interview, I will arrange a time and location that is convenient for you. You may also be invited to participate a second time for a follow-up interview to ensure your views are well represented in our preliminary results. Your participation in any phase of this study is entirely voluntary. You may refuse to participate or withdraw at any point in the research process (i.e. during and after the initial interview or follow-up).

This is not a government or industry survey. Names will be kept confidential and will not be released to anyone outside of the study. Only group results will be presented and any work that may be identifiable will be made public only with your informed consent. A copy of the results of the study will be available by request after the interviews and prior to the completion of my thesis. This research project is funded primarily by the UBC Bridge Program and the University of British Columbia.

If you have any further questions please do not hesitate to contact me. You may also contact me at 604-781-2072 or carolina@mining.ubc.ca or the principal investigator Dr. Tim McDaniels at 604-822-92 88 or timmcd@interchange.ubc.ca. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Thank you for your interest in this important study.

Sincerely,

Carolina Silva, Bridge Program Fellow
University of British Columbia
Phone: 604-781-2072
Fax: 604-822-5599
carolina@mining.ubc.ca

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

UBC

www.bridge.ubc.ca

(Company name here)
(Company address here)

May 2006

Dear Manager,

I am a doctorate student from the University of British Columbia working on research project entitled: *Evaluation of the lead-acid battery recycling system in British Columbia.* The purpose of this research is to identifying strengths and weaknesses in government mandated recycling programs in British Columbia. It is important for me to hear the experiences of people who are involved in these recycling programs in order to get a better understanding of the similarities and differences among provincial recycling systems and I would like to conduct individual interviews with you in order to gather your experience regarding the recycling program you are involved with. These experiences will serve as a basis to gather description of key factors that shape the nature of recycling systems in the province.

This research consists of two parts: an initial interview and a follow-up. During the initial interview I will ask you to share your perceptions of the current recycling program. This interview will last for 1 hour. I will contact you in one week's time by telephone to determine if you are willing to participate in the initial interview. If you agree to take part in this interview, I will arrange a time and location that is convenient for you. You may also be invited to participate a second time for a follow-up interview to ensure your views are well represented in our preliminary results. Your participation in any phase of this study is entirely voluntary. You may refuse to participate or withdraw at any point in the research process (i.e. during and after the initial interview or follow-up).

This is not a government or industry survey. Names will be kept confidential and will not be released to anyone outside of the study. Only group results will be presented and any work that may be identifiable will be made public only with your informed consent. A copy of the results of the study will be available by request after the interviews and prior to the completion of my thesis. This research project is funded primarily by the UBC Bridge Program and the University of British Columbia.

If you have any further questions please contact me. You may also contact me at 604- 781-2072 or carolina@mining.ubc.ca or the principal investigator Dr. Tim McDaniels at 604-822-92 88 or timmcd@interchange.ubc.ca. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Thank you for your interest in this important study.

Sincerely,

Carolina Silva, Bridge Program Fellow
University of British Columbia
Phone: 604-781-2072
Fax: 604-822-5599
carolina@mining.ubc.ca

Appendix G: Interview questions

Bridging Public Health, Engineering and Policy Research
THE Bridge PROGRAM
www.bridge.ubc.ca

(Company name)
(Company address)
May 2006

Dear Manager,

As part of my work towards a PhD in Mining Engineering at the University of British Columbia (UBC), I am working on a thesis entitled: *Evaluation of the lead-acid battery recycling system in British Columbia.* This study is funded primarily by the UBC Bridge Program and the University of British Columbia.

I am interested in developing a set of indicators to evaluate the current lead-acid battery recycling system in the province and identify strategies on how it could be improved. It is important for me to hear the experiences of people who are involved in the recycling process. Therefore, I would like to conduct individual interviews with you. This study consists of two parts: an initial interview and a follow-up. During the initial interview I will ask you to share their perceptions of the current recycling program. These interviews will last for 1.5 hour. If you would like to take part in an interview, I will arrange a time and location that is convenient for you. You may be invited to participate a second time on follow-up interviews to ensure your views are well represented in our preliminary results. You may withdraw from the study at *any point* in the research process (i.e., both during or after the interview and follow-up).

I am also attaching a brief questionnaire to provide background information for the interviews. Names will be kept confidential and will not be released to anyone outside of the study. To ensure confidentiality, participants will not be identified by name and all data will be stored in a secure location. Only group results will be presented and any work that may be identifiable will be made public only with your informed consent. If the questionnaire is completed it is assumed that you have given your consent for your interview responses to be used in the study. If you agree to participate in the follow-up interview, I will contact you at a later date to confirm your participation in this second phase.

A copy of the results of the study will be available by request after the interviews and prior to the completion of my thesis. If you have any questions please ask me at any time. You may also contact me at 604- 781-2072 or carolina@mining.ubc.ca or the principal investigator Dr. Tim McDaniels at 604-822-92 88 or timmcd@interchange.ubc.ca .This interview is part of a doctorate research at UBC and the results will be used to study recycling alternatives for lead-acid batteries in the province. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Thank you for your interest in this study.

Sincerely,

Carolina Silva
Bridge Program Fellow
University of British Columbia
Phone: 604-781-2072
Fax: 604-822-5599
carolina@mining.ubc.ca

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

www.bridge.ubc.ca

Evaluation of the lead-acid battery recycling program in British Columbia

INTERVIEW QUESTIONS

Background questions (10 min)
1. To begin with please tell me about your involvement in the lead-acid battery recycling system in the province.

2. How would you describe your overall impressions of the recycling system in a few sentences? [Generally positive, generally negative, mixed]. Would you tell me more about this?

3. What do you see as your role in the recycling system? [Clarification:
What responsibilities or contributions to the process does your company bring to this process?]

4. Are you familiar with the Transportation Incentive Program?
[If yes] Can you describe it for me?

5. What are your expectations regarding the performance of the recycling program in the future?

Strengths and weaknesses (25 min)
6. Thanks for the background information. Now I would like to ask you about the things you like and dislike about the recycling program. I am first going to ask you about the things you like and then about the things you don’t like. I will ask about each phase of the recycling system. Is that right?

Collection / Transportation / Processing
7. Is there anything you like about the collection system? Can you give me a specific example? What is effective? What is helpful?

8. Thanks for that example. I am going to continue asking you the same question to make sure that I get all of your ideas. Is there anything else you liked? (*repeat until no more new*)

9. Is there anything you don’t like about the collection? Can you give me a specific example?
What else? (*repeat until no more new*)

10.Thanks for that example. Is there anything else you didn’t like? (*repeat until no more new*)

Specifics (25 min) - address these after more open-ended strengths and weaknesses Questions
11. Thanks for sharing your assessment of the process. I just have a few more questions that I would like to ask. What are some ways that the recycling process could be improved? Why do you think this is important (*repeat for each statement*)? How could you achieve this *(repeat for each statement)*?

12. Before we finish the interview. How was it to participate in this interview? Were any questions too hard, unpleasant or unclear to answer? Are there any issues you thought but did not have a chance to talk about?

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

UBC

www.bridge.ubc.ca

(Company name)
(Company address)
May 2006

Dear Manager,

As part of my work towards a PhD in Mining Engineering at the University of British Columbia (UBC), I am working on a thesis entitled: *Evaluation of the lead-acid battery recycling system in British Columbia.* This study is funded primarily by the UBC Bridge Program and the University of British Columbia.

I am interested in identifying facilitators and barriers in government mandated recycling programs in British Columbia. It is important for me to hear the experiences of people who are involved in these recycling programs in order to get a better understanding of the similarities and differences among provincial recycling systems. Therefore, I would like to conduct individual interviews with you. This study consists of two parts: an initial interview and a follow up. During the initial interview I will ask you to share their perceptions and understandings of the recycling program. These interviews will last for 1.5 hour. If you would like to take part in an interview, I will arrange a time and location that is convenient for you. Although I would prefer to meet with you in person, I can also arrange a telephone interview. You will also be invited to participate for a second time on follow-up interviews to ensure your views are well represented in our preliminary results. You may withdraw from the study at *any point* in the research process (i.e., both during or after the questionnaire, interview and follow-up).

I am also attaching a brief questionnaire to provide background information for the interviews. Names will be kept confidential and will not be released to anyone outside of the study. To ensure confidentiality, participants will not be identified by name and all data will be stored in a secure location. Only group results will be presented and any work that may be identifiable will be made public only with your informed consent. If the questionnaire is completed it is assumed that you have given your consent for your interview responses to be used in the study. If you agree to participate in the follow-up interview, I will contact you at a later date to confirm your participation in this second phase.

A copy of the results of the study will be available by request after the interviews and prior to the completion of my thesis. If you have any questions please ask me at any time. You may also contact me at 604- 781-2072 or carolina@mining.ubc.ca or the principal investigator Dr. Tim McDaniels at 604-822-92 88 or timmcd@interchange.ubc.ca .This interview is part of a doctorate research at UBC and the results will be used to study recycling alternatives for lead-acid batteries in the province. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Thank you for your interest in this study.

Sincerely,

Carolina Silva, Bridge Program Fellow
University of British Columbia
Phone: 604-781-2072
carolina@mining.ubc.ca

Comparing facilitators and barriers in provincial recycling schemes

INTERVIEW QUESTIONS

Background questions (10 min)
1. To begin with please tell me about your involvement in the recycling system.

2. How would you describe your overall impressions of the recycling system in a few sentences? [Generally positive, generally negative, mixed]. Would you tell me more about this?

3. What do you see as your role in the recycling system? [Clarification:
What responsibilities or contributions to the process does your company bring to this process?]

4. What are your expectations regarding the performance of the recycling program in the future?

Strengths and weaknesses (20 min)
5. Thanks for the background information. Now I would like to ask you about the things you like and dislike about the recycling program. I am first going to ask you about the things you like and then about the things you don't like. I will ask about each phase of the recycling system. Is that right?

Collection/Transportation/Processing
6. Is there anything you like about the collection system? Can you give me a specific example? What is effective? What is helpful?

7. Thanks for that example. I am going to continue asking you the same question to make sure that I get all of your ideas. Is there anything else you liked? (*repeat until no more new*)

8. Is there anything you don't like about the collection system? Can you give me a specific example? What else? (*repeat until no more new*)

9. Thanks for that example. Is there anything else you didn't like? (*repeat until no more new*)

Specifics (30 min) - address these after more open-ended strengths and weaknesses Questions
Thanks for sharing your assessment of the process. Now I would like you to refer to the attached influence diagram. This is a general diagram illustrating main aspects that contribute to collection, transportation and sorting of materials.

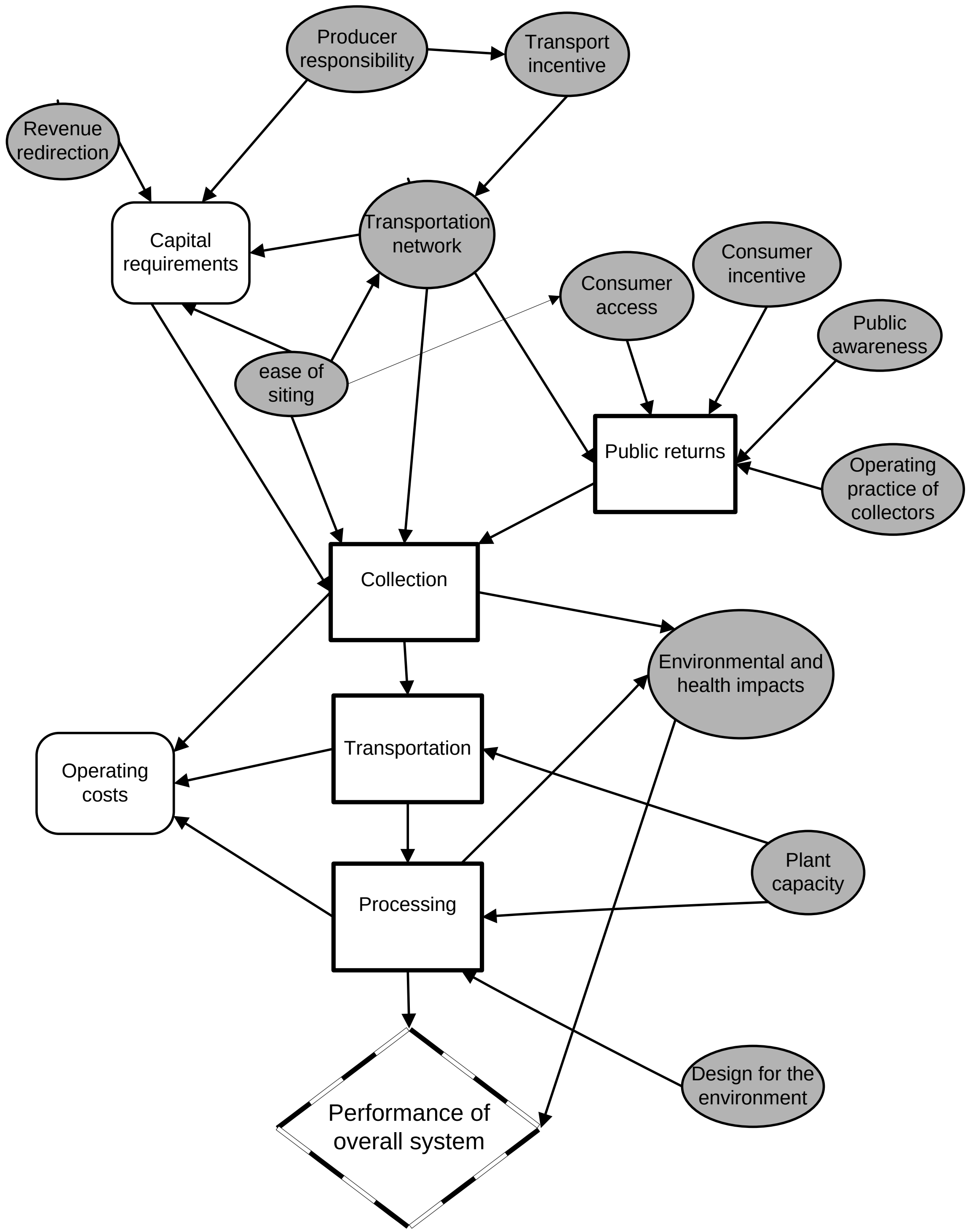
10. What comes to your mind when you see this diagram?

11. How would you make this diagram better reflect the realities of your system? Can you tell me more about this *(repeat for each statement)*?

12. What are some ways that the recycling process could be improved? Why do you think this is important *(repeat for each statement)*? How could you achieve this *(repeat for each statement)*?

13. Before we finish the interview. How was it to participate in this interview? Were any questions too hard, unpleasant or unclear to answer? Are there any issues you thought but did not have a chance to talk about?

An Influence Diagram of a recycling system



Appendix H: Interview consent form

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

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INTERVIEW CONSENT FORM (Recycling sites)

Evaluation of the lead-acid battery recycling system in British Columbia

Principal Investigator and Faculty Advisor:

Dr. Tim McDaniels, Professor, Institute for Resources, Environment and Sustainability (Tel: 604-822-9288)

Co-Investigators:

Carolina Silva, PhD Candidate, Department of Mining Engineering (Tel: 604-781-2072)

Purpose:

The purpose of this research is to gather the experiences of participants regarding the lead-acid battery recycling system in British Columbia. These experiences will serve as a basis to design a set of criteria to evaluate the current lead-acid battery recycling system in the province. This research is being conducted as part of my PhD in Mining Engineering at the University of British Columbia. The results of the research will be published in a dissertation that will be a public document.

Study Procedures:

This study consists of two parts: an initial interview and a follow-up. In this initial part of the study you will be interviewed by the researcher (Carolina Silva). I will ask you about your perceptions of the recycling system in British Columbia. The interview questions be open-ended and will expand on the topics covered in the questionnaire. The interview will go for about an hour. If you agree, the interview will be audio-taped and then parts of the discussion will be transcribed in order to be able to analyze themes that arise.

Confidentiality:

All information collected will remain confidential. You will not be identified by name in any reports of the completed study and identifying details in direct quotes will be adjusted to ensure confidentiality, unless you ask me to attribute your comments to you in the published study results. You may request the opportunity to review direct quotes of your comments prior to publishing. All documents will be identified only by code number and kept in a locked filing cabinet. Electronic data will be password-protected on a computer stored in a secure location.

Contact Information:

If you have any questions or desire further information with respect to this study, you may contact Carolina Silva at 604-781-2072 or the principal investigator Dr. Tim McDaniels at 604-822-9288. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Consent:

By signing below you consent to participate in this study. You may be invited to participate a second time for a follow-up interview to ensure your views are well represented in our preliminary results. Please indicate below if you would like to participate in the follow-up interview. If so, I will contact you again at a later date to confirm your participation in this second phase. Your participation is entirely voluntary and you may refuse to participate or withdraw from the study at any time (i.e., during or after the interview and follow-up). Your signature below indicates that you have received a copy of this consent form for your own records.

Would you like to be contacted again for the follow-up interview? YES NO

______________________________ ____________________

Subject Signature Date

Bridging Public Health, Engineering and Policy Research

THE Bridge PROGRAM

www.bridge.ubc.ca

INTERVIEW CONSENT FORM

Comparing facilitators and barriers in recycling schemes in British Columbia

Principal Investigator and Faculty Advisor:
Dr. Tim McDaniels, Professor, Institute for Resources, Environment and Sustainability (Tel: 604-822-9288)
Co-Investigators:
Carolina Silva, PhD Candidate, Department of Mining Engineering (Tel: 604-781-2072)

Purpose:
The purpose of this research is to gather perceptions and understandings of participants regarding the aspects that influence performance in government mandated recycling programs in the province. This information will serve as a basis to gather description of key factors that shape the nature of recycling systems. This research is being conducted as part of my PhD in Mining Engineering at the University of British Columbia. The results of the research will be published in a dissertation that will be a public document.

Study Procedures:
This study consists of two parts: an initial interview and a follow-up. In this initial part of the study you will be interviewed by the researcher (Carolina Silva). I will ask you about your perceptions of the recycling system in British Columbia. The interview questions be open-ended and will expand on the topics covered in the questionnaire. The interview will go for about an hour. If you agree, the interview will be audio-taped and then parts of the discussion will be transcribed in order to be able to analyze themes that arise.

Confidentiality:
All information collected will remain confidential. You will not be identified by name in any reports of the completed study and identifying details in direct quotes will be adjusted to ensure confidentiality, unless you ask me to attribute your comments to you in the published study results. You may request the opportunity to review direct quotes of your comments prior to publishing. All documents will be identified only by code number and kept in a locked filing cabinet. Electronic data will be password-protected on a computer stored in a secure location.

Contact Information:
If you have any questions or desire further information with respect to this study, you may contact Carolina Silva at 604-781-2072 or the principal investigator Dr. Tim McDaniels at 604-822-9288. If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

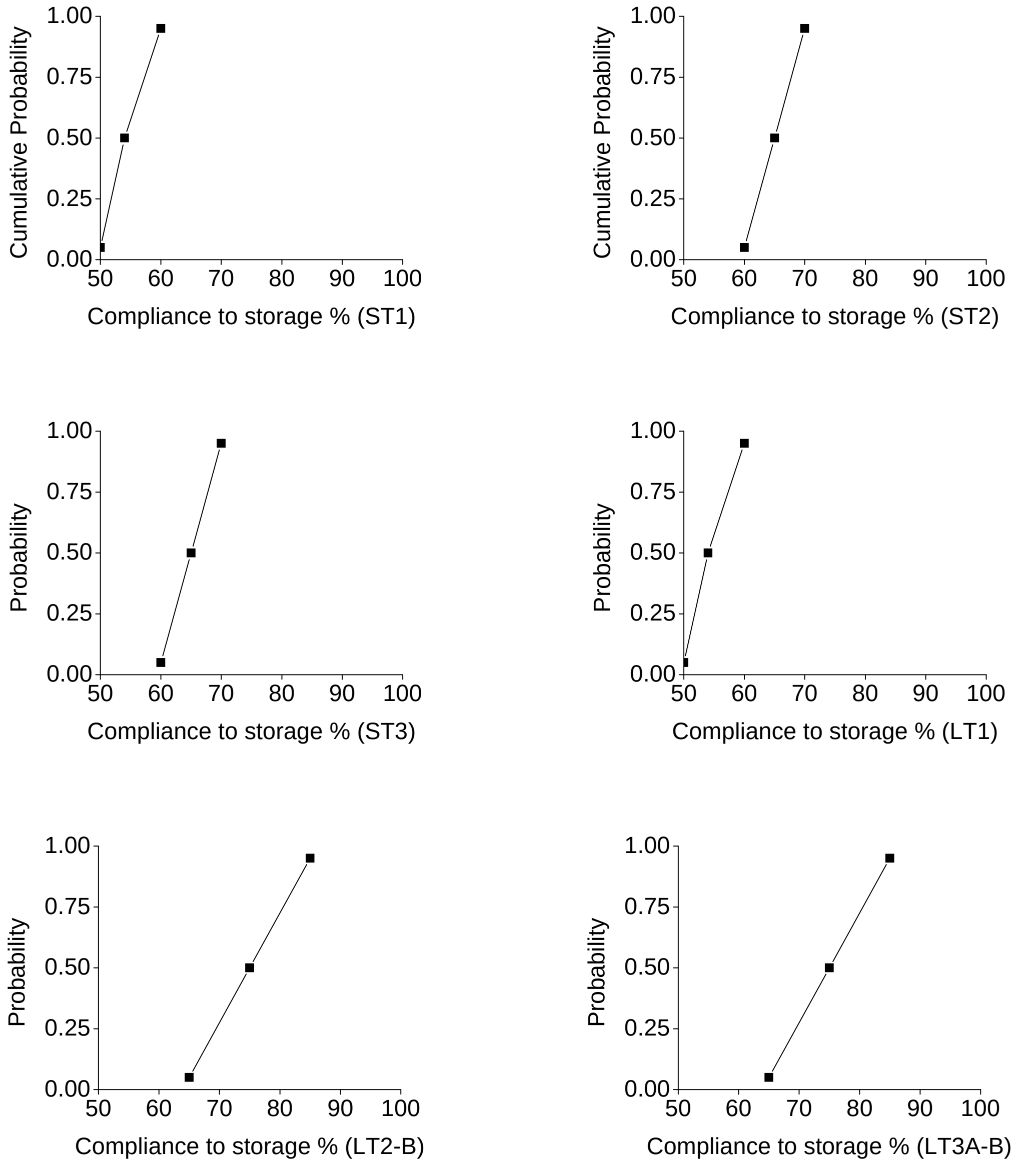
Consent:
By signing below you consent to participate in this study. You may be invited to participate a second time for a follow-up interview to ensure your views are well represented in our preliminary results. Please indicate below if you would like to participate in the follow-up interview. If so, I will contact you again at a later date to confirm your participation in this second phase. Your participation is entirely voluntary and you may refuse to participate or withdraw from the study at any time (i.e., during or after the interview and follow-up). Your signature below indicates that you have received a copy of this consent form for your own records.

Would you like to be contacted again for the follow-up interview? YES NO

______________________________ ____________________

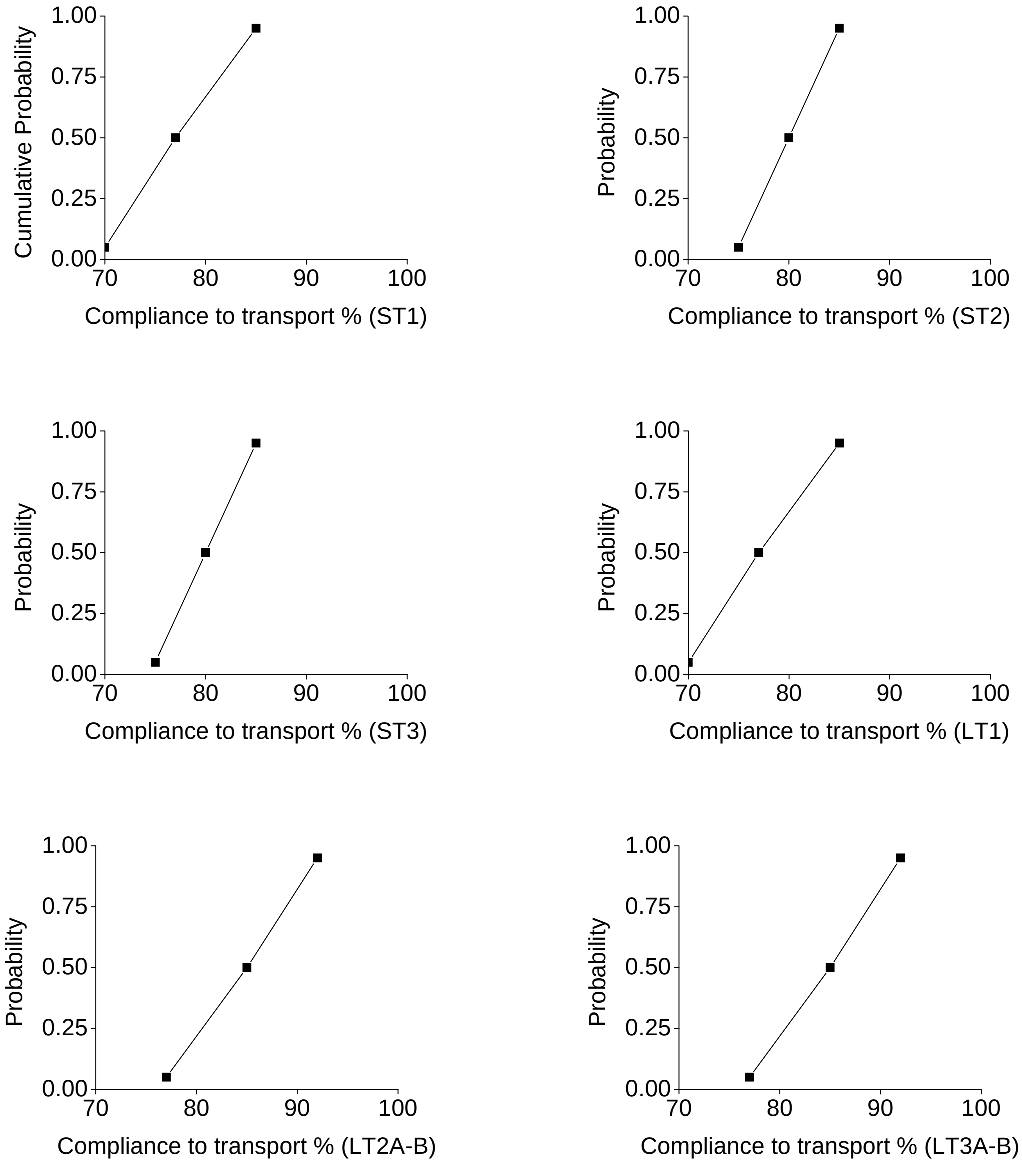
Subject Signature Date

Appendix I: Cumulative probability distribution for compliance to storage



Source: Chapter 5

Appendix J: Cumulative probability distribution for compliance to transport



Source: Chapter 5

Appendix K: Economic costs of recycling (Chapter 5)

Strategy ST1 (current)

Program costs to taxpayers:	
Tonnes of batteries	17,284
# of batteries	1,004,895
Revenue ($CAN)	**5,024,477**

Program costs (to taxpayers) are calculated based on total revenue from the $5 dollar environmental levy

Strategy ST2

Program costs to taxpayers and stewardship agency

tonnes of batteries	17,284	source: chapter 2
# of batteries (17.2 kg per battery)	1,004,884	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Deposit operation cost (0.1c per battery)	$100,488	source: interview Battery Council International
Transportation subsidy**	$390,740	source: survey transport companies**
Total	**$1,741,228**	

*****include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A distance to plant	B*** km rate	C collected	D consumed	E=D-C not collected	F=B*E*X cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
C0 Okanagan	311	0.72	1,327	1,616	289	14,679
D0 Kootenay	100	0.23	349	426	77	1,263
E0 Thompson Nicola	271	0.63	723	859	136	6,019
F0 Cariboo	710	1.65	321	373	52	5,991
F1 Cariboo	1989	4.61	12	15	3	876
G1	1813	4.20	296	348	51	15,216
G2 Prince George	969	2.25	425	202	202	0
G3	1697	3.94	19	23	4	1,040
G4	2441	5.66	0	0	0	31
H0	1446	3.35	357	380	23	5,527
H1	1807	4.19	35	35	0	44
I0 Kootenay	231	0.54	281	335	53	2,008
						390,739.84

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

Results of survey	Y load size (tonnes)	X cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3

Strategy ST3
Program costs to taxpayers and stewardship agency

tonnes of batteries	17,284	source: chapter 2
# of batteries (17.2 kg per battery)	1,004,884	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Transportation subsidy**	$390,740	source: survey transport companies**
Total	**$1,640,740**	

*****include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A	B***	C	D	E=D-C	F=B*E*X
	distance to plant	km rate	collected	consumed	not collected	cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
C0 Okanagan	311	0.72	1,327	1,616	289	14,679
D0 Kootenay	100	0.23	349	426	77	1,263
E0 Thompson Nicola	271	0.63	723	859	136	6,019
F0 Cariboo	710	1.65	321	373	52	5,991
F1 Cariboo	1989	4.61	12	15	3	876
G1	1813	4.20	296	348	51	15,216
G2 Prince George	969	2.25	425	202	202	0
G3	1697	3.94	19	23	4	1,040
G4	2441	5.66	0	0	0	31
H0	1446	3.35	357	380	23	5,527
H1	1807	4.19	35	35	0	44
I0 Kootenay	231	0.54	281	335	53	2,008
						390,739.84

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

	Y	X
Results of survey	load size (tonnes)	cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3

Strategy LT1 (current)
Program costs to taxpayers:

Tonnes of batteries	19,590
# of batteries	1,138,951
Revenue ($CAN)	**$5,694,753**

Program costs (to taxpayers) are calculated based on total revenue from the $5 dollar environmental levy

Strategy ST2A

Program costs to taxpayers and stewardship agency

tonnes of batteries	19,590	source: chapter 2
# of batteries (17.2 kg per battery)	1,138,951	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Deposit operation cost (0.1c per battery)	$113,895	source: interview Battery Council International
Transportation subsidy**	$429,814	source: survey transport companies**
Infrastructure costs	$500,000	source: interview recycling plants
Total	**$2,293,709**	

*****include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A	B***	C	D	E=D-C	F=B*E*X
	distance to plant	km rate	collected	consumed	not collected	cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
C0 Okanagan	311	0.72	1,327	1,616	289	14,679
D0 Kootenay	100	0.23	349	426	77	1,263
E0 Thompson Nicola	271	0.63	723	859	136	6,019
F0 Cariboo	710	1.65	321	373	52	5,991
F1 Cariboo	1989	4.61	12	15	3	876
G1	1813	4.20	296	348	51	15,216
G2 Prince George	969	2.25	425	202	202	0
G3	1697	3.94	19	23	4	1,040
G4	2441	5.66	0	0	0	31
H0	1446	3.35	357	380	23	5,527
H1	1807	4.19	35	35	0	44
I0 Kootenay	231	0.54	281	335	53	2,008
						$390,740
						$429,814
						adjusted for population increase

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

Results of survey	Y load size (tonnes)	X cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3

Strategy ST2B

Program costs to taxpayers and stewardship agency

tonnes of batteries	19,590	source: chapter 2
# of batteries (17.2 kg per battery)	1,138,951	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Deposit operation cost (0.1c per battery)	$113,895	source: interview Battery Council International
Transportation subsidy**	$429,814	source: survey transport companies**
costs of exporting 10% batteries overseas	$250,000	source: interview transport companies
Total	**$2,043,709**	

*include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A	B***	C	D	E=D-C	F=B*E*X
	distance to plant	km rate	collected	consumed	not collected	cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
C0 Okanagan	311	0.72	1,327	1,616	289	14,679
D0 Kootenay	100	0.23	349	426	77	1,263
E0 Thompson Nicola	271	0.63	723	859	136	6,019
F0 Cariboo	710	1.65	321	373	52	5,991
F1 Cariboo	1989	4.61	12	15	3	876
G1	1813	4.20	296	348	51	15,216
G2 Prince George	969	2.25	425	202	202	0
G3	1697	3.94	19	23	4	1,040
G4	2441	5.66	0	0	0	31
H0	1446	3.35	357	380	23	5,527
H1	1807	4.19	35	35	0	44
I0 Kootenay	231	0.54	281	335	53	2,008
						$390,740
						$429,814
						adjusted for population increase

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

Results of survey	load size (tonnes)	cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3

Strategy ST3A

Program costs to taxpayers and stewardship agency

tonnes of batteries	19,590	source: chapter 2
# of batteries (17.2 kg per battery)	1,138,951	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Transportation subsidy**	$429,814	source: survey transport companies**
infrastructure	$500,000	source: interview recycling plants
Total	**$2,179,814**	

***include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A distance to plant	B*** km rate	C collected	D consumed	E=D-C not collected	F=B*E*X cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
C0 Okanagan	311	0.72	1,327	1,616	289	14,679
D0 Kootenay	100	0.23	349	426	77	1,263
E0 Thompson Nicola	271	0.63	723	859	136	6,019
F0 Cariboo	710	1.65	321	373	52	5,991
F1 Cariboo	1989	4.61	12	15	3	876
G1	1813	4.20	296	348	51	15,216
G2 Prince George	969	2.25	425	202	202	0
G3	1697	3.94	19	23	4	1,040
G4	2441	5.66	0	0	0	31
H0	1446	3.35	357	380	23	5,527
H1	1807	4.19	35	35	0	44
I0 Kootenay	231	0.54	281	335	53	2,008
						$390,740
						$429,814 adjusted for population increase

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

Results of survey	Y load size (tonnes)	X cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3

Strategy ST3B

Program costs to taxpayers and stewardship agency

tonnes of batteries	19,590	source: chapter 2
# of batteries (17.2 kg per battery)	1,138,951	
Administrative costs*	$450,000	source: BC Used Oil Management Program
Communications and public relations	$350,000	source: BC Used Oil Management Program
Management and administration contracts	$400,000	source: BC Used Oil Management Program
Compliance review	$50,000	source: BC Used Oil Management Program
Transportation subsidy**	$429,814	source: survey transport companies**
Cost of transporting 10% batteries overseas	$250,000	source: interview transport companies
Total	**$1,929,814**	

*****include office and general expenses, legal fees, rent, financial audits (source: BC Used Oil Management Program)

****Transport subsidy calculation**	A	B***	C	D	E=D-C	F=B*E*X
	distance to plant	km rate	collected	consumed	not collected	cost of subsidy
A0 Vancouver Island	599	N/A	2,844	4,053	1,209	159,951
B0 Lower Mainland	431	1	7,110	9,634	2,524	178,095
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						$390,740
						$429,814
						adjusted for population increase

***pro-rated distance based on Lower Mainland distance to recycling plants (except for Vancouver Island)

	Y	X
Results of survey	load size (tonnes)	cost/per tonne
Transportation from Lower Mainland	20.4	70.56
Transportation from Vancouver Island	14.6	132.3