A MULTIPLE ACCOUNTS APPROACH FOR ANALYZING THE EFFECTIVENESS OF NOx EMISSIONS CONTROLS IN THE GVRD AIRSHED

by

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ABSTRACT

This thesis presents an analysis of air quality control initiatives in the GVRD. Starting with an examination of deteriorating regional air quality, oxides of nitrogen emissions (NOx), are the focus (as a precursor to ground level ozone.) The research demonstrates that if the status quo is maintained, episodes of ground level ozone will get worse and the effects will be far reaching and expensive. The Greater Vancouver Regional District's Air Quality Management Plan is reviewed, with emphasis on analysis and evaluation of emission reduction strategies. Emission Reduction Measures (ERMs) are various methods of reducing air pollution (including scrubbers on smoke stacks, transportation demand management, alternative fuels and motor vehicle inspection/maintenance programs.) Emission Reduction Measures are viewed as the tools that must be implemented to solve air quality problems. Environmentally, the most desirable solution would be to implement all ERMs. However, factors such as cost effectiveness and social, financial, political and customer service impacts must be considered and the best measures should be implemented first. The best solutions are those that meet as many objectives as possible while causing the least amount of negative impacts on the economy, society, government and the environment. Finding optimal solutions is a task that requires formalization of common sense. Analytical frameworks such as the cost/benefit analysis, decision analysis and the multiple account/objective analysis are considered as potential tools to help "make sense" of the complexity of air quality policy decisions. The intent is to provide useful and readily understandable information to decision makers. The Multiple Account Analysis (as used by The Crown Corporations Secretariat) is applied to an assortment of Emission Reduction

Measures to help identify the "best" order for implementation. This method provides results that compare accounts of importance (such as cost effectiveness and emission reduction potential) and presents decision makers with quality information highlighting tradeoffs and preferences. In the scope of this paper, four ERMs are analyzed across accounts and the results presented in a matrix. The AirCare Program appears as the best choice for effective reduction of oxides of nitrogen when compared to alternative fuels, vanpooling and the Burrard thermal generating plant rebuild.

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List of Abbreviations:

AQI: Air Quality Index

AQMP: Air Quality Management Plan

BTGP: Burrard thermal generating plant

CB: cost benefit

CBA: cost benefit analysis

C.C.S: Crown Corporations Secretariat

CE: cost effectiveness

CV: contingent valuation

DA: decision analysis

GVRD: Greater Vancouver Regional District

HOV: high occupancy vehicle

MAA: multiple account analysis

MAUT: multiattribute utility technique

MOA: multiple objective analysis

MVB: motor vehicle branch

NAAQS: National Air Quality Standards

NG: natural gas

NOx: oxides of nitrogen

SOV: single occupancy vehicle

TCM: transportation control measure

VOC: volatile organic compound

This analysis was based on information from secondary sources of information available in 1994. New studies have come out since then but do not detrimentally impact the research approach. The basic insights and conclusions are robust

SECTION 1: THE AIR QUALITY PROBLEM

A) The Problem

Maintaining environmental quality is one of the greatest challenges mankind will face in the next century. Exponential population growth fuels economic activity, which in turn degrades the resources we have long taken for granted. Having clean air as a resource is not only important for the well being of humans and animals, but also for the health of crops, vegetation and entire ecosystems we depend on for existence. Humans also depend heavily on energy produced from fossil fuels. The combustion of fossil fuels for the generation of electricity and mobility is the major cause of air pollution in many cities. Coal, oil, and natural gas are relied on to produce the electricity, while petroleum products are use by automobiles. The automobile has changed mankind's lifestyle dramatically in less than one century. The prevalence of increased access to mobility has dominated land use patterns, especially in North America. With a car it is easier to increase the distance between place of residence and place of work. As a result, more vehicles are needed to move people over widespread distances. The end result is heavily congested roadways and the discharge of thousands of tonnes of pollutants into the atmosphere.

In some parts of the world, pollution levels have gone to the extreme. In Los Angeles, congested expressways serve millions of motorists daily and results in the worst urban air quality in the United States. In Mexico City, the air quality is so poor, there are now booths where residents can purchase clean air (at a high price) to breath for a few minutes. In Bangkok, spending eight hours on a downtown street is as unhealthy as smoking nine cigarettes (Pendakur, 1993).

In the Lower Mainland, ground level ozone is already a priority problem. Two types of emissions; Oxides of Nitrogen (NOx) and Volatile Organic Compounds combine in the presence of ultra-violet light to form ground level ozone, the primary unhealthy ingredient in photochemical smog (B.C. Hydro, 1993). The formation of ground level ozone in the lower mainland occurs primarily on warm, sunny days from May to September. Smog is the brown haze that usually forms over Vancouver and moves east to the lower Fraser Valley. Because of light winds, high atmospheric pressure and the surrounding mountains, smog tends not to dissipate. This results in periods of low air quality and can cause various problems.

Besides the most obvious impairment of visibility and aesthetics, lingering smog and ozone have detrimental impacts on health, vegetation and property. In low concentrations, ground level ozone can cause minor eye, nose and throat irritation. As the concentration increases, health problems can become more serious. Some symptoms include: asthma, bronchitis, coughing, increased susceptibility to respiratory infections, decreased lung function and lowered physical performance (Ministry of Environment, 1993).

Ground level ozone has serious impacts on vegetation and crops as it can damage leaves and thus reduce photosynthetic capability. As a direct result, growth and productivity may be retarded, and reproduction functions may be impaired. It can also increase the plants susceptibility to disease and damage from insects (Ministry of Environment, 1993). Smog also affects property as it soils buildings and speeds up the aging process of materials such as paint, stucco, fibers, plastic and rubber. Smog buildup may also have long term negative impacts on the aesthetic values attached to the region. This could potentially reduce the desirability of the region as an international tourist destination.

All of these detrimental impacts caused by smog and ground level ozone pose significant costs to society. These costs are not only associated with market items that can be measured in dollars; they also include environmental and social values that have no clear monetary value.

These include intangible values placed by society on such things as clear days versus days spent inside because of poor air quality. These values have different levels depending on the members of society they affect most. Putting a dollar figure on these values is a complex matter that will be discussed in Section III of this paper.

As in all public policy contexts, values can cloud an already complex problem. Other factors such as numerous stakeholders, conflicting objectives, and uncertainty contribute to the difficulty of making tradeoffs among policy objectives and options. It is eminently difficult to decide what level of environmental improvement is worth the cost. As a result the controversial issue of tradeoffs is often easier for a decision maker to avoid.

Some public policy decisions, especially those pertaining to environmental quality have focused on standards based approaches where a predetermined level of pollution is identified that all emitting sources must adhere to. These policy methods are usually economically inefficient as cost effective measures to reduce pollution are over-looked. In addition, the traditional sources that the public perceives as heavy polluters are becoming less significant contributors to total emissions. It is evident better approaches are necessary to improve environmental quality.

New policies approaches designed to curb air pollution are receiving an increasing amount of attention and effort at international, national and regional levels. The international protocols for freezing NOx at 1987 levels and the Canadian Council of Ministers of the Environment: NOx \VOC Plan, among others, call for more serious undertakings to reduce harmful emissions, especially those that form ground level ozone (CCME, 1990). The Greater Vancouver Regional District's Air Quality Management Plan examines many avenues to reduce air pollution. Best available control technology, inspection and maintenance programs, transportation demand management (TDM), and alternative fuels are just some of the emission reduction strategies that are currently being investigated. However, all emission reduction strategies are subject to several constraints and limitations that determine their worth. Limited budgets, huge government debt loads, timing, political acceptability and public pressure dictate that good choices be made to protect air quality. Good choices must be cost effective, affordable, equitable and politically acceptable.

Identifying the "best" options for improving air quality requires logic, sound reasoning, analysis and evaluation. Essentially, the process begins by setting priorities, defining problems, examining alternatives and evaluating tradeoffs to help inform decision making. The GVRD's Air Quality Management Plan accomplishes the first three steps of the process nicely, but could be improved when it comes to comparing the results and evaluating the tradeoffs. Section II, "*Air Quality Management Plan*" provides an illustration of the existing policy context to highlight its strengths and weaknesses.

B) Purpose of the Thesis

The purpose of this thesis is to apply an analytical framework (Multiple Account Analysis) to an environmental policy problem (selecting air quality improvement strategies) in order to demonstrate one way of improving the quality of information provided to decision makers. The intent is to present relevant, concise and useful information about air quality management options in a readily understandable fashion. The Multiple Account Analysis accomplishes these challenges and the results explicitly show performance of alternatives across accounts of importance. By employing this kind of analysis, it is hoped the effectiveness of decisions to control air pollution will be improved.

C) Structure and Key Issues of Thesis

This thesis is structured into five main parts. The first three sections serve as a literature review by setting up: (I) the air quality problem, (II) the policy context in which efforts to improve air quality currently exist and (III) potential analytical tools to improve the quality of information provided to decision makers. The fourth section ties the previous together by applying an analytical framework to air quality management in the regional context. The final section describes the results and draws conclusions for this analysis and air quality management in general. The appendices explain assumptions and calculations involved with the application of the Multiple Account Analysis to the problem of air quality management in the Greater Vancouver Regional District.

Section I "The Air Quality Problem" describes causes and potential impacts of deteriorating air quality to establish context of the problem. Smog is identified as a serious concern as episodes of ground level ozone are increasing in the Lower Mainland. (The extent and magnitude of smog is obvious during the warm summer months.) Oxides of Nitrogen (NOx) are the limiting precursors to ground level ozone (smog), and is therefore perceived by regional residents as being a priority issue. Because of the perceived priority, NOx becomes the focus of this analysis.

Section II, the *Air Quality Management Plan,* examines the existing policy in place at the regional level, its benefits, and where it can be improved. The planning process is focused on to highlight where analytical frameworks would be most useful in deriving better information for decision makers. One weakness of the plan is that it can only makes recommendations for action and thus, does not explicitly establish an order for implementing strategies that reduce air pollution in the most effective manner.

Section III*: Selecting Analytical Frameworks to inform Air Quality Management Decisions* provides information on the "tools" used to inform the decision making process. This section describes the Benefit/Cost Analysis, Decision Analysis, Multiple Objective Analysis and the Multiple Account Analysis. These four frameworks offer various levels of integrating values with technical information to compare alternatives across objectives of importance. These frameworks, their applicability, and the pros and cons of each are discussed. The Multiple Account Analysis, as used by the Crown Corporations Secretariat is highlighted as the framework of choice for applicability to Air Quality Management in Section IV.

Section IV *Application* ties together the previous parts by utilizing the Multiple Account Analysis with selected emission reduction measures for the purpose of evaluating a hypothetical example of air quality management. This section clarifies the decision to be made, describes accounts of importance (with emphasis on cost effectiveness), analyzes selected alternatives and determines the consequences of those alternatives. The results are presented in an alternatives by accounts matrix.

The last section, *Results and Conclusions* summarizes results of the matrix and employs cost effectiveness values for comparing impacts across alternatives to establish an order for implementation. A list of questions is developed that could be used to help establish the preferences of decision makers by highlighting critical values and tradeoffs. The objectives gained or forgone when choosing one alternative over another are highlighted as the tradeoffs, while cost effectiveness differences are suggested as a means of determining critical values. Conclusions for this analysis and its applicability to air quality policy decisions are described at the end of the section.

Section II: Air Quality Management Plan

Overview

Policy efforts targeting air pollution are receiving attention globally. Locally, the GVRD has put concentrated effort toward reducing air pollution to levels experienced previously (i.e. 1985.) To attain this regional objective, emission reduction measures are to be implemented as solutions. However, implementation of all emission reduction measures is not feasible financially and is also not expected to achieve the desired level of pollutant reduction. Also, actions that may initially appear to be good solutions to air quality problems, may also have detrimental impacts on other objectives that matter to society. Important objectives dictate the need to improve air quality by implementing the "best" solutions first, followed by those that are less attractive later. The "best" solutions are those that achieve the best balance of pros and cons among the objectives. This section examines GVRD efforts to control air pollution with the AQMP. The intent of this chapter is to show that the process can be improved by looking at the problem as a specific decision context regardless of the complexity of jurisdiction and source sector. Improvements are suggested for important steps in the policy framework process such as analyzing and evaluating emission reduction measures. This section begins by identifying the jurisdictional responsibilities of the various levels of government in the lower mainland. Then, the planning process is discussed, focusing on important stages such as: problem identification, development of objectives, selection of alternatives, public consultation and analysis and assessment of proposed solutions. Ingredients important for air quality management success are mentioned at the end.

The Greater Vancouver Regional District has the responsibility to develop and implement an Air Quality Management Plan (AQMP) for the region. The AQMP is part of an inter-governmental, integrated approach to enhancing air quality for the protection of human health and the environment. All levels of government will play a role in the cooperative efforts specified in the plan depending on the responsibility that particular organization has authority for. The federal government is responsible for new vehicle emissions standards, enhanced diesel fuel emission standards, and consumer products. The provincial government is responsible for in-use vehicle emissions, transportation demand management strategies(TDM's) and alternative and reformulated fuel development and implementation. The GVRD is responsible for managing many point and area sources, as well as creating trip reduction measures (other than TDM's.) Municipal governments are responsible primarily for land use and regulation of area sources. The agencies with fundamental responsibility are the GVRD Air Quality and Source Control Department, BC Environment and Environment Canada. The AQMP is integrated with the provincial Clean Air Strategy and the Federal Green Plan. The GVRD initiated regional air quality management in 1972 and remains the primary authority for developing plans and programs within the Greater Vancouver area.

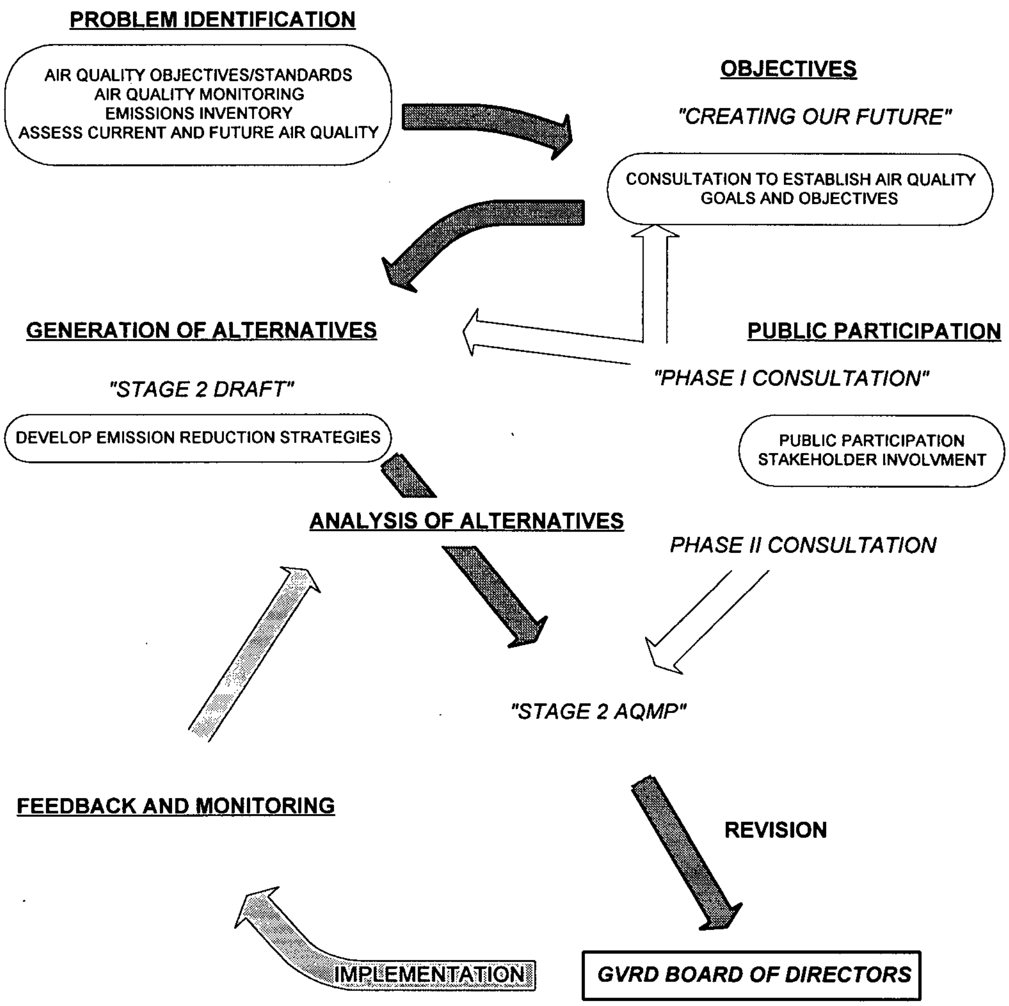
Planning Process

The AQMP grew out of the "*Creating Our Future: Steps to a Livable Region*" process. The plan was adopted by the GVRD Board of Directors which was mandated to develop and implement an air quality management plan to protect and enhance regional air quality (GVRD, 1994). The mission statement of the plan articulates the GVRD will work cooperatively with communities to shape regional land use and transportation, encourage clean air lifestyles and manage anthropocentric emissions for protection of human health and the environment. The intent is to manage these emissions by employing emission reduction strategies as solutions to air quality problems. To determine if solutions are appropriate and are indeed going to solve the problem, a systematic, well organized planning effort is needed. The approach could be characterized as a "rational planning" model (Meyer and Miller, 1984), and includes the following steps: problem identification, formulation of goals and objectives, generation of alternatives, public participation, evaluation of alternatives, decision, implementation, feedback and monitoring (see figure 2-1.) The following sub-sections (A to D) describe the important steps of the planning process involved with developing the AQMP.

A) Problem Identification

National Ambient Air Quality Objectives are used as the standard to which regional air quality is compared for the protection of health and environment. (National Ambient Air Quality Objectives (NAAQO's) were developed under the Federal Clean Air Act for the purpose of protecting public health and the environment from the detrimental effects of pollution (GVRD, 1994). National objectives are similar to United States standards in that they have been established for pollutants such as ozone, particulate matter, carbon monoxide and nitrogen dioxide. Three concentration levels of these pollutants are designated for

FIGURE 2-1: AQMP PLANNING PROCESS



reference to the objectives (NAAQO's). The three levels are: Maximum Desirable, Maximum Acceptable, and Maximum Tolerable. The Maximum Desirable level represents a long term goal for air quality and provides a basis for policy protection of pristine areas of the nation (GVRD, 1994). Maximum Acceptable levels are intended to provide "adequate" defense for human health from pollutants. Maximum Tolerable levels represent a short term, concentration of pollutants that present "diminishing margin of safety" (GVRD, 1994). Beyond the maximum tolerable threshold, impending action is necessary to rectify the situation. The NAAQO's are the levels of criteria pollutants that the AQMP uses as a basis for protection of health and environment. This is manifested by the use of an Air Quality Index (AQI) that relates measured concentrations of pollutants to the ambient air quality objectives for that contaminant. In regards to the three criteria levels mentioned above: the maximum desirable is represented by an AQI of 25, maximum acceptable by an AQI of 50 and maximum tolerable by an AQI of 100. The AQI for each hour at each monitoring site is determined from the highest reading of any pollutant measured.

Forty-seven stations around the lower mainland comprise an extensive regional monitoring network to quantify levels of the five criteria pollutants (CO, VOC, NOx, PM and SOx). Monitoring of the five criteria pollutants is conducted by GVRD staff in fourteen member municipalities in the lower mainland. The monitoring network contains 198 samplers distributed around the region at the same 47 stations (GVRD, 1994). Twenty-two of these stations are directly connected by telemetry to the GVRD's central computer to facilitate an constant view of air quality. A mobile monitoring unit also is employed to achieve site specific measures of pollutants in areas not well covered by the set stations. An emissions inventory was compiled to quantify the sources of regional air pollution using 1985 as a reference point (GVRD, 1992).

In 1985, over 600,000 tonnes of pollutants were discharged into the Greater Vancouver airshed (GVRD, 1994). There are many sources of air pollution in the lower mainland that contribute to deteriorating air quality. In order to delineate the problem, the sources have been grouped into the following categories: point, area, and mobile sources. Point sources include all commercial and industrial sources that are regulated by the GVRD discharge permits and may also include other large emitters that are not GVRD regulated. Area sources include painting and solvent use, residential and commercial space heating, fuel transport, storage and filling (GVRD, 1994). Mobile sources can be broken down into on and off road categories. Off road sources include marine vessels, trains, airplanes and large construction equipment such as earth-movers. On road sources are made up almost entirely of light duty vehicles such as cars/ light trucks and heavy duty vehicles such as trucks and buses. The relative contribution of all of the previously mentioned emission sources is shown in table 2.1.

Table 2-1. 1990 GVRD Emissions Inventory

Source Sector	**CO tonnes**	**VOC tonnes**	**NOx tonnes**	**SOx tonnes**	**PM tonnes**	**Combined overall**
Mobile:						tonnes
light duty vehicles	346,886	36,981	18,531	716	1,385	404,479
heavy duty vehicles	9,275	1,398	8,125	970	2,006	21,774
other mobile	17,352	4,283	14,671	2,172	1,083	39,561
Mobile total	**373,493**	**42,662**	**41,327**	**3,858**	**4,474**	**465,814**
Point	6,527	8,576	8,811	3,766	11,969	39,649
Area	4,802	34,069	3,303	351	3,033	45,558
ALL SOURCES*	**384,822**	**85,307**	**53,441**	**7,975**	**19,476**	**551,021**

*excluding road dust, (adapted from pages 4-2 GVRD 1994.)

Light duty vehicles are by far the largest source of emissions in the region and account for 73% of the five criteria pollutants (GVRD, 1994). Despite the common misconception of these being large polluters, heavy duty vehicles such as trucks and buses only contribute approximately 4% of pollutants, (this is less than the off- road category which contributes about 7%). In 1990, light duty vehicle's accounted for 40% of the combined NOx and VOC emissions which cause ozone smog, while heavy duty vehicles added another 7% (GVRD, 1994). This is considerably more than point source contribution to ground level ozone problems, which added only about 13% of smog forming precursors.

Information from the emissions inventory, NAAQS, and updated monitoring data were used by GVRD staff as input for modeling the effect economic activity, population growth, total vehicle numbers and trip data would have on current and future air quality (GVRD, 1994). Scenarios were developed to model a base case situation where only current emissions reduction programs were included (excluding the provincial AirCare Program.) This scenario did not include any new emissions reduction programs except for new vehicle emission standards to be introduced in 1994. The on-road vehicle emissions forecasts included data pertaining to increases in economic activity and population growth in the region, focusing on the increasing number of vehicles and extra distance traveled in years to come. The most reliable technique available: the Mobile 5C computer model; was employed by the GVRD to forecast emissions from motor vehicles. The results demonstrated that the projected increases in vehicle number and distance traveled will add significantly to the total amount of emissions discharged into the airshed. To model emissions from point and area sources in the future, projections of growth in areas such as population, employment, industrial activity and energy consumption were utilized (GVRD, 1994). This report became the Stage One AQMP: "*Assessment of Current and Future Air Quality*." It emphasizes that if current trends continue unabated, air quality could deteriorate to unacceptable levels over the next 20 years. The stage one report supplied necessary information to advance to the next stage of planning: the development of detailed strategies and a formal plan (GVRD, 1994). The first step was the identification of objectives.

B) Objectives

The main objective of the AQMP is to protect human health and the environment. Lower order objectives determine how this goal can be attained and usually relate to the process; "the AQMP must ensure that the task of clearing our air is carried out in the most effective, equitable and timely manner" and that it must be a "comprehensive strategy which assesses issues, prioritizes problems and develops appropriate actions" to improve air quality (GVRD 1994). This comprehensive strategy is based on four important principles. Firstly, adopt an integrated planning approach with regional land use and transportation planning efforts. Secondly, strengthen management approach for all sources that the GVRD has responsibility for, especially point source emissions. Third, cooperate with all levels of government in the area to achieve an integrated airshed approach to dealing with air pollution. Fourth; ensure full public and stakeholder involvement so that efficient and effective solutions are identified and applied to specific issues or problems in a fair and equitable manner (GVRD, 1994).

The revised draft (February, 1994) states that the fundamental objective of the AQMP is to reduce overall emissions by 50% (of 1985 levels) of five criteria pollutants (carbon monoxide, oxides of nitrogen, volatile organic compounds, particulate matter and sulfur oxides) by the year 2000. The relationship among the objectives is represented in figure 2-2.

FIGURE 2-2: AQMP OBJECTIVES

HIGHER ORDER

IMPROVE AND ENHANCE AIR QUALITY

REDUCE EMISSIONS BY 50% (1985 LEVELS) BY 2000

DEVELOP COMPREHENSIVE STRATEGIES FOR REDUCING EMISSIONS

LOWER ORDER

However, forecasts of the five pollutants showed that emissions would be reduced by only 32% by the year 2000 if no new Emission Reduction Strategies (ERM's) were implemented. (The reductions are due mostly to higher new vehicle emission standards imposed on the automobile industry by the Canadian Federal government.) Because the predicted reduction in emissions falls short of the 50% objective, further planning effort was needed to identify strategies for action.

C) Develop Emission Reduction Strategies

The *Stage Two AQMP: Priority Emission Reduction Measures(ERM's)* is a comprehensive study of over fifty reduction measures applicable to criteria pollutant emissions from major point, area, mobile and gasoline marketing sources in the GVRD. Combinations of emission reduction strategies highlighted in the Stage Two report are expected to result in a 46% decrease in total emissions (from 1985 levels) (GVRD, 1994).

From the consultation programs it was clear that allowing regional air quality to deteriorate to unacceptable levels was not an option. To protect and improve air quality, solution oriented strategies are needed to deal with the problems perceived to be the greatest threat to air quality. Also, any initiatives must be effective and efficient. Development of strategies has two important steps: (1) Setting priorities for action and (2) Analysis and assessment of alternatives.

C-1) Setting Priorities

With the information gathered from earlier stages of the consultation process with the public, stakeholders and decision makers, the problems which were perceived to be the greatest to the quality of life were identified. Priority was determined by the severity of the impact currently experienced or perceived to be a growing concern in the future (GVRD, 1994). Each issue is assigned one of four priorities in decreasing order of importance. Priority one emissions are those that are not currently meeting air quality objectives or are projected to have impacts significant enough to warrant new emission reduction efforts as soon as possible (GVRD, 1994). Priority two emissions are those that have suspected impacts, but additional study is required to define the problem and measures to mitigate them. Lower priority issues are considered only in their relationship as precursors to higher priority concerns.

In the lower mainland smog or ground level ozone is perceived to be a high priority issue for several reasons. These reasons include the obvious health and environmental impacts but also comprise effects such as reactivity with other pollutants (i.e. acid deposition and impairment of visibility), uncertainty with respect to cause and effect (concerning health and environment) and the fact that episodes of unacceptable levels are predicted to increase after 1995 due to increased growth in the areas east of Greater Vancouver (GVRD, 1994).

C-2) Analysis and Assessment of Alternatives

For priority problems, assessment of emission reduction strategies to find optimal solutions is based on the following criteria: emission reduction potential, technical feasibility and cost effectiveness. The analysis starts with identification of major emission sources within each sector for a given pollutant. This is determined by the cumulative emissions of 75 % for that sector, (i.e. all sources that comprise the first seventy five percent of a pollutant are targeted for emission reduction measures.) The identification of 'significant' emitters for each sector is necessary for focusing initial studies and efforts to speed implementation of emission reduction measures.

A list of emission reduction measures was compiled by the GVRD using various plans such as the Canadian Council of Ministers of Environment (CCME) NOx/VOC plan, South Coast Air Quality Management District (southern California's AQMP) and the Bay Area Air Quality Management Plan. Priority was given to Phase A technology, which is the best available technology, strategy or management practice that has proven successful commercially (GVRD, 1992). (If the technology was in use by the private sector, it was determined to be technically feasible.) The measures were also assessed in terms of their cost-effectiveness. Cost effectiveness is expressed in dollars per tonne of emissions reduction. This information was obtained from various literature sources, as well as discussions with suppliers and users of some of the technology (GVRD, 1992). GVRD staff stress that the cost effectiveness (CE) information should only be viewed as preliminary and caution should be exercised when comparing the CE of ERM's . The primary reason for this disclaimer is that the data was collected from various sources and refer to inherently different systems (GVRD, 1992). As a result of the nature of data collection, the cost estimates could contain large margins of error and variability depending on the design parameters used to determine cost effectiveness. However, preliminary assessment and ranking in terms of cost effectiveness was attempted by GVRD staff (employing a Marshall Swift Index), using 1990 as a common year and an exchange rate of $ 1.15 Canadian per $1.00 US. (GVRD, 1992) to attain an a estimate of cost effectiveness. Analysis of emission reduction potential was based on applying identified control measures to uncontrolled emission sources (GVRD, 1992). The estimation of future emissions reductions to specified years (1995 and 2005) was accomplished by employing OMNIS software which was originally used to prepare the 1985 emissions inventory (GVRD, 1992).

The format for analysis of point and area sources included source descriptions, regulatory standards, potential control measures, secondary impacts, assessment and implementation. Analysis for mobile sources was done with the Mobile 4C computer model and then updated with the 5C. This model estimates emissions from exhaust depending on variables such as fleet age, distance traveled and average speed. Because of the nature of this input (loaded with assumptions), uncertainty exists as to the estimated amount of emissions (found to vary by as much as 30%) (GVRD, 1994). Transportation Control Measures

(TCM's) were analyzed by first examining TCM's proposed or in use in other areas, then their design and applicability to the region was postulated by GVRD staff.

D) Public Consultation

The GVRD Stage Two report went to consultation in May of 1992. Input from industry, business, government, environmental groups, public health officials and the general public was used to gain initial feedback on potential emissions reduction strategy priorities. The results demonstrated a high level of support for improving air quality by developing and implementing the AQMP. Some areas of agreement included:

- the economic and social impacts of ERM's need to be factored into all solutions
- goals of AQMP need to be strengthened and considerable focus placed on human health and the environment
- ensure equity and balance efforts between industry and vehicles
- strengthen link between land use planning, transportation planning and air quality management
- increase public awareness and education

(adapted from AQMP, Executive Summary, Phase-One Consultation, 1990.)

Given the concerns expressed in the phase one consultation program, it is evident that the AQMP has to be focused on human and environmental health but must also deal explicitly with economic and social factors. To be effective, the plan will have to prosper in the public eye, especially with the increasing media scrutiny experienced by current governments over issues of significant public interest. The only way for the plan to prove itself is to achieve the goals it aims for and reflect societal values accurately. If the plan does not show significant progress towards its goals, the plan will not receive the wide spread commitment necessary to be successful.

Findings and Recommendations

Beyond the pollutant sources the GVRD has authority to regulate, the AQMP is essentially limited to presenting its findings and making recommendations to levels of government with responsibility for regulating the remaining sources of air pollution. Some key findings include the need for all levels of government to act cooperatively together, and that broad based support is needed for regional air quality to improve in the future. General recommendations include continued integrated planning efforts and support for provincial, national and international air quality commitments. Specific recommendations of the plan include calls for curtailment of NOx precursors on a priority basis.

The plans effectiveness may be limited due to the numerous organizations involved with managing air quality. One way to improve the effectiveness would be to establish a rank order for priority emission reduction measure implementation, regardless of who has authority for regulation. If enough information was available and decision makers were aware of the importance, the plan may produce better results as priorities could be recognized and acted on. The first step to improving the performance of the AQMP is to make it decision oriented to identify the best means of solving air quality problems. In this specific example, it should be focused on implementing the most effective measures for reducing oxides of nitrogen emissions.

Conclusions

There are many levels of government with responsibility for various polluting sources within the Lower Mainland. Coordinated efforts between these agencies are necessary for effective air quality management. Continuos emissions monitoring, updating of the emissions inventory and on-going modeling to forecast future air quality are important parts of the planning process performed by GVRD staff. These activities provide up to date understanding of air quality issues in the region and, along with results from public consultation programs, allow priorities for action to be determined. When an air quality issue is considered a priority, emission reduction strategies are developed to find efficient and effective solutions to the problem. Most of the proposed solutions to air quality issues affect the public, industry, private business or the government in some way. The strategies outlined in the AQMP require commitment from these various groups to be successful. To get this commitment, the plan must:

- be focused on priority problems and be able to resolve them
- achieve reductions in a cost effective manner
- be acceptable to public, stakeholders and government

Therefore, any strategies will have to identify the most efficient way to spend money, reduce the largest amount of priority emissions possible and consider factors such as equity and employment. There is a need to use a decision framework that focuses on goals and objectives, clarifies decisions and takes many other impacts into consideration. In the next section, four such analytical frameworks are examined and their relative appropriateness for this problem is discussed.

SECTION III:

SELECTING ANALYTICAL FRAMEWORKS TO INFORM AIR QUALITY MANAGEMENT CHOICES

Policies to improve environmental quality pose difficult choices for decision makers. These decisions are complex for various reasons. Conflicting objectives, uncertainty and technical complexity are only part of the problem. High stakes, the sequential nature of decisions and numerous affected parties mandate an analytical approach to encompass all aspects of any decision. Analytical frameworks such as the Cost/ Benefit, Decision, Multiple Objective, and Multiple Account analyses all help to "make sense" of environmental policy problems by identifying and evaluating the consequences of alternative modes of action. These four frameworks offer various levels of integrating values with technical information to compare alternatives across objectives of importance. The pros and cons of each of these frameworks are discussed in this section. Multiple Accounts Analysis, as used by the Crown Corporations Secretariat, is identified as a useful framework for Air Quality Management in the GVRD.

All decisions require tradeoffs among objectives when choosing one alternative over another. Environmental decisions present tough choices because tradeoffs often conflict with tightly held societal values such as preserving environmental resources or maintaining a healthy economy. The nature of conflicting objectives denotes that one must give up some of one desirable attribute to attain more of another. Conflicting objectives such as balancing environmental and economic values are only part of the reason that these decisions are difficult. Other aspects of environmental decisions (specifically air quality issues) that pose challenges include:

- **uncertainties:** effects of air pollution on public health and environment, emissions forecasts, population growth, global climate change.
- **technical complexity:** different control technologies offer various levels of environmental improvement, often with wide ranges in costs.
- **interdisciplinary structure:** many agencies and levels of government have responsibility for different sources of air pollution.
- **sequential nature of decisions**: programs are to be implemented over time and revised as monitoring and reassessment are carried out.
- **interest groups:** many groups of people may be affected by decisions to improve environmental quality; all demand to have their opinions heard. Some groups include industry, business, the public, environmental groups, and health advocates.
- **high stakes**; because of limited resources (financial capital, time, and environmental (air)), decisions to improve air quality are high profile and politically important.

These factors mandate a planning approach that will provide help in understanding these complexities. Analytical frameworks that will integrate values and technical information, focus on important objectives and make sense of complexity by highlighting the value tradeoffs are necessary. One way to use such a framework is to take the need for emissions reduction as given and then find the best way to achieve the objectives of importance in reducing emissions. The term "best" is subjective and implies value judgments and tradeoffs. Essentially, seeking the "best" solutions to a problem forces us to ask: "Is it Worth It? What levels of benefits are worth the cost in dollars?" To answer this question we need to know which alternatives provide the most of what is desired and how much they cost. This approach would lead to selecting the most effective solutions first, followed by the options that are incrementally less attractive. The intent, especially with policy problems that involve sequential decisions, is to order the choices of alternatives to achieve the highest amount of benefits at the least cost to society. For Air Quality Management, there are several decision frameworks and associated value measures that could assist decision makers with ordering emission control technologies. Some common methods are shown in table 2-1 and described in the following sub-sections.

Table 3-1: Decision Frameworks and Value Measures

Decision frameworks	Value Measures
Social Cost-Benefit Analysis	Contingent Valuation , average values
Decision Analysis	Multiattribute Utility techniques (MAUT)
Multiple Account/Objective Analysis	MAUT or CV

DECISION FRAMEWORKS

1)Social Cost-Benefit Analysis

Cost -Benefit analysis (CBA) involves the systematic enumeration and evaluation of socially desirable and undesirable effects of public sector projects and programs. (Davis, 1990). C\B analysis arose out of the economic analysis of water projects in the United States earlier this century (Wright, 1990). The main objective of CBA is to assist decision makers in choosing among alternative means of attaining public goals by providing information on the relative levels of costs and associated economic benefits (measured in dollars) attached to any project. This information provides more efficient allocation of resources in society, particularly in the public sector (Davis, 1990).

To determine which project to proceed with, the monetary costs and benefits are summed up and then a discount rate is applied. The discounting process applies an interest rate, also know as the social opportunity cost of capital, to the cash flows realized over the life of the project. This step creates a “level playing field” in which many alternatives with different rates of return and payback periods can be judged. After the rate is applied, the costs and benefits are compared, (either by subtracting costs from benefits or dividing to obtain a benefit/cost ratio) yielding a single number decision rule. There is an underlying presumption that any project should not be undertaken unless its benefits outweigh its costs (Kelman, 1981).

Benefits are measured by consumers willingness to pay for that particular good or service. This introduces several problems; firstly, for some tradable goods, no market demand and supply functions exist and secondly some “goods” are not bought and sold on markets (intangible goods.) The economists’ answer to these difficulties is to construct values for the intangible benefits based on the amount consumers should be willing to pay for them if a market existed. One technique, contingent valuation (CV), asks respondents how much they would be willing to pay for the intangible benefit if a market existed. CV introduces margins of error as the results are subject to personal judgment and the biases inherent in it. That is to say, that differences in the respondents’ income, experience and age will affect the results.

There are several aspects of the cost benefit analysis that may make it inappropriate as a single means of informing decisions. The main reasons relate to assumptions of the analysis: the first being that the "right" plan must have monetary benefits that outweigh monetary costs (Kelman, 1981). A second assumption is that all important impacts can be quantified and then combined into dollar terms. The results of this type of analysis are limited because the relative advantages and disadvantages of alternatives, such as equity or distributional effects, are masked or easily excluded. A third assumption is that a utilitarian perspective, which ignores the distribution of benefits and costs, is a complete basis for public decisions. Finally, CBA generally takes the problem as given, without trying to create more attractive alternatives. It also may do very little to identify which alternatives are incrementally better than others. The limited usefulness of the cost benefit analysis is demonstrated in the GVRD's cost benefit analysis of the AQMP.

The draft report entitled "Clean Air, Benefits and Costs in the GVRD" prepared by ARA Consulting and Bovar-Concord Environmental assess the costs and benefits of the AQMP. The report examines the benefits and costs of reducing the five criteria pollutants by implementing all 54 emission reduction measures laid out in the plan for mobile, point and area sources of pollution. The analysis also includes the new vehicle emission standards as part of a complete package of strategies to improve regional air quality. Estimates of the costs and benefits were obtained using engineering, financial, epidemiological, economic and scientific information pertaining to the lower mainland and drawing from studies in other areas (ARA- B.C.E, 1994).

The report estimates the benefits from reduced pollution (by relating emission reductions to health improvements, damage averted to property and crops in the GVRD and the eastern lower Fraser valley) will outweigh any associated implementation and operation costs. However the report looks at the whole plan, not individual emission reduction measures (ERMs). This is unlikely to help as it is not feasible to expect that all ERMs will be implemented within the time frame laid out in the plan and thus does not help in determining an order of alternatives for implementation. What is needed is a method of determining which ERMs should be implemented now to attain the highest level of reduction for pollution problems such as ground level ozone, in a cost effective manner. Other analytical frameworks allow analysts to examine more of the problem to address better ways to resolve it. Two such frameworks are Decision Analysis and the Multiple Account Analysis.

2) Decision Analysis

Decision Analysis (D.A.) can be called a "formalization of common sense for decision problems that are too complex for informal use of common sense" (McDaniels, 1992). This approach focuses on the need to clarify the character and composition of the decision to be made. It is also motivated to satisfy many objectives for any particular decision and does so by evaluating alternatives with different consequences and levels of uncertainty. Decision analysis understands that different consequences of alternatives are not equally valued (McDaniels, 1992). This framework usually includes the following four major steps:

1) Structure the Decision

Key steps include defining the decision to be made, identifying alternatives and specifying objectives that are important in selecting between alternatives. Defining the decision to be made is often where other analysis go awry. Whenever there is a perceived problem, any proposed solution can seem more attractive than the status quo. As a result, only the status quo and one possible solution are examined, the result will most likely be sub-optimal. A better way would be to consider all possible existing alternatives and generate new ideas as well. The specification of objectives is another important initial step for this analysis; objectives define what elements are important for any decision (to be discussed later in this chapter.)

2) Assessing Impacts of Alternatives

This step usually employs studies of the environment, financial constraints and engineering reports. Decision analysis includes the consideration of uncertainty with respect to the consequences of alternatives by employing probabilities. Scenarios can be developed to determine what consequences are most likely given certain circumstances. The consequences of concern are determined by the objectives relevant for selecting one alternative over the others.

3) Determining preferences of decision makers

This requires hard thinking about the objectives listed in the initial stages of the analysis and then attributes or operational measures of performance are defined to provide a basis for evaluating how the alternatives perform. "Tradeoffs between objectives are investigated with constructive elicitation procedures, from which a utility function is developed" (McDaniels, 1992). "A utility function is a mathematical representation of the tradeoffs that decision makers view as appropriate between objectives" (McDaniels, 1992).

4) Evaluating and comparing alternatives

"Emphasis is placed on gaining insight into the differences between the alternatives. Comparisons are based on expected utility;(probabilities and utility (or values) are considered separately and then integrated into the framework. Expected utility refers to the desirability of outcomes, weighted by their likelihood) The magnitude of expected utility can be used to establish a cardinal ranking that indicates the decision makers preferences for alternatives"(McDaniels, 1992).

These preferences can be determined by applying multiattribute utility techniques (MAUT). MAUT is a process that develops utility functions that scale the attributes of values to reflect relative desirability of the different attribute levels. This information is then employed to develop quantitative value models that reflect the tradeoffs between units of different attributes (Gregory, Keeney, and von Winterfeldt, 1992). This framework allows for ordering of alternatives from most desirable to least desirable in a quantitative fashion for the decision maker, based on his or her preferences. An extension of decision analysis is the multiple objective analysis (MOA) which is a form of decision analysis in which multiple objectives are explicitly considered in the analysis.

3a) Multiple Objectives

In Multiple Objective Analysis tradeoffs are made explicit and objectives are developed through interviews as opposed to using a pre-specified list (as in multiple account analysis - to be described in next sub section.) In addition, uncertainties are explicitly considered using probabilities. Structuring objectives and problem definition are early important stages in the analysis process. It is also important to clarify whose objectives matter to determine perspective of the analysis (McDaniels, 1993). In regional air quality issues, there are many stakeholders and people who will be affected by decisions to improve air quality. To be safe, the perspective of society as a whole should be incorporated into the analysis. Future generations should also be included in environmental issues such as protecting regional air quality. The GVRD has included future generations' concerns by incorporating long term planning horizons in the AQMP and Transport 2021, the long range transportation plan.

Ideally, the elicitation and structuring of objectives should involve all stakeholders from the outset of the process. The AQMP employed surveys and questionnaires for feedback on proposed strategies to improve air quality. From these activities it was evident that protecting air quality is important but so was achieving improvements in a fair, equitable and economically feasible manner. In practice, stakeholders are asked to articulate what objectives are important for any specific decision context. Keeney (1988), presents techniques for helping stakeholders probe their values to distinguish between means and ends objectives and identify the fundamental concerns for the decision at hand. Essentially, these relationships are clarified by asking why a particular concern is important; the answers can be further broken down until fundamental ends of interest are identified. An objectives hierarchy with the main concerns represented as larger branches and the fundamental, measurable objectives at the "twigs" can be constructed to help illustrate the relationships of objectives of the stakeholders. In multi-party contexts, the objectives from various stakeholders are then combined and reworded to eliminate any redundancies. Iteration is necessary for the success this process; refining objectives hierarchies until all relevant values are included will reduce disagreements at later stages. At this stage, no ranking of importance is attempted to reduce any conflict between stakeholders.

Objectives are then used to identify possible alternative plans of action. Both fundamental and means objectives are important as they represent an initial point for thinking about mitigating factors and other design options that can assist in creating new, more attractive alternatives (Gregory and Keeney, 1992). From this process several alternatives can be created to address the multiple objectives inherent in environmental policy problems (Gregory and Keeney, 1992).

Stakeholders are then asked to rank sets of objectives in terms of their importance for the decision context. This ranking procedure requires a range of possible outcomes for each objective be made explicit. The results of ranking then indicate the relative importance of moving an objective from its least desirable consequence to its most desirable consequence

(Gregory and Keeney, 1992). Although relative ranking can be used to estimate relative importance, average rankings should not be interpreted directly as indicating the importance of different objectives (Edwards and von Winterfeldt, 1986). The actual value of the rankings should not be used quantitatively to determine the relative values of the objectives, they should only be applied to determine which objectives are more important in a broad sense. From this exercise, the alternatives can be compared across the objectives of importance and the value tradeoffs considered by the decision maker. Either applications of MAUT could be employed to quantitatively assess the tradeoffs or qualitative assessments may be sufficient to establish an order of decreasing desirability of the various alternatives.

3b) Multiple Accounts

The British Columbia Crown Corporations Secretariat has prepared guidelines for Multiple Account Evaluations of programs and projects of public interest. The purpose is to systematically identify and evaluate the implications and relative merits of alternative plans and projects. The intent is to contribute to well informed decision making by presenting a rank order of the alternatives (i.e. best to worst.)

The ultimate objective of the analysis is to identify the alternative that will best solve the problem. The guidelines emphasize the importance of developing a clear understanding of the problem at the outset by examining the issue in a broader societal context. After the problem is clearly understood, the execution of the following steps is required to find the best solution: identification and consideration of a wide range of alternatives, specification of evaluation accounts, documentation and assessment of implications under each account and, the presentation and interpretation of results. The analysis of accounts resembles cost benefit procedures with two differences: not all accounts are monetarized and not all measures are combined into one specification of net benefit.

Evaluation accounts define the range of criteria to determine the relative performance of alternative plans. This is important to assist decision makers in evaluating and judging which options best serve their interests. "Their" refers to the corporation that the decision maker(s) represent and, because Crown Corporations have to consider broader provincial government concerns, societal goals and objectives underlie the inputs for analysis. The choice of accounts is corporation specific but should include the major concerns of government such as financial; customer service, environmental; economic development and social implications (Crown Corporations Secretariat, 1993).

Financial accounts document revenue and expenditure of alternatives from the perspective of the corporation and the broader government viewpoint. These cash flows are considered over the planning period and discounted to the present. "Financial accounts should reflect the incremental effect of each alternative on the total system revenues and expenditures as opposed to the capital and operating expenditures of the alternative considered on its own, and should not include secondary or indirect effects"(C.C.S, 1993).

The guidelines suggest that a discount rate of 8% be used, but encourage sensitivity analysis to be done in a consistent manner with 6 and 10 % as well. Sensitivity analysis should be included as part of the calculations to get a better understanding of the effects that uncertainty may have on the results. Other important constraints on calculating the NPV of financial effects are that interest and depreciation should not be included in the estimates and that all assumptions should be made explicitly.

Environmental impacts are recognized as important for consideration in the evaluation of any public project. The purpose of this account is not to replace the Environmental Impact Assessment process but to highlight tradeoffs of environmental quality among alternatives (C.C.S, 1993). "The nature, magnitude and other important aspects of detrimental impacts on the environment should be documented. These include the impacts on human health, resource use (both commercial and non-commercial), aesthetics and cultural attributes."(C.C.S, 1993). Depending on whose perspective is taken, the nature and significance of the environmental impacts will vary. The guidelines state that impacts can be estimated in monetary or non-monetary terms. Social external costs are suggested as monetary estimates of impacts. Social external costs refers to the amount of money people would be willing to pay to maintain or enhance environmental quality or would be willing to be compensated for environmental damages. Techniques for estimating these values such as contingent valuation and damage cost methods can be used. When no monetary estimates or indices for determining monetary values exist for environmental changes, qualitative assessments of significance may be used. These assessments indicate the severity of impacts and the relative importance in terms of broader societal goals and objectives. " The qualitative assessment should help to provide an understanding and perspective of the environmental implications and to assist decision makers in the resolution of environmental tradeoffs"(C.C.S, 1993). Qualitative descriptions can be employed to calculate the critical value that the major impacts would be in order to be worth more than the advantages or disadvantages on other accounts. In the case of air pollution, the question of critical value may become: what is the difference in monetary costs to reduce a unit of air pollution (in dollars per tonne) needed to offset a specified advantage in say, employment increases or equity concerns. The assessment could then address whether the air pollution costs can reasonably be equilibrated to, or exceed the critical amount.

Other accounts of interest to Crown Corporations include customer service, economic development, and social impacts. Customer service is important to agencies that provide services such as electricity (B.C. Hydro), and transportation (B.C. Transit, B.C. Ferries). Projects or programs should not have substantial negative impacts on the quality or quantity of service received by their customers. Due to the wide range of customers to any service, many different perspectives may have to be documented to understand the range of suspected implications. The guidelines state both monetary and non-monetary descriptions can be employed to determine the impacts on customer service. Again, contingent valuation is suggested for attaining estimates in dollar figures although it is recognized this method may mask important aspects of the consequences of alternatives. Critical values are recommended for comparing non-monetary impacts to financial costs to determine significance of impacts on this account. "Differences in financial performance between two alternatives determine the critical value that the customer service differences would have to be worth for the customer service implications to outweigh the financial account."(C.C.S, 1993). Essentially, this asks the question: Is the incremental difference in cost between option A and option B worth the incremental difference in customer service between these same alternatives.

Economic development accounts represent the provincial governments' concerns for income and employment affects of alternative plans of action undertaken by crown corporations. There is emphasis on understanding the difference between gross impacts and net benefits with respect to these two attributes of this account. The reason is that many times projects are "sold" to decision makers on the premise of significant economic benefits while the true impacts are masked by not including the detrimental affects of the increases in jobs or income. For example, increases in short term employment may have long term negative impacts on an region if substantial in-migration occurred at the outset of the project: increases in crime or long term unemployment could result. For these reasons, both provincial and regional perspectives are suggested for this account. Estimating the incremental income created by each alternative provides a good monetary yardstick for this account. Qualitative assessments could include estimates of the significance that an alternative may have on employment conditions when compared to the base case scenario (i.e. without project.)

The documentation of social implications of the alternatives is to highlight the distribution affects and tradeoffs they may entail. This account is not meant to replace a comprehensive social impact assessment (C.C.S, 1993). The guidelines stress that attempts to monetarize social impacts should be avoided, especially for concerns over quality of life and equity.

The presentation of the results of a multiple account analysis is important to communicate planning efforts to decision makers. A summary matrix that contains measures of performance for the alternatives across accounts can provide a clear, consistent and comprehensible method of comparing alternatives. "The summary matrix highlights the advantages and disadvantages of the options and the tradeoffs they may entail" (C.C.S, 1993).

The Crown Corporations Secretariat Guidelines for multiple account analysis also includes a section on risk and uncertainty. The guidelines provide that an assessment of risk management strategies and flexibility for the alternatives be included along with the evaluation of accounts. Lack of flexibility to adapt to future uncertain events can be considered a major disadvantage of any alternative, regardless of how favorable it may perform on the accounts of importance. Uncertain events give rise to risks that could possibly detract from the appeal of any option. Some sources of uncertainty that may cause risks are changes in economic, demographic or market forces, technology (performance and duration), environmental impacts and political or regulatory constraints (C.C.S, 1993). A good risk assessment should identify which factors are subject to greater levels of uncertainty and what impacts the uncertainty could possibly have on the accounts. This assessment should include a re-examination of the assumptions that were made for evaluation and either sensitivity or scenario analysis should be employed. Sensitivity analysis examines the effects of a change in one particular value or assumption while scenario analysis looks at the combined effect of changes on the whole set of assumptions (i.e. best versus worst case scenarios).

Once the major sources of risks have been identified for the alternatives, risk management strategies are to be developed to increase positive impacts and decrease negative aspects. The most important ingredient for a risk management strategy is the level of flexibility they offer.

Flexibility refers to the extent to which different alternatives can respond to, and benefit from any new information that emerges over time (C.C. S, 1993).

The Crown Corporations Secretariat guidelines provide a good framework for analyzing programs and projects with environmental, social, economic and other relevant implications. This approach is attractive as it avoids some of the pitfalls of cost benefit analysis while still relying on its strengths for calculating only the impacts that can be monetarized. The results of non-monetary estimates can be used to define critical values (which is the amount a non-monetary advantage or disadvantage would have to be in order to offset identified financial effects) In the case of air quality critical value questions could contain the following:

Is creating 260 jobs worth X dollars more per tonne than alternative A? B? etc.

Is disrupting 1, 000,000 people for 2 hours per year (2 million hours) worth X dollars more per tonne than alternative C?

Questions about critical values are incorporated with qualitative assessments of significance to provide good information to assist decision makers in resolving tradeoffs in an informed manner. Results of an analysis of this nature may also highlight new and innovative ways to devise better options through the inclusion of mitigating or compensating factors. This may produce attractive alternatives that better satisfy more accounts of importance.

Conclusions and Methodology

Air quality management, like all environmental policy contexts, poses difficult choices for decision makers. Conflicting objectives, sequential nature of decisions, multiple stakeholders and uncertainty with respect to cause and effect denote that solid analytical methods be used. Four such analytical frameworks, Cost/Benefit, Decision, Multiple Objectives, and Multiple Accounts Analyses can "make sense" of a policy problem by incorporating value and technical information to compare consequences of alternative modes of action. These consequences are then evaluated with respect to the objectives/accounts of important for the decision. These four frameworks all have their own benefits and shortcomings when it comes to the quality of information provided to decision makers. The Multiple Account Analysis is favorable for the context of this paper because it makes assumptions explicitly, avoids placing monetary values on intangibles, and is able to compare a wide range of alternatives and impacts.

The methodology for this analysis will follow the multiple accounts approach with some modifications. Analysis of the GVRD's Air Quality Management Plan Emission Reduction Strategies begin with a clearer definition of the problem of enhancing air quality in the lower mainland. This will focus the analysis as much as possible on the aspects that *I feel* are most important with respect to the GVRD's efforts so far. The next step is to employ the main accounts as laid out in the Crown Corporations Secretariat Guidelines as an initial list of what objectives should be important for decisions regarding air quality. Through interviews with someone knowledgeable about air quality issues in the lower mainland, a more complete objectives hierarchy (Keeney and Raiffa, 1976) can be constructed. After refining the hierarchy the main objectives of importance can be used as input criteria for analysis of different emission reduction strategies outlined in the AQMP. Due to the number of initiatives outlined in the AQMP (54), only a few will be considered. The choice of alternatives to be compared is based on the inter-governmental responsibility and source sectors that are most pertinent to the problem of ground level ozone. (The AirCare program will be used as a bench mark to compare other alternatives since it has been in operation for three years already.) Since no single corporate entity is responsible for more than one of the alternatives compared in this analysis, financial accounts will be calculated from the viewpoint of society as a whole. The results of the analysis will be summarized and compared on their overall effectiveness to provide a comprehensive basis for evaluation. To estimate the social value of emissions reductions, cost-effectiveness analysis will be employed. Comparing the costs of different approaches to achieving a given reduction in air emissions can be used as a proxy measure of the value of those reductions (McDaniels, 1992). This approach assumes that there is a need to reduce emissions and seeks the most cost effective avenues to achieve those reductions (ibid., 1992). The alternatives will then be evaluated on the tradeoffs they entail for cost effectiveness and other objectives of concern.

SECTION IV: APPLICATION OF MULTIPLE ACCOUNT ANALYSIS FOR COMPARING NOx CONTROL TECHNOLOGIES

This section begins by defining the problem and highlighting the complexity of selecting appropriate NOx emission control technologies. Accounts important for this type of decision are then structured and described as input for analysis. Four alternative emission strategies for reducing oxides of nitrogen are selected (summarized in tables 4.4 to 4.7) for comparison in an accounts by alternatives matrix (table 4.8) This matrix highlights the advantagres and disadvantages of the options and the tradeoffs they may ential. The last section will examine the results of analysis and discuss the tradeoffs.

The AQMP lists ground level ozone as one of two top priority concerns for air quality in the greater Vancouver region. If ground level ozone is a high priority issue for air quality in the GVRD, then we need to find the best way to reduce the incidence of ground level ozone episodes (smog). Instead of only examining ground level ozone as top priority, the precursors of smog should be focused on. However, in the AQMP, VOC and NOx are classified as lower priority concerns because they have little associated impacts on their own. There is some uncertainty involved with the impacts of these pollutants alone but the scientific community is quite certain both are precursors to ground level ozone. By only focusing on ozone and not its precursors, any proposed solution will be sub-optimal.

Various levels of government have jurisdictional responsibilities pertaining to the implementation of the AQMP. The federal government is responsible for new vehicle emissions and fuel standards. The provincial government is responsible for in-use vehicle emissions through the AirCare inspection and maintenance program for light duty vehicles. The GVRD is responsible for point source discharge permits under the BC Waste control Act, (which includes all major point source emissions that require permits under the GVRD to operate). Municipal governments are responsible for land use and transportation planning. In addition, any initiatives to curb air pollution in the Greater Vancouver Regional District will have an impact on the areas to the east and south east of the GVRD. Three regional districts to the east and Whatcom county in the United States make up part of the lower mainland airshed. For the most part, air pollution is generated in the western section of the airshed and travels to the east, which complicates matters of equity(distribution of costs and benefits) as well.

Uncertainty exists as to the amount of emissions generated currently and the volume that will be discharged in the future. Extensive modeling and emissions inventory programs are an on-going part of the GVRD's activities designed to get a clearer picture of air quality. Other areas of uncertainty include future regional growth, economic conditions, political concerns, available technologies and the status of the environment, not only at regional levels but nationally and globally as well.

Several interest groups and stakeholders will be affected by the implementation of the AQMP's initiatives to reduce air pollution. The current political climate attest that those who are affected by government actions should be included in the process of development of the plan. Because of the nature of the AQMP which will influence a wide number of individuals, government agencies, business and industry, many conflicting objectives will come to light over any proposed solution to air pollution problems. Conflicting objectives arise in many issues regarding environmental quality as improvements in the status of the environment usually come at a cost: monetary, socially and economically. In order to incrementally improve any aspect of a decision, tradeoffs will be necessary between these conflicting objectives.

With all the complexity inherent in air quality management, good methods are necessary to make sense of the tough problems that face society today. Analytical frameworks such as the multiple account analysis can help resolve problems such as decisions to reduce ground level ozone. These frameworks usually contain the following steps:

1. clarify the decision to be made
2. decide what objectives / accounts are important
3. analyze a wide range of alternatives
4. determine the consequences of the alternatives with respect to the accounts
5. evaluate in an objectives by alternatives matrix to identify tradeoffs
6. make the decision

A) Problem Definition

The first step in this analysis is to clarify the decisions that need to be made. From the opening paragraph of this section, the goal of emission reduction strategies now becomes: "Find the best way to reduce Ground Level Ozone by focusing on its precursors." The term 'best' will need definition. For this case, it can be assumed that 'best' refers to an alternative that fulfills as many objectives as possible while not causing any significant detrimental impacts on other objectives. So, to clarify this decision, it can be assumed we want to rank the ERM's to highlight which ones will achieve the highest reduction in precursors in a cost effective manner, while explicitly considering impacts on economic and social factors. However, it should be noted that for this issue, there is not one single decision to be made but several. It can best be described as a series of decisions to improve air quality, in that the options that best satisfy the objectives will be implemented first, followed by the emission reduction measures (ERMs) that provide the most incremental improvements over the status quo. It is important to realize that the best alternatives should be implemented first to achieve the highest reductions in ozone forming precursors and then the less attractive ones later. Optimally, a set of ERMs with favorable reduction potential, attractive cost-effectiveness, and minimal detrimental impacts is desired.

For this analysis of ERMs mentioned in the AQMP, it is assumed that the GVRD Board of Directors will make the final decision as to which alternatives will be pursued before others. Actual implementation and funding of the emission reduction measures depends on which level of government and specific agency has authority and responsibility for that source sector.

Even though both VOC and NOx are precursors to ground level ozone, to further focus this problem, NOx will be considered a primary problem for following reasons:

- the Stage Two report groups ERMs by specific pollutants targeted for reduction
- relatively small % decrease predicted for NOx emissions in near future (GVRD, 1994).
- NOx can be considered a limiting factor in smog formation
- gasoline marketing initiatives will reduce VOCs (ozone precursor)

After considering the assumptions and the reasons stated above, the task at hand becomes:

Find the "BEST" ways to reduce NOx emissions by ranking the alternatives under consideration.

B) Structuring Objectives

The next step in the analysis is to determine what is important for this decision. Objectives are fundamental ends of interest and have been described as the aspects of a decision that one cares about (Gregory and Keeney, 1992). For any decision, desirability of the consequences of the alternatives depends on how the objectives are satisfied or fulfilled. Alternatives are therefore analyzed and assessed in terms of their performance across objectives of importance. Inquisition and hard thinking are necessary to discover objectives that are important for any decision. Well structured objectives assist the Air Quality Management Plan in the following manner:

- objectives provide a basis for evaluating Emission Reduction Measures
- well structured objectives facilitate the generation of new and innovative solutions
- objectives provide a basis for judging what information is required to do a thorough analysis of ERMs (McDaniels, 1993).

The first step for structuring objectives must clarify whose perspective matters for the decision. For this example, the assumption is made that the residents of British Columbia, as represented by the provincial government is the perspective to take. The Crown Corporations Secretariat Guidelines (C.C.S, 1993) indicates that provincial government objectives (refered to as accounts) should include the following: financial costs and benefits, environmental impacts, economic impacts and social impacts. These four main areas of concern have been adapted to this example.

The four main account headings were employed as an initial list of objectives important for this decisions and then built on through an interview with a person knowledgeable about air quality issues. An expert on air quality was interviewed to help structure an objectives hierarchy. Dr. V. Setty Pendakur, who teaches Urban Transportation Planning, Congestion Management and Air Quality courses at the University of British Columbia was used for expert input into this process. Ideally, interviewing many stakeholders involved in this issue would provide a more complete list of objectives however, for the scope of this paper and due to his expertise in this area, other major concerns for analysis would be of minimal importance for the overall context of a decision of this nature.

The process began by supplying him with a list of objectives and measures adapted from the Crown guidelines. He was asked to review these and then add any he considered relevant to the issue of Air Quality Management. Effort was put into clarifying means and ends relationships. The results of this process are listed in table 4-1.

It should be noted that Dr. Pendakur put most emphasis on an objective he called mobility and technology which he explained refers to the efforts to reduce the number of single occupant vehicles, number of trips and trip distance. These concerns will be addressed late in the summarization of objectives for analysis.

The next step for structuring these objectives is to provide precise definitions to determine exactly what each objective means (third column in table 4-1.) Measures define not only meaning, but intent of all objectives and can be expressed in qualitative or quantitative descriptions, or constructed scales. Constructed scales define a range of impacts by placing weights that reflect desirability of consequences (Edwards and von Winterfeldt, 1986). Constructed scales can usually be derived by probing into the stakeholders objectives further. A typical constructed scale will have least desirable consequences on one objective receiving a mark of 0 and the most desirable consequence valued at 10.

Table 4-1. Objectives Hierarchy

MAJOR CONCERNS	LOWER ORDER OBJECTIVES	SPECIFICATION (MEASURES)
FINANCIAL	minimize costs to government, society, crown corporations	Net Present Value
	uses monetary resources effectively and efficiently	cost in dollars per tonne of pollutant reduction (NOx)
ENVIRONMENTAL	maximize improvements in air quality by maximizing reductions in ozone forming pollutants	tonnes of ozone precursors reduced per year from baseline
	minimize ozone related illnesses to the public	hospital admissions due to ozone
SOCIAL	ensure equal distribution of costs and benefits of ERM's	(constructed scale) or description of impact
	minimize detrimental impacts to society	qualitative description of impact & number of people affected
ECONOMIC	minimize detrimental impacts on jobs or income in the region	description of impact on employment and /or income
POLITICAL	public confidence and acceptance of AQMP	commitment to the plans measures measured in percentage of population or constructed scale
	ease of implementation	description of effort required to implement the project
	flexibility of ERM's- to adjust to changing air quality , technology, or political factors.	effort to adjust to changing institutional environment, measured with a qualitative description

C) Description of Accounts

Financial Accounts

Two main objectives pertaining to the financial accounts are one; to minimize total costs to the provincial government, Crown Corporations and, in the case of the AirCare program, minimize costs to society (represented by the motorists in the GVRD) and two; to utilize resources efficiently. The total costs are measured in Net Present Value terms discounted to 1994 Canadian dollars at 8%. Present Value is a method of discounting future cash flows to the present to give a current picture of what the costs and benefits will be over the life of the longest lived capital investment. The usual time frame is 25 years. Alternatives with shorter lifespans will require reinvestment of capital for a meaningful comparison.

The costs considered are actually incremental costs which reflect the impact on the system that each alternative exists in, (i.e. not in isolation.) Incremental costs are derived by considering the base case scenario to which each alternative is being compared. An example is the purchase of new buses. The incremental costs of purchasing a natural gas bus are the difference between that total cost and the total cost of buying say, a diesel bus (as a base case.)

Efficient resource use relates to spending money in the most cost effective manner by achieving the greatest reduction in ozone forming pollutants for every dollar spent. Costs per tonne of NOx reduction are used to illustrate effective resource utilization. For this analysis, cost effective resource use will differ from typical "cost-effectiveness" in that financial costs per tonne will be used while the societal value of reducing emissions will not be considered. One reason for this approach is to avoid the margin of error associated with the values derived for the GVRD's AQMP. Cost-effectiveness estimates for emission reduction measures were obtained from literature sources and various users and producers of the technology. The lack of consistency in estimating and calculating cost effectiveness from many different sources introduces large margins of error. This paper assumes that reducing air pollution is important and avoids the common but problematic approach of using average values for benefits to determine what society ought to pay for environmental improvements. In addition, most cost effectiveness analysis compares similar technologies or management strategies, this thesis will compare the performance across objectives of a wide range of alternatives.

Environmental Account

Environmental objectives are to improve air quality for the protection of human health, vegetation and crops. Air quality is improved by eliminating pollutants however, actual ambient ozone levels are not proportional to precursor emissions (ARA-Bovar-Concord, 1994). Various factors such as sunlight and other meteorological conditions have influence on this time dependent process. Photochemical modeling is the best method available to attain estimates of ground level ozone concentrations. Although such modeling techniques exist and are currently being refined at this University, they are unavailable and beyond the scope of this paper. Thus, actual amount of precursor emissions will have to be used to as a proxy measure for air quality improvements in terms of reducing ground level ozone concentrations. This can be measured in tonnes of NOx avoided and compared to the total amount of NOx discharged to the airshed in the GVRD (based on the baseline in the Emission Inventory.)

Other environmental concerns could include minimizing the amount of other pollutants discharged to the atmosphere. This is important in the case where a specific emission reduction strategy, such as an alternative fuels initiative, reduces ozone precursors but increases the total amount of other pollutants such as sulphur dioxide or particulate matter. For this analysis this fact is mentioned only briefly to keep the analysis focused on NOx. In fact, two of the alternatives (Burrard thermal generating plant rebuild and natural gas buses) cause slight increases in discharges of nitrogen (N2) and particulate matter respectively.

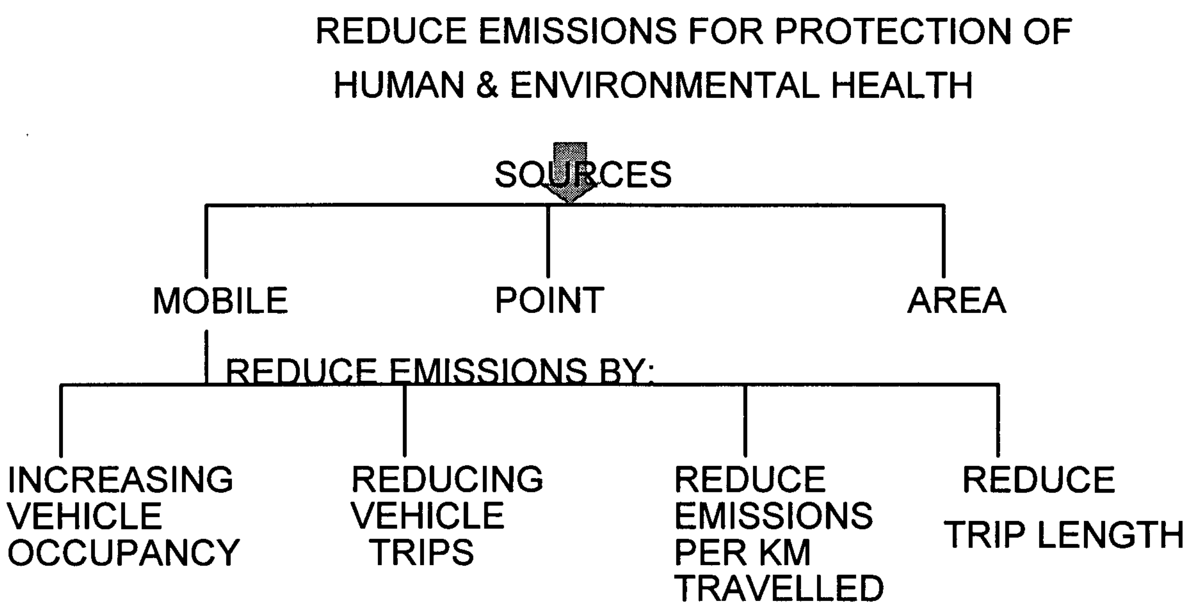
It should be noted that objectives such as aesthetic values and health impacts due to ozone are implicitly included in the environmental objectives. The importance of minimizing health impacts to society is obvious but the specification or measure of this objective raises some problems as there is no direct way of evaluating the impact of any specific emission reduction strategy will have directly on human health. The GVRD, ARA Consulting and Bovar-Levelton Cost-Benefit report used the results of photochemical modeling efforts and dose-response relationships to estimate the health damages averted by implementing all 54 ERM's on peak ozone concentrations. The health benefit indicators addressed in the report include premature deaths, hospital emergency room visits, restricted activity days and ozone symptoms (sore throat, mild cough, chest discomfort.) (GVRD, 1994). Estimates of these damages were obtained for reductions of air emissions due to the implementation of all 54 ERM's combined.

Intangibles such as the aesthetic value of improved visibility due to reduced ozone levels are difficult to quantify for two reasons. The first reason is that not all impairments of visibility are due to smog; particulate matter may play an even larger role. Secondly, methods such as contingent valuation have attempted to place a monetary figure on the value of air quality improvements in the GVRD. Large margins of error are associated with the results as is the case with any procedure that attempts to attach a dollar figure to non-market goods.

Due to the problems associated with quantifying the amount and value of these two objectives, the total amount of NOx reduced through implementation of specific ERM's will be used as an indicator of how any alternative does with respect to these objectives. In other words, it can be assumed that a decrease in NOx will improve aesthetic values and reduce ozone related illnesses, all other things being unchanged.

During the interview with Dr. Pendakur, he expressed concern for an objective he called "mobility and technology", which he explained referred to the importance of getting people out of single occupant vehicles and into other forms of transportation. The main reasons for this concern were to reduce pollutants from motor vehicles in four ways: reducing total vehicle trips, reducing trip distance, reducing motor vehicle emissions per capita, and reducing emission per kilometer traveled. So these methods or means objectives are just part of the larger objective of reducing ozone forming pollutants from the mobile source sector (see figure 4-1.) For this analysis it is assumed then that reducing NOx from cars will only partly address his concern. An additional objective along the lines of "maximizing shift in alternative modes at peak hours" could be used as an indicator of how this issue is dealt with by any emission reduction strategy. The measure for this objective could be the percentage of total trips or trip distance reduced. However, due to the nature of the alternatives to be examined (see next section), not all options will have impact on this objective. Therefore, the objective of reducing motor vehicle trips (especially single occupant trips) will be considered through the inclusion in the analysis of a specific emission reduction strategy that targets the number of trips and attempts to encourage mode shifts (vanpooling).

Figure 4-1 . Environmental Objectives Hierarchy:



Social Account

Since the overall objective of an air quality management plan is to protect and enhance regional air quality for the protection of human and environmental health, several social implications arise due to impacts on the public. Two main concerns are equity and disruption to lifestyle. The equity objective relates to who pays and who benefits with respect to any emission reduction strategy. This can be qualitatively estimated by determining who will pay for the ERM (i.e. motorists, crown corporations, transit users or other customers, provincial or municipal governments or private business) and who will receive the benefits. The determination of benefits for ERM's specific to the GVRD vary depending on the time frame (short, medium or long term), nature of source sector targeted (i.e. point or mobile sources) and location within the lower mainland. The time frame is important as short term benefits may be realized by members of the public who reside near a polluting point source whereas longer term benefits may be realized by all residents of the GVRD, lower mainland, province and ultimately the world (for example global warming). Location is important in the short to medium term due to the topographical and climatological factors that are specific to the lower mainland. For example, all BC taxpayers fund BC Hydro's operating budget but the benefits of retrofitting the Burrard thermal generating plant accrue mainly to those people who live within a localized area to the east (downwind) of the plant (such as Ioco, Port Moody, and Coquitlam.) Another important factor is that benefits accrue to individuals at different rates depending on their health status. Reduced ambient ozone concentrations will benefit all of society as a whole but people who are more susceptible to pulmonary illnesses such as asthma and cystic fibrosis may experience benefits from even incremental changes in air quality. In other words, healthy people may not actually realize they are receiving any air quality benefits (especially if they spend most of their time indoors), while those who are more susceptible may actually notice differences in their physiological and psychological well being. A qualitative description of the impact on equity will be employed to evaluate this account.

Customer Service Account

The objective of minimizing detrimental impacts to consumers or on customer service could have many aspects to it including the number of people affected, significance of disruption to their lifestyle and the services they receive. These impacts would arise as a result of any changes to the quantity, quality or terms and conditions (price paid) of the services provided (C.C. S, 1993). These changes could be measured in net changes in total willingness to pay less expenditures, to provide a summary monetary measure of customer service implications (C.C.S, 1993). However, quantified effects of this nature are often full of assumptions and large margins of error depending on the perspective taken and who is interviewed. What one person may consider a minor disruption may pose significant constraints on others depending on the nature of the problem and the value that those affected hold for their time. Many ERM's will cause disruption to the way people do business and conduct their personal lives. For example, transportation control measures and economic incentives to discourage use of the private automobile will force some people to make mode changes to other forms of transportation. Depending on age, gender, income and location of work and place of residence, the personal impacts associated with changing modes will vary drastically. Within the scope of this paper, a qualitative description of the impact and number of people affected will be employed to measure this objective. To document customer service implications in non-monetary terms, the nature of the benefit (dis-benefit) must be identified, and the number of customers affected estimated, then it can be assessed in qualitative terms of significance. Critical Value analysis can be used to analyze the significance of non-monetary impacts. " Differences in financial performance between two alternatives determine the critical value that the customer service differences would have to be worth for the customer service implications to out weigh the financial account" (C.C. S, 1993).

Economic Objectives

Economic objectives are different from financial objectives in that the latter is concerned only with the use of monetary resources while the former is concerned with the impacts to regional income and employment as a result of implementing and operating any alternative emission reduction measure. Although none of the alternatives examined in this paper could have a major impact on a region as large as the lower mainland, the relative impact of each alternative will be described qualitatively.

Political Concerns

Political concerns deal with the levels of confidence that are held by the public and other levels of government (such as municipalities and possibly American governments) for elected officials and government agencies responsible for implementing and operating ERM's. The level of confidence is important not only for politicians public images, but for achieving commitment to the plan by residents of the GVRD. Without a strong commitment by the public, many ERM's will not be effective in reducing air pollution and thus the AQMP will not succeed in improving regional air quality. Aspects of political concerns include ease of implementing alternatives and the flexibility of plans and programs to adapt to changing public concern, technology and other political factors. For the sake of this analysis, these objectives are assumed to be dependent on factors such as improving air quality and the level of disruption to the public. (In all likelihood, if air quality is improved with little disruption, the alternatives may satisfy most of these political concerns.) A qualitative description of the most important aspects of flexibility, ease of implementation and political ramifications will be used to evaluate this account. Again, critical value analysis could be employed to compare significance of political concerns to the financial account. A summary of the accounts (objectives) and measures to be used for evaluating alternatives in this analysis is presented in table 4-2.

The **relative importance** of these objectives could be established through consultation with stakeholders. Edwards and von Winterfeldt (1987) accomplish this by applying a modification of Multi-Attribute Utility Assessment. This method elicits values from participants by asking questions that highlight the importance between objectives. For every set of objectives, the weights will vary depending on whose perspective is considered.

In the process of structuring objectives with Setty Pendakur, he was asked to rank the objectives in the order he felt represented their relative importance. The concern he considered most important was that of mobility technology which upon further investigation is determined to be a means of reducing pollution from automobiles by discouraging their use and thus the per capita pollution generated. When it came down to actual ranking the objectives he stated that financial and environmental objectives as being most important, followed by economic objectives, social objectives and then political concerns. These preliminary results are helpful in evaluating alternatives but more effort may be required to specify actual tradeoffs between attributes.

Table 4-2. Objectives and Measures for NOx reduction strategies

MAIN OBJECTIVES	MEASURES
FINANCIAL: i) minimize costs ii) use resources effectively	 Net Present Value (current year dollars) dollars per tonne of emission reduction
ENVIRONMENTAL:. maximize reduction of **NOx emissions**	 tonnes of NOx eliminated
SOCIAL: minimize detrimental impacts to society by ensuring equity	 description of distribution of costs and benefits
CUSTOMER SERVICES: minimize negative impacts on customer services	 qualitative description: number of people affected and significance
ECONOMIC: minimize detrimental affects to employment and income	 description of impact on employment and / or income
POLITICAL CONCERNS including: flexibility to change, ease of implementation and political ramifications	 qualitative description of impact on the three aspects of this account

When the alternatives are ordered by their performance across accounts, the relative importance of accounts will become more evident as critical values will be defined for non-monetary impacts. These values will help to establish a ranking, or order of alternatives which will reflect which ERMs should be implemented before the others.

D) Selection of Alternative NOx Control Technologies

The next step is the identification of alternative emission reduction measures (ERM's). The AQMP Stage Two "Priority Emissions Reduction Measures" report lists 54 different ERM's that cover mobile, point, and area sources of air pollution. These alternatives are grouped according to the source sector and the specific pollutant targeted for reduction. The report indicates that all alternatives to be evaluated should be cost effective, technically feasible and have favorable emission reduction potential. The ERM's are prioritized by the total emission reduction potentially achievable for a specific pollutant targeted (GVRD, 1992). Ranking for ERM implementation was achieved by an effectiveness measure that was based on the ability to reduce the pollutant. Actual cost effectiveness rating is to be deferred to later stages when stakeholders could be consulted (GVRD, 1992). As mentioned in Section II of this paper (AQMP), the estimates of cost effectiveness have large margins of error associated with them for various reasons.

For this analysis, four alternatives have been chosen that meet the criteria mentioned above (cost effective, technically feasible and have favorable emission reduction potential.) This set may not contain the "best" solutions but for the scope of this paper, they will illustrate the application of the framework nicely. The four alternatives are the AirCare program, BC Hydro's Burrard thermal generating plant rebuild, an alternative fuel example from BC Transit (McDaniels,1993), and an example of Trip Reduction Measures (Vanpooling), (see table 4-3.) These alternatives comprise a range of government responsibility, costs, associated benefits (in terms of emission reductions), cost effectiveness and cover two different source sectors targeted for emissions reduction. Point Sources of pollution have been extensively monitored, regulated and targeted for emissions reductions. Essentially, retrofitting point sources with the best available technology is the only acceptable way to reduce emissions from stationary sources.

Table 4-3: Alternatives: Government responsibility and source sector

ALTERNATIVES	AUTHORITY	SOURCE SECTOR
AirCare Inspection\Maintenance	provincial	mobile
Burrard Thermal Generating Plant	regional	point
Trip Reduction Measures	regional	mobile
Alternative Fuels	provincial	mobile

Due in part to past efforts and legislation such as the Waste Control Act, point sources are becoming less of an air quality threat on an individual basis. Mobile sources on the other hand, have several factors that add to the magnitude of emissions generated and the complexity of reduction efforts. Many small sources (cars), societal dependence on automobile(seen as a right), and land use patterns dictate that residents of low density areas have to rely on private autos. There are four primary ways of combating pollution from autos: eliminate or reduce vehicle trips, reduce trip length, increase vehicle occupancy and reduce rate of emissions per vehicle kilometer traveled. The alternatives chosen for this analysis cover these methods in an attempt to compare the relative efficiency and effectiveness of reducing oxides of nitrogen.

To reduce the total number of alternatives considered, this paper will not include initiatives targeted to reduce VOC's, SOx, CO or particulate matter and will not examine initiatives that target area sources. This is not to say that these pollutants or sources are not important, but they just lie outside of the area of interest.

The four alternatives demonstrate some the GVRD's objectives of developing a comprehensive process as described on page 1-5 AQMP (GVRD, 1994) for the following reasons:

- demonstrates an integrated approach in that two types of planning are involved; transportation and air quality planning.
- compares GVRD's strengthened management approach for its jurisdiction to that of the province.
- will demonstrate how effective and how equitable alternatives may be.
- demonstrates complexity of the process and provides a richer comparison of alternatives applicable to different sources.

1 AIRCARE

The AirCare program is an inspection and maintenance (I/M) program designed to reduce air pollution from light duty vehicles. Over half of total emissions from autos are caused by a small percentage (15 %) of the cars that do to meet the original manufacturers specifications because of deliberate tampering with pollution control devices, poor maintenance or use of improper fuel (GVRD, 1992). This program is the first of its kind to test for NOx (Brenda Jones. Public Relations Manager Ebco-Hamilton, personal communication). It also is one of the few I/M programs that employs a Dynamometer test, which is more representational of the cars actual emissions during driving. Cars are tested (fee: $15 + 1.05 G.S.T.) against manufactures specifications that are reasonable for any car that hasn't been tampered with. If the car passes the test, it may be insured for another year. If the car fails, three things can happen:

1) The owner takes the car to a certified AirCare repair center to fix the problem. The owner is guaranteed some consumer protection as these repair centers are government regulated and can be de-certified for not conforming to guidelines set out in the Motor Vehicle Act. (at the time of writing, three repair centers had been de-certified in the lower mainland (Brenda Jones, Public Relations Manager Ebco-Hamilton, personal communication)). After repairs, the vehicle is required to be retested before it can be insured.

There is a temporary provision for cars that have problems passing the test. A repair cost limit allows cars to be insured even if they don't conform on the second test, but these repairs must be done by a certified technician at a certified repair center. This is a way for government to introduce the program to the public successively, the repair limit will gradually be phased out.

2) The owner can attempt to repair the car on their own and then re-test. The repair cost limit does not apply.

3) The owner can elect to retire the vehicle.

Since AirCare is a centralized, independent contractor program, it involves no net cost to government, including all administrative, research, and development costs (personal communication with Claire Eraut, Director of AirCare, 1993). All costs are born by the contractor Ebco-Hamilton Partners which receives revenue from the inspection fee of fifteen dollars. Of this fee, $12.75 goes to the contractor, and 2.25 goes to the provincial government. From their portion, Ebco-Hamilton covers all costs including wages, land leases, research and development. The $2.25 that goes to the provincial government pays the wages of the fifteen employees in the Motor Vehicle Branch who administer the AirCare program from the Burnaby test center. However, the program does impose costs to the motoring public of the lower mainland. The costs arise not only from the fee, but the expense of repairs to conform to the test. Data collected by the Motor Vehicle Branch shows that, on average, failing cars in 1994 paid $177 to conform to AirCare standards. This amount is expected to increase by approximately 10% per year (Martin Lay, Director of AirCare, 1994). On a present value basis, the program could cost lower mainland motorists in the neighborhood of 1338 million dollars (see table 4.4) over twenty five years (see Appendix A for calculations and assumptions.)

The AirCare program is predicted to reduce NOx emissions from automobiles by 20% per year. This estimate comes from the Ministry of Environment's Mobile 4C emissions model (GVRD, 1992) and could amount to a reduction of 33,760 tonnes of NOx over twenty five years (GVRD, 1992). Of the total costs, 1.125% is attributed to NOx control based on actual percentage of emissions reductions. The resulting cost effectiveness is $446 per tonne of NOx reduced (see table 4.4). Basing the share of NOx control costs on total emissions reductions assumes that all emissions reductions achieved by the program are valued the same by society.

In terms of economic impacts, the AirCare program created 260 full and part time jobs (Claire Eraut, director of AirCare. 1993). These jobs are primarily entry level, so it can be assumed these people were probably under employed before the program. There is potential to have large positive impacts to the auto repair industry as repair costs alone could amount to over $925 million dollars (present value basis, at 8%) over twenty five years.

On the Customer Service account, the Air Care program has the potential to disrupt approximately one million motorists anywhere from half an hour to 2- 3 hours per year (an estimate based on my experience with the program), depending on traveling time (to test center), time spent waiting in line, time taken to actually test the vehicle and whether it passes or fails. If a vehicle fails, the amount of time consumed as a direct result of the program could increase dramatically (as illustrated by options 2 & 3 on the previous pages.) This program could pose even more significant disruptions to people who are financially disadvantaged. There are two main reasons why people with less money may experience more disruption: one, they tend to drive older, heavier polluting vehicles as the newer, cleaner burning cars are financially out of reach and two; the expense of getting the car tested (fee and fuel) and repaired are likely to constitute a larger portion of their total available resources. However, when looking at the social impacts, even though the program causes some minor disruption to lifestyle, it does impose the cost directly to the source of the problem; lower mainland motorists. In this sense it is very equitable in terms of distribution of social costs and benefits for the people of the province even if the argument is made that not every car is "dirty". Newer cars still contribute by adding to the absolute volume of emissions and it could be said that while those who pollute have to pay, those who pollute more, have to pay more (through repair costs.)

Political concerns relate to flexibility to adapt to changes, ease of implementation and possible political ramifications of the program. The implementation of this Inspection and Maintenance program required detailed studies of I/M programs across North America with adaptations for applicability to the lower mainland. Actual implementation required coordination with ICBC (on going) and the Motor Vehicle Branch. The contractor, Ebco-Hamilton was responsible for acquiring land and building the test centers.

The AirCare program is flexible in terms of adapting to new emission standards and technological changes but not flexible in terms of decommissioning the program as the land has been acquired and the facilities constructed. Also, the contractor is guaranteed to test at least one million vehicles per year for a determined period of time (originally five years, currently being negotiated.) Premature breaking of this contract would result in inefficient use of resources as the contractor may have to be paid off.

Table 4.4 AirCare Accounts Summary

Accounts	AirCare
Financial (NPV @ 8%, in millions of Canadian dollars)	$ 1338.52
Pollutant reduction NOx (total tonnes to 2018)	33,760
COST-EFFECTIVENESS: NOX REDUCTION	$ 446 / tonne NOx
Economic	-260 direct full /pt jobs created -increase in income and employment in repair centers
Social (equity)	-equitable cost structure: all motorists pay for air pollution- those who pollute more, pay more
Impacts on Customer Services	disruption to over one million motorists per year for a few hours each test
Political Concerns	-flexible to technology changes and changes in emission standards -politically dangerous

The very nature of this program (affecting many people over an issue considered extremely sensitive) makes this program potentially dangerous for elected government officials. The attention received by the media regarding public outrage over the program at the outset is testimony to the fact that no provincial government would implement a program like this close to election time.

2-BURRARD THERMAL GENERATING PLANT REBUILD

The Burrard thermal generating plant (BTGP) is a natural gas fired power station on Burrard inlet. It has been in full operation since 1974. The primary purpose is to supply firm energy during periods of high demand and low run-off (low supply from hydro-electric plants). It accounts for 12% of BC Hydro's' total firm energy. BTGP has 6 boiler-units, and when all are operating, the plant is capable of producing just under 7000 gigawatt hours (GW.h), which is the electricity required by 700,000 homes (BC Hydro Fact Sheet, 1993). Normal operation ranges between 4000 and 5000 GW.h. Burrard also produces NOx emissions at the rate of 2400 tonnes per year, making it the single largest source in the region (GVRD, 1992). BC Hydro has taken steps in the past to reduce emissions by changing from oil to natural gas as a fuel source and employing boiler optimization strategies that reduce emissions (BC Hydro Fact Sheet, 1993). The Greater Vancouver Regional District issues the operating permits for the BTGP and is calling for BC Hydro to take steps to reduce emissions. As a result, several options have been examined, the alternative of choice is Selective Catalytic Reduction or SCR for short (B.C Hydro, 1993). This technology involves injecting a catalyst and ammonia into the outlet duct of the boilers. Ammonia and NOx combine in the presence of the catalyst to produce nitrogen (N_2) and water vapor. This technology is currently in use in thermal generating plants in Japan, Germany and California and has a proven NOx emission reduction record (BC Hydro, 1993). In addition to emission reduction strategies, the Burrard upgrade project also includes initiatives to increase production efficiency of the plant to make more electricity available to the power grid. These power initiatives have costs disassociated from the costs of installing

SCR technology. Thus, power production initiatives will not be considered in this evaluation as they have no direct effect on NOx emissions.

The first of six boiler units is to be fitted with SCR technology by 1995 and its results evaluated. If the results are desirable, BC Hydro may decide to equip the remaining five units (BC Hydro, 1993). For this analysis, it is assumed that all six units will be equipped with SCR technology. The last unit will be installed and operating in the year 2001. An estimate of the cost of retro-fitting the BTGP to reduce NOx emissions is $88.53 million (@8%, NPV) if the base case scenario is continued operation of the plant as is (see Appendix B for assumptions and calculations).

The installation of Selective Catalytic Reduction technology is estimated to reduce NOx emissions from each of the boilers between 288 and 360 tonnes per unit per year depending on level of power generation (GW.h) (BC Hydro, 1992). At 4500 GW.h, each unit reduces 324 tonnes of NOx. Therefore the plant reduces a total of 39,852 tonnes of NOx over 25 years (see table 4.5). The resulting cost effectiveness is 2221 dollars per tonne of NOx avoided.

The upgrade project is estimated to create 800 person years of construction employment in addition to maintaining the 80 full time positions for operating the plant, (BC Hydro, 1993) which has the potential to generate on-going positive economic benefits over the years. Negative social impacts can be considered to be insignificant for this evaluation. In terms of equity, the costs are shared by all residents of the province, while the benefits of

NOx reduction are realized by people in the lower Fraser Valley (specifically east of the plant). Therefore the project has a relatively unequitable distribution of costs and benefits.

Table 4.5 BTGP Summary

Accounts	BTGP Rebuild
Financial (NPV @ 8% millions of CDN dollars)	$ 88.53
NOx reduction (total tonnes to 2018)	39,852
COST-EFFECTIVENESS: NOX REDUCTION	**$ 2,221 / tonne NOx**
Economic	-800 person/years of construction -maintain 80 full time jobs
Social (equity)	entire province (rate payers) pay, while benefits accrue mainly to those residing downwind of plant
Impacts on Customer Services	minimal impact due to phased SCR installation
Political Concerns	-flexible over time of phased installation -allows BC Hydro system flexibility -maintain positive corporate image

The capability of BC Hydro to provide energy to society in the future is an important consideration for the customer service account. There are many problems associated with creating new hydro-electric facilities in this province. Any alternative means to meet growing power demand that doesn't have detrimental impacts to the resources this province depends on (mining , fisheries and forestry and tourism) must receive attention. The Burrard thermal generating plant is an existing facility that will not require more damage to the environment if properly managed.

So even if this retrofit increases the price hydro consumers pay slightly, the long term costs of power production may be lower than the option of retiring the plant.

The actual impact on quality of service, such as availability of power would not be affected to any great extent because, as one boiler is fitted with SCR, remaining units will be operated closer to capacity to make up for lost power generation.

The project will most likely go ahead as planned if BC Hydro is assured that more stringent standards won't be introduced after the installation of SCR that will prevent cost recovery. The rebuild is relatively flexible to change before all units are installed. If there are changes in environmental status, political climate, economic conditions or power demand, later units can either be fitted with technology other than SCR, or shut down completely. After the last unit is installed, flexibility exists in shut down of the plant or reinvestment in new technology, which is inefficient use of capital. The rebuild provides BC Hydro system flexibility as it allows for a long term, readily available means to meet energy demand (without having to purchase power from elsewhere.) This project allows Hydro to maintain a positive public image by conforming to long term environmental standards while still providing an assured supply of firm energy.

3) BC TRANSIT BUS REPLACEMENT:

25 CONVENTIONAL DIESEL BUSES WITH 25 NATURAL GAS BUSES

New vehicle emissions standards have become increasingly stringent in recent years to curb air pollution. Further reductions may be realized by using cleaner burning fuels such as reformulated gasoline; ethanol; methanol; propane (LPG); clean diesel and natural gas. The California Air Resources Board has approved regulations that require vehicle manufacturers to produce certain numbers of low emissions vehicles that run on one, or a combination of the previously mentioned alternative fuels (GVRD, 1992 App C). Heavy duty vehicles, although a smaller contributor to mobile source emissions than private autos, have higher per vehicle emissions rates (CanMET, 1990). B.C Transit is considering replacing some of their older, high emitting buses with cleaner burning vehicles (McDaniels, 1993). Urban bus fleets offer the following advantages for using alternative fuels:

- continually operate in urban areas
- operate within predetermined areas
- relative standardization of engine type within a given fleet (CanMET, 1990).

The inclusion of this alternative for NOx reduction relates to GVRDs' mention of converting fleet and transit vehicles to cleaner burning fuels. This alternative provides another way of reducing per vehicle emission rates. The replacement of 25 conventional diesel buses with 25 natural gas buses is one of three proposed alternatives referred to in "BC Transit 1993, Bus Replacement Decision: An Analysis of Clean Fuel Alternatives", prepared by Dr. Tim McDaniels. In this report, this alternative produced the greatest reduction of NOx of the three (the others: #1: 20 conventional. diesel buses + 5 natural gas and #2: 20 clean diesel + 5 natural gas buses). Natural gas is a cleaner burning fuel than diesel and contributes 43% less NOx emissions based on g/bhp.hr (McDaniels,1993).

The proposed alternative includes the purchase of 25 natural gas buses at $300,000 each (instead of conventional diesel buses at $247,000 each.) The incremental present value (@ 8%, 1994 dollars) of purchasing this capital (including reinvestment in the ninth and eighteenth years) is calculated to be $ 2,319,410 (see Appendix C for assumptions and calculations.) For this example, there are fuel cost savings when using natural gas instead of diesel fuel that amount to approximately $180,000 per year (Ibid., 1993). When fuel and operating costs are considered, the incremental cost to B.C Transit of acquiring and operating natural gas buses over conventional diesel buses is only $244,243 (see table 4.6). That is to say that if the buses were to be replaced anyway, an additional cost of $244,243 would be incurred to improve air quality by purchasing natural gas buses instead of conventional diesel ones. (In the paper mentioned above, a BC Gas subsidy is included in the analysis, it is not considered here for simplicity.) BC Transit, like BC Hydro is a crown corporation so any costs should be looked at from the perspective of the province as a whole even though some expenses are covered by a fuel tax in the lower mainland.

In terms of social impacts, it should be noted that the purchase of these buses benefits a relatively small portion of transit users in the lower mainland, while the costs are born by the entire province and people who operate vehicles in the lower mainland (fuel tax.)

Table 4.6 Bus Summary

Accounts	25 Natural Gas Buses
Financial (NPV @ 8%, in millions of Canadian dollars)	$ 0.24
NOx reduction (total tonnes to 2018)	436
COST-EFFECTIVENESS: NOX REDUCTION	**$ 245 / tonne NOx**
Economic	-minimal impact as buses are purchased from out of province
Social (equity)	province pays half of capital expenses, motorists pay (through fuel tax), riders pay little, benefits to few
Impacts on Customer Services	carries about 6 less passengers and 8% less total load at peak capacity than a conventional diesel bus
Political Concerns	-flexible as buses can be moved around -shows initiative to use cleaner burning fuels on fleet basis

If the status quo is considered to be the operation of 25 conventional diesel buses, the amount of NOx reduction for this alternative is 17.45 tonnes per year (see appendix C) which totals 43.9% of the emissions reduced by using natural gas buses. Over 25 years, 436 tonnes of NOx is avoided (see table 4.6). After allocating this share of costs attributable to NOx control, the resulting cost effectiveness of $245 per tonne is observed.

Economic impacts for the purchase of 75 buses over 25 years are negligible, mostly due to the fact that the buses are produced outside of BC. If the number of natural gas buses purchased was to increase substantially, some economic benefits may be realized through the increased revenue to BC Gas or from movement of a bus manufacturing company into the area.

Customer service impacts associated with operating natural gas buses instead of diesel buses are minimal. Natural gas buses carry about 6 less passengers and 8% less total load at peak capacity due to the heavier vehicle weight (McDaniels,1993). This amount of reduced capacity means that more buses would have to be used on routes where capacity is previously met or exceeded.

In terms of flexibility, natural gas buses provide system flexibility as they can be moved around to different routes within the lower mainland (difficult to do with electric trolley buses.) If other alternative fuels and/ or technology prove to be more attractive in the near future, the natural gas buses can be used over their useful life to replace older diesel and even electric buses. Implementing alternative fuel buses also shows initiative to change to cleaner burning fuels on a fleet basis and could have positive longer term political benefits for BC Transit.

4) Trip reduction measures: Vanpooling

The AQMP Stage Two Report cites that Transportation Control Measures (TCM's) will be necessary to achieve the 50% emissions reduction goal laid out in the Creating our Future report. Transportation Control Measures reduce dependency on the automobile by decreasing vehicle trips and increasing vehicle occupancy. Since private cars are the main source of ozone forming emissions, TCM's have great potential to improve air quality, especially in the lower mainland. TCM's promote other forms of transport by making them more attractive than driving alone. Transportation control measures include demand management approaches such as High Occupancy Vehicle (HOV) lanes, road and bridge tolls, and parking management strategies that make single occupant vehicle (SOV) travel unattractive. Trip reduction measures such as ride sharing and telecommuting are designed to make alternative modes of transport more attractive.

Trip Reduction Measures provide benefits of comfort, convenience and personal safety. These criteria are necessary for the success of alternative modes of transportation. Vanpooling is one trip reduction measure that offers these important aspects of mobility. The GVRD Air Quality Management Plan working paper entitled Regional Trip Reduction Measures, focuses on vanpooling along with regional employer based programs and ride matching. Vanpooling programs provide an opportunity for the GVRD to get actively involved in reducing demand for single occupant vehicles on the road.

The Jack Bell foundation has developed a vanpooling program that demonstrated the capability of such endeavors. The program is based on ride sharing for groups of commuters who live and work in similar locations. One person is responsible for maintenance, fueling and driving the van. This person is usually not charged a fare and may be allowed limited personal use of the van. All other riders pay a monthly rate in advance (around $90) depending on the distance traveled by the group. The fares charged by the Jack Bell Foundation currently cover the costs of leasing and operating the vans, but administration costs are not recoverable under the Motor Carrier's Act (GVRD, 1994 b). The Act stipulates that non-governmental agencies cannot operate vanpools for profit. The benefits of such a program are reduced stress, more efficient use of travel time, less absenteeism and tardiness(GVRD, 1994 b). These benefits could make the workplace more productive and thus make vanpooling attractive to some of the region's larger employers.

With information in the Regional Trip Reduction Working paper, the following scenario can be developed as a viable alternative to SOVs and thus reducing Oxides of Nitrogen emissions. The Jack Bell Foundation was provided an interest free loan ($ 2 million) from Richmond Savings for the purchase of the first 100 vans. Ideally, these costs will be covered by the vanpool monthly fares. (It is assumed that capital reinvestment will be required in the ninth and eighteenth years, see Appendix D.) The GVRD estimated total annual operating costs for a scenario where the regional district provided full funding (including staff costs and annual operating costs such as administration and advertising) to be about $ 255,000. This scenario included the creation of at least two full time positions (GVRD, 1994 b). The total cost of this alternative is $2.81 Million dollars (on a net present value basis, 1994 Canadian Dollars at 8%) (see table 4.7).

Estimates of emissions reductions by operating 100 vanpools are attained by calculating the amount of emissions that a van full of commuters would generate on an SOV basis and subtracting the amount of emissions produced by the van (see appendix D.) A vanpool operation with 100 vans has the potential to reduce NOx emissions between 7.35 and 7.7 tonnes per year. This is based on each van carrying nine passengers a minimum of forty kilometers (round trip), five times a week for fifty weeks per year (GVRD, 1994 b). The total NOx reduction over 25 years amounts to 185 tonnes (see table 4.7). The resulting cost effectiveness is $950 per tonne of NOx avoided.

In terms of the economic impacts account, the results of a vanpool operation are small (at this scale) as only two full time positions would be created. However, it is possible that small negative impacts to the economy could occur if every person in a vanpool stopped purchasing and operating their own personal vehicles. This however, is unlikely to happen as vanpooling couldn't satisfy all mobility needs of the commuters.

When looking at the social implications of vanpooling, there could be two different reactions depending if it was used in conjunction with HOV lanes. If these lanes were introduced and enforced, it could have one of two effects: it could either disrupt other traffic flow if the lane was taken from existing traffic routes. If the lane was added to traffic routes, the traffic may not be disrupted as much, but there may be problems associated with obtaining room for the additional lane. In terms of this scenario presented, 100 vanpools and no HOV lanes, it is unlikely to cause disruption to other traffic flow.

In terms of equity, the distribution of costs and benefits extends beyond emissions reductions. The users pay for the majority of the cost with the GVRD and possibly private companies picking up the remainder. The benefits of emissions reductions are distributed across the lower mainland airshed. However, the vanpoolers also receive other benefits (more efficient use of travel time, less stress etc.) With the other benefits taken into account, it is likely this alternative will provide a fairly equitable distribution of costs and benefits.

Some disruption may occur to the vanpool commuters themselves as relying on others may cause problems if the members of a vanpool group are constantly tardy or have habits that may offend or threaten the well being of others during the commute. A well organized vanpool could eliminate the possibility of this type of problem with initial screening, and enforcing strict time and etiquette regulations (possibly with fines or expulsion from the vanpool.) Overall, it is assumed that a vanpool operation with 100 vans , each carrying 9 passengers would have relatively little disruption or other negative impacts to society associated with it.

Customer Service implications are related to the impacts felt by the vanpoolers as a result of the program. As mentioned previously, levels of comfort, convenience and possibly personal safety may be slightly less than operating their own single occupancy vehicle. However, a well run program could mitigate these effects and focus on the positive impacts such as more efficient travel time and increased productivity. Less personal flexibility could be mitigated by allowing "guaranteed rides home" in the case of a personal emergency for example.

The impact of vanpooling on the three aspects of the political account are worth noting. A vanpooling operation could take some well thought out planning to implement. Effort will be required to convince people to leave their car at home every work day. It may be necessary to make vanpooling mandatory at certain times (either within a corporation / company or during summer months) or provide economic incentives with employer based participation.

Table 4.7 Vanpooling Summary

Accounts	Vanpooling (100 vans)
Financial (NPV @ 8%, millions of CDN. dollars)	$2.81
NOx reduction (total tonnes to 2018)	185
COST-EFFECTIVENESS NOX REDUCTION	**$ 950 / tonne NOx**
Economic	-minimal impact two administrative positions created
Social (equity)	equitable cost structure:
Impacts on Customer Services	- comfort, convenience and safety - efficient use of travel time -takes 900 people out of sov's
Political Concerns	- positive corporate image -flexible - changes to motor carriers act needed to implement on a wide scale

It may be easier to start the program by having flexible vanpooling days when people may opt to use their own vehicles (but still have to pay for the program.) A flexible introduction of the program may highlight it's usefulness and avoid the negative feelings and resistance associated with top down imposition of the program. Other barriers to implementing a widespread vanpooling operation include the Motor Carriers Act. The act should be changed to allow private companies (and government agencies) to operate vanpools on a cost recovery basis at least.

Vanpooling would be more flexible than other Transportation Control Measures in that it can be used in conjunction with other measures such as high occupancy vehicles lanes and economic incentives such as parking fees and road tolls. Like buses, the vans could also adapt to changing geographic factors quite easily (such as relocation of place of work or residence.)

The implementation and operation of a successful vanpool operation could improve the public image of the corporation or government agency responsible for the program. Making an effort to improve the environment while providing a relatively affordable service to employees could have long term economic benefits to the initiating entity.

Comparative Summary

All of the information regarding accounts of interest for the four alternatives (previously summarized in tables 4.4 to 4.7) is presented in an accounts by alternatives matrix for comparison (see table 4-8). Table 4.8 highlights the relative performance of these accounts in a readily understandable fashion. The intent is to provide a means of identifying relative advantages and disadvantages of the alternatives across accounts of importance. This comparison is over twenty five years, the expected life of the longest lived capital investment (installation of SCR Technology on the Burrard Thermal Generating Plant.) Detailed descriptions of the calculations and assumptions behind information in the cells of the matrix are given in the appendices A to D: A)AirCare; B) BTGP; C) Natural gas buses; D) Vanpooling. The results of the matrix and the impacts and tradeoffs inherent with making an air quality decision will be presented in the next section of this paper: Section V: Results and Tradeoffs.

Table 4.8. COMPARATIVE SUMMARY: ACCOUNTS X ALTERNATIVES MATRIX (up to and including 2018)

Accounts	AirCare	BTGP Rebuild	25 Natural Gas Buses	Vanpooling (100 vans)
Financial (NPV @ 8%, in millions of Canadian dollars)	$ 1338.52	$ 88.53	$ 0.24	$2.81
Pollutant reduction NOx (total tonnes to 2018)	33,760	39,852	436	185
COST-EFFECTIVENESS: NOX REDUCTION	**$ 446 / tonne NOx**	**$ 2,221 / tonne NOx**	**$ 245 / tonne NOx**	**$ 950 / tonne NOx**
Economic	-260 direct full /pt jobs created -increase in income and employment in repair centers	-800 person/years of construction -maintain 80 full time jobs	-minimal impact as buses are purchased from out of province	-minimal impact two administrative positions created
Social (equity)	-equitable cost structure: all motorists pay for air pollution- those who pollute more, pay more	entire province (rate payers) pay, while benefits accrue mainly to those residing downwind of plant	province pays half of capital expenses, motorists pay(through fuel tax), riders pay little, benefits to few	equitable cost structure: commuters, employers, and or GVRD pay and receive benefits in addition to air quality improvements
Impacts on Customer Services	disruption to over one million motorists per year for a few hours each test	minimal impact due to phased SCR installation	N.G bus carries about 6 less passengers and 8% less total load at peak capacity than a conventional diesel bus	-provides adequate levels of comfort, convenience and safety -more efficient use of travel time -takes 900 people out of sov's
Political Concerns	-flexible to technology changes and changes in emission standards -politically dangerous	-flexible over time of phased installation -allows B.C. Hydro system flexibility -maintain positive corporate image	-flexible as buses can be moved around -shows initiative to use cleaner burning fuels on fleet basis	-creates positive corporate image for initiating agency -flexible -legal changes to motor carriers act needed to implement on a wide scale

SECTION V RESULTS AND CONCLUSIONS

This section summarizes results of the matrix and employs the cost effectiveness values as the basis for comparing impacts across alternatives to establish an order for implementation. A list of questions is developed that could be used to help establish the preferences of decision makers by highlighting critical values and tradeoffs. The objectives gained or forgone when choosing one alternative over another are highlighted as the tradeoffs, while cost effectiveness differences are suggested as a means of determining critical values. These critical values are the dollars per tonne difference necessary to change the initial ranking. Conclusions for this analysis and its applicability to air quality policy decisions are described at the end of the section.

Summary of Analysis

A summary of the matrix will follow organized by relative performance of the alternatives. Beginning with the Air Care program, the most notable factors are the large reduction of NOx emissions at the highest total cost. On closer inspection, AirCare also has an equitable distribution of costs and benefits as the program charges all of the expense to the largest source of NOx emissions (motorists) while all residents will benefit from emissions reductions. It could be argued this is unequitable as all motorists have to pay even if they have newer cars. One answer to this may be; even though newer cars are considerably cleaner than older ones, they still contribute to the sheer volume of emissions discharged into the airshed. As the polluter pays, people with higher polluting cars will pay more through repairs and retesting. Air Care provides some positive economic benefits by creating employment and increasing income in the automotive repair sector. NOx emissions reductions come at a relatively low price because the program also reduces large amounts of other pollutants. As a result, the share of costs attributable to NOx control are small. However, the program results in some disruption to the public. The Insurance Corporation of BC has taken steps since the implementation of the program to minimize disruption, the most notable being the introduction of flexible renewal dates for insurance policies. Previously, all renewals were done at the end of any particular month which caused bottlenecks at AirCare test centers. Now insurance policies may be renewed any time during the month. This has spread out the demand for inspections and reduced waiting time. Nevertheless, this alternative could still prove to be politically dangerous to elected government officials.

BC Hydro's Burrard thermal generating plant rebuild offers the second largest total NOx emission reductions at the least cost effective rate of the four Emission Reduction Measures (ERMs) considered in this analysis. The main reason for this project not being cost effective with respect to emissions reductions is that it only reduces NOx. As a result, 100% of costs are attributed to NOx control. (Installation of SCR technology does not increase electricity production on its own. There are separate initiatives to upgrade output from five boiler units from 150MW to 160MW that have no effect on NOx control.) However, the rebuild can produce large positive economic benefits. The creation of 800 person years of construction employment (to take about seven years), continuance of 80 full time positions, and the fact no new hydro electric facilities will be needed to replace it, combine to create several long term economic benefits. Nevertheless, all B.C. Hydro customers will pay for this ERM while emission reduction benefits will accrue mainly to those people who reside in the areas to the east (downwind) of the plant (i.e. Ioco, Port Moody, Port Coquitlam.) Negative customer service and political ramifications are considered to be minimal.

The replacement of 25 diesel buses with 25 natural gas buses is the most cost effective way to reduce emissions of the four alternatives. When incremental costs are considered (the cost increase involved with purchasing natural gas buses instead of conventional diesel buses) this alternative is the most attractive financially. BC Transit, like BC Hydro, is a crown corporation and thus provincial taxes fund the majority of their capital budgets. Because of this, the purchase of 25 natural gas buses to improve air quality does not have equitable distribution of costs and benefits. This ERM does not pose any significant disruption to customer services, has few negative political impacts and as laid out, creates few economic benefits.

Vanpooling is a low cost emission reduction strategy that places most of the expense on to the commuters who would also receive personal benefits in addition to air quality improvements. The cost of NOx reduction is moderately unattractive on a per tonne basis and at this scale, vanpooling offers few emission reductions and essentially no positive economic benefits. However, this alternative does provide a means for the GVRD to become actively involved in emissions reduction measures that could help change the way people choose transport options. A successful vanpool operation provides a viable mobility alternative and may reduce dependency on the automobile.

Basis for Comparison

None of the alternatives considered in this analysis are unequivocally better on all accounts than the others. As the decision has no clear winner, tradeoffs will be necessary between accounts to achieve the most desirable consequences. Comparing the alternatives to each other in a meaningful way requires some simplifying assumptions in order to determine what the tradeoffs will entail. The first assumption is that none of these ERMs have been implemented already (while in fact some have). The second assumption relates to the financial account. Since no single agency is responsible for more than one ERM, the financial account is to be taken from the viewpoint of society as a whole. Thus, incremental costs of alternatives are less important to society (as a whole) as they are to the system in which they exist (i.e. Crown corp.) Also, comparing the financial account is deceiving because of who pays and who benefits: lower mainland motorists pay for AirCare and part of BC Transit initiative(through fuel tax); crown corporations projects are paid for by the province (taxpayers); vanpooling is paid for mostly by the commuters with some funding coming from the GVRD. These reasons suggest that it makes more sense to focus on the relationships between incremental costs and emissions reductions to establish an initial order of preference for implementation.

The costs associated with emissions reductions for these alternatives range from approximately $245 to $ 2,220 per tonne of NOx reduced (see table 5-1). These values are based solely on NOx emissions eliminated as a percentage of total emissions reductions attributed to each respective ERM (in other words, the share of costs attributed to NOx control.) This approach ignores the value that society ought to be willing to pay for air quality improvements and takes the need to reduce emissions as given. It should be noted the time stream of emission reductions varies between alternatives. Natural gas buses and vanpooling have steady NOx reductions, as does Burrard (after installation of the last SCR unit). NOx reductions from the AirCare program are expected to increase, partly due to the increase in total vehicle numbers. A levelized cost per tonne of NOx reduced could be calculated to give a present value to the flow of NOx emissions from AirCare for the 25 year time frame. However, Levelizing the value of NOx emissions may be inconsistent with the underlying premise of "taking the need to reduce emissions as given" because it discounts the value of future emissions reductions.

Table 5-1. Cost per tonne of NOx Reduction

Natural Gas Buses	$ 245
AirCare	$ 446
Vanpooling	$ 950
BTGP	$ 2,221

Cost effectiveness measures ($/tonne) of NOx reductions can also be used to help define critical values, which are differences the cost of emission reductions would have to be in order to outweigh advantages (or disadvantages) on other accounts. This amount would be the cost difference per tonne required to change the initial order of implementation. A critical value answers the question: "*What difference in dollars per tonne (between two alternatives) is necessary to offset a specified advantage held by one alternative on a non monetary account*?"

Critical Values and Tradeoffs

The following section highlights questions that could be used to identify the critical values needed to justify amending the order of ERM implementation. By asking questions regarding critical values, important tradeoffs will also be more explicit. (Critical values essentially provide a dollar figure to non-monetary impacts to highlight tradeoffs in a readily understandable manner.) This approach, in practice, may help decision makers better understand their preferences and the relative importance of accounts.

To begin, one approach is to think of the AirCare program as a standard, or benchmark to which the other alternatives can be compared. The rationale behind this is the program has been in operation for three years and provides a way to compare the "goodness" of the decision when compared to other alternatives. When AirCare is compared to the other alternatives in this manner, the difference in cost effectiveness can be used to establish the critical value of non-monetary impacts (see table 5-2). The idea is to ask if performance on accounts other than cost effectiveness are important enough to justify changing the initial ranking of ERMs. For example, to determine the importance of negative impacts on customer services associated with AirCare, one could ask if disrupting one million motorists is justified due to savings of $1775 per tonne of NOx reduced (when comparing the AirCare program to the BTGP rebuild). If the answer is yes, the savings of $1775 per tonne is worth implementing AirCare ahead of the Burrard thermal generating plant and the performance of the cost-effectiveness account is more important than disrupting one million motorists. If the answer is no, higher savings per tonne are needed to justify the initial ranking and resulting disruption to motorists. This new amount, critical value of customer services impacts, is determined by asking a series of questions with higher savings until the decision maker agrees. Even though critical values represent the preferences of decision makers, examining the most obvious questions provides more knowledge about those preferences and can help determine the "best" order for implementation.

Table 5-2. How costs per unit of NOx emission reductions differ among alternatives and resulting order for implementation

Alternative	Difference in costs per tonne of NOx	Rank
Natural Gas Buses	$ 0	1
AirCare	$ 201	2
Vanpooling	$705	3
BTGP	$ 1976	4

Examples of Questions to Identify Critical Values and Tradeoffs

These hypothetical questions are designed to determine if the differences in cost per tonne of NOx reduction are important enough to maintain the initial ranking in table 5-2.

1) An example of a question to help determine the relative importance of **cost effectiveness** versus **total tonnes of NOx** eliminated:

- the BTGP rebuild has the least effective C/E rate (but reduces the largest amount of NOx), as a result, it is ranked last of the four alternatives.
- vanpooling and natural gas buses are ranked ahead of the BTGP rebuild in terms of C/E but have a low total emissions reduction.

Does the high cost per tonne of the BTGP rebuild make it less attractive than vanpooling or natural gas buses even though it reduces over 39,000 additional tonnes of NOx in the same time period?

If the BTGP is less attractive that these two alternatives, the difference in C/E is most important and the initial ranking remains unchanged. If the BTGP rebuild is more attractive than these two alternatives, the difference in C/E is not as important as total NOx reduced. A series of questions with decreasing $/tonne values could be addressed to the decision maker(s) to establish the Cost Effectiveness value required to move the BTGP up in the rankings ahead of natural gas buses and vanpooling.

The same reasoning applies to the comparison of AirCare to the bus replacement option based on NOx emissions and cost effectiveness. The AirCare program reduces significantly more NOx (33,575 tonnes over 25 years) but is slightly less cost effective than the natural gas bus option.

If AirCare is less attractive than the bus option, then the total emissions reduced is not as important as cost effectiveness. If AirCare is more attractive to decisions makers, then the difference in cost effectiveness is not as important as the total amount of NOx avoided.

2) To determine importance of **total costs** versus **cost effectiveness**, the following could apply:

Even though AirCare a cost effective way to reduce NOx emissions (when relative impacts of emissions types are ignored), it is the most expensive. BTGP reduces more NOx (6092 tonnes over 25 years) at a much higher cost per tonne ($1,775/ tonne higher). However, the total cost of BTGP is 1250 million dollars (NPV) lower. Is AirCare still a better choice than the BTGP rebuild based on the difference in $/tonne?

If the answer is yes, then the C/E value is more important than the total cost and a lower $/tonne figure for BTGP is needed to make it more attractive. A series of value questions with lower C/E values for the BTGP could be asked until the decision maker agrees to change the order. This amount is the critical value of total costs in comparison to $/tonne. If the answer is no, the total cost may be a more important objective (to minimize costs) than the cost effectiveness.

3) Comparing **cost effectiveness** against **customer service impacts**:

- AirCare has an attractive C/E rating but disrupts the public
- BTGP has unattractive C/E but has virtually no negative impact on its customers.

Is it worth saving $1,775 per tonne of NOx reduced to disrupt at least 1 million people a year for twenty five years?

If yes, then C/E is more important than customer service impacts or disruption to the public. If no, then a larger difference in cost per tonne between the two alternatives is needed to maintain the ranking.

These three questions have compared cost effectiveness with only one other account in isolation. These complex problems require many factors to be considered at once. The following examples of questions attempt to incorporate more than two factors for comparison.

4) Comparing cost effectiveness against several accounts (economic impacts, emissions reductions, customer services and political concerns):

Vanpooling and natural gas buses have favorable cost effectiveness. The BTGP rebuild has positive economic benefits, large emissions reductions and minimal impacts on customer services or political concerns. However it is not cost effective with respect to emission reductions.

Are vanpooling and natural gas buses still more attractive than the rebuild?

If yes, the differences in C/E values are large enough to justify the initial ranking and a lower cost per tonne for the BTGP is needed to offset impacts on other accounts to change the ranking.

If no, the performance on accounts other than cost effectiveness are more important than the difference in cost per tonne in isolation.

5) To examine importance of scale of costs and benefits:

When taking the scale of costs and benefits into consideration, would it be more desirable to implement a natural gas bus program or vanpooling operation (or a combination of both) instead of AirCare and receive fewer benefits (in terms of emissions reductions) at less total costs to society?

6) To determine the importance of social equity:

Are any social impacts important enough to change the ranking based on cost effectiveness?

7) To determine the importance of negative customer services and political concerns:

Do the negative effect on consumers (and the resulting political concerns) make AirCare less desirable than the other alternatives?

From these questions it is evident there are two types of tradeoffs emerging with respect to these alternatives: one involving the scale of costs and emissions reductions and the second focusing on cost effectiveness versus other accounts. The tradeoffs of scale involve two levels of costs and emissions reductions: the AirCare Program and the Burrard thermal generating plant rebuild have large total costs and large NOx reductions, while vanpooling and the natural gas bus purchase have significantly smaller impacts on these two accounts. Deciding on the level of costs and benefits to achieve is a matter of decision maker preferences and priorities. If it is most desirable to reduce as much NOx as possible, then AirCare and the BTGP should be considered for initial implementation ahead of the other ERMs. If the political will is to start the process of reducing emissions in a low cost, resource efficient manner with little disruption to the public, then vanpooling and natural gas buses may be a better decision.

Aside from tradeoffs of scale, others deal with the relationships between cost effectiveness versus customer service impacts, economic impacts, political concerns and equity. Tradeoffs between these entail giving up some of a desirable objective to achieve more of another desirable objective. Potential tradeoffs are illustrated by four examples of different implementation choices.

Implementing the AirCare program first attains high NOx emissions reductions at an attractive rate while ensuring equity and creating economic benefits. The tradeoffs are high total costs and significant disruption to lower mainland motorists. This may also prove to be politically risky.

If the decision to implement natural gas buses(instead of diesel buses) is favored, positive aspects would include low total costs, low costs per tonne of NOx, and minimal negative impacts to customers. This option reduces very few NOx emissions, largely due to the fact that the emissions eliminated by using 25 natural gas buses instead of 25 diesel buses is relatively small. On a larger scale this alternative would provide many more reductions benefits.

The tradeoffs involved with implementing a vanpooling operation as a priority center around the fact that even though most impacts are positive, the emissions reductions are insignificant for 100 vans. A larger number of vanpools would be needed to compare favorable with AirCare or the BTGP rebuild in terms of emissions reductions. In order to “convince” the number of people needed to make an impact on NOx emissions, other impacts would probably change (as participation in a vanpool would most likely become mandatory.) Some positive impacts may be less reliance on the automobile and less congested roadways.

If the Burrard thermal generating plant rebuild was the ERM of choice, large emissions reductions and positive economic benefits would be realized with no significant negative impacts on the public or the customers. This alternative however, would not reduce dependency on private automobiles and would not provide a cost effective means of reducing NOx.

With these tradeoffs in mind, the order of implementation could change considerably depending on the preferences of the decision making body. Some examples of the resulting ranking differences are presented in table 5.3.

Table 5.3 Changes in Implementation Order depending on Preference

Order for Implementation	Preference: Reduce NOx	Preference: Cost effective	Preference: Customer srv.	Preference: Political	Preference: Minimize $
1	BTGP	25 natural gas buses	vanpooling	vanpooling	25 Natural gas buses
2	AirCare	AirCare	BTGP	25 Natural gas buses	vanpooling
3	25 Natural gas buses	vanpooling	25 Natural gas buses	BTGP	BTGP
4	vanpooling	BTGP	AirCare	AirCare	AirCare

CONCLUSIONS

The AirCare Program appears to a logical choice for initial implementation for three main reasons. AirCare reduces a large amount of NOx emissions cost effectively, while all costs are covered by the source of the problem. (Even though AirCare reduces about 6000 tonnes of NOx less than Burrard over twenty five years, it is much more attractive based on cost effectiveness. Also, the cost effectiveness value is close enough to that of the bus option that the significant increase in NOx avoided should outweigh the $ 201 per tonne difference between the two alternatives.) This selection is reinforced by looking back to the elements needed to make the AQMP successful. For the plan to be successful, any emission reduction measure must be focused on priority problems and be able to resolve them; achieve reductions in a cost effective manner; and it must be acceptable to the public, stakeholders and government. This program is focused on a priority problem (emissions from cars) and will reduce a significant portion of emissions from this source. It is also cost effective with respect to emissions reductions and although not accepted graciously by the public at the outset, changes to the program and increased public awareness are helping AirCare to gain acceptance.

The order for implementation of the remaining alternatives in this comparison is dependent on the subjective nature of decision makers' preferences. If improving air quality (at any cost) was top priority, BC Hydro's Burrard thermal generating plant rebuild would receive second billing followed by the natural gas bus purchase and then vanpooling.

Even though the decision to establish an order for implementation of ERMs rests with decision makers, this analysis has examined one avenue to assist that decision making process. The modification of the multiple account analysis employed in this paper was useful in delineating the many dimensions of a tough air quality decision. By breaking down a decision into the objectives or accounts of importance, many dimensions of the problem can be presented in a readily understandable fashion. The framework allows for a logical, systematic examination of value and technical components of air quality management decisions and allows for comparison across several accounts.

This approach, or modifications of it could be very useful in all public policy contexts, especially those where conflicting objectives and multiple accounts are involved. In a practical setting, the task of deciding how far down to rank a list of alternatives could depend on factors such as available time and resources for analysis, priority concerns, political agendas and timing of implementation. The GVRD selects alternatives for analysis by targeting the sources that comprise the first 75% of emissions for the sector of interest. If a specific emission was targeted for reduction, as in this analysis, the 75% rule could apply to the pollutant(s) of interest instead of source sector. This would be an effective way to solve problems such as ground level ozone or particulate matter across source type. The end result of this form of analysis can only lead to selection of alternatives that best solve planning problems.

Some caveats are in order for the application of this analysis as presented in this paper. Firstly, the list of alternatives in the analysis, although providing a rich mix for comparison was probably not the most realistic choice. The scale differences resulted in a wide range of costs and benefits that determined cost effectiveness the most logical account to focus on. In practice, this type of analysis would take place within a system (i.e. Crown Corp or Government Agency) as opposed to across jurisdictional boundaries and most likely would be focused on one source type for emission control. Also, personal timing was off for the selection of an emission type to concentrate on. It was decided over one year ago to focus on Oxides of Nitrogen emissions as precursors to ground level ozone. Since then particulate matter has gained higher priority status as a pollutant of concern. Ultimately, an index that combines the value and effects of major emission types (such as NOx, VOC, CO and PM) would provide a more comprehensive and meaningful approach.

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APPENDICES

ASSUMPTION AND CALCULATIONS OF COSTS AND EMISSIONS REDUCTIONS TO THE YEAR 2018

APPENDIX A) AirCare

This appendix estimates costs to society posed by the AirCare program (where the base case scenario is that no Inspection and Maintenance Program exists). The AirCare program tested one million cars in 1993. Growth in population and the economy is estimated to result in an 3 to 4 % growth in vehicles tested per annum (Martin Lay, 1994, personal communication). It was originally estimated that approximately 30% (300,000) of these will fail (Clair Eraut, 1993, personal communication). The actual percentage of vehicles failing is approximately 15% (Martin Lay, 1994, personal communication). Several assumptions are necessary to estimate the total cost to society. The first assumption is that most of the cars that fail will be repaired and 20% of the failing vehicles (3% of the total vehicles) will be retired (Martin Lay, 1994, personal comm). Thus, 12 % of vehicles will be repaired and 3% retired (not included in this analysis is the cost of retiring vehicles to society). In a discussion with the current director of AirCare, Martin Lay (Motor Vehicle Branch) he stated that expects the portion of cars that fail to remain fairly constant (around 15%) over time because of changing emission standards (even with the introduction of progressively cleaner cars.)

The second assumption relates to the cost of repairs, the average value of repairs so far will be employed. This data comes from AirCare repair centers and in 1994 was $177 per vehicle on average. This amount will increase at approximately 10% per year (Martin Lay, 1994). If the time frame to be considered is up to, and including the year 2018, the average repair costs are assumed to reach approximately $1750 per vehicle. After the cars are repaired, all must re-test (pay $15 again, this provides the MVB with a way to keep track of cars that failed and provides an indirect way of monitoring certified AirCare repair centers.) The third assumption is that all "repaired" cars pass the second test. One last assumption is that the fee of $15 will not change. With these assumptions, the cost to society for the

AirCare program up to and including the year 2018 can be estimated (taxes not included) see table A-1.

Table A-1. Costs estimate for the AirCare Program

year	# of cars tested (**3.5 %** increase per year)	failures (constant at **15%** per year)	cars repaired (**12.0%**)*	average repair costs (**10%** increase per year)	Total Annual Costs** (million $)
1994	1,000,000	150,000	120,000	$ 177	38.04
1995	1,035,000	155,250	124,200	$ 195	41.61
1996	1,071,225	160,684	128,547	$ 215	45.63
1997	1,108,718	166,308	133,046	$ 236	50.03
1998	1,147,523	172,128	137,703	$ 260	55.08
1999	1,187,686	178,153	142,522	$ 286	60.72
2000	1,229,255	184,388	147,510	$ 314	66.97
2001	1,272,280	190,842	152,674	$ 345	74.05
2002	1,316,810	197,521	158,017	$ 379	82.00
2003	1,362,898	204,435	163,548	$ 417	91.10
2004	1,410,600	211,590	169,272	$ 459	101.39
2005	1,459,971	218,996	175,197	$ 505	113.00
2006	1,511,070	226,660	181,328	$ 556	126.20
2007	1,563,957	234,594	187,675	$ 611	140.94
2008	1,618,695	242,805	194,244	$ 672	157.72
2009	1,675,350	251,303	201,042	$ 740	176.92
2010	1,733,987	260,099	208,079	$ 813	198.30
2011	1,794,677	269,202	215,362	$ 895	222.90
2012	1,857,490	278,624	222,899	$ 984	250.54
2013	1,922,502	288,376	230,700	$1083	282.15
2014	1,989,790	298,469	238,775	$ 1191	317.81
2015	2,059,433	308,915	247,132	$ 1310	358.34
2016	2,131,512	319,728	255,782	$ 1441	404.39
2017	2,206,116	330,918	264,734	$ 1585	456.67
2018	2,283,330	342,500	274,000	$ 1744	516.22

*(1,168,750 cars retired over 8 years)

* *Total annual costs = (number of cars tested X $15) + (cars repaired X $15) +

(cars repaired X average repair costs)

Total costs:

NPV = sum Pt/ (1+i) to t power (Davis pg. 120) use (i = 8%), t= 25 years

= $ 1338.52 million dollars (1994 Canadian dollars @ 8%.)

NOx Reductions

From pages A-27 to A-30 of the AQMP (GVRD, 1994), the AirCare program is expected to reduce NOx emissions from the baseline in the following manner:

year	1994	1995	2000	2005	2020
NOx Emissions Reductions	3%	3%	6%	10%	10%

At these rates, the amount of NOx reduced per year increases from approximately 505 tonnes in 1994 to 1734 tonnes in 2018. The total reduction over the 25 year time frame of this example results in a total of approximately 33,760 tonnes. The resulting cost effectiveness is $446 per tonne. *(If these emissions where to be levelized (assuming a societal value was assigned to NOx emission reductions) the levelized cost per tonne of NOx avoided would become $1160/tonne.)*

There are no reductions in SOx or PM attributed to the AirCare program, therefore, total emissions reduced are VOC + CO + NOx (assumes social value for all these emissions reductions are the same)

Allocation of costs to NOx control:

From table 11-1 AQMP, an estimate of NOx emissions reductions as a percentage of total emissions reduced from the AirCare program is:

956 tonnes NOx / 85,932 Total tonnes reduced = 1.125 %

Thus,

1.125 % x $ 1338.52 million(NPV) = $15.06 million dollars (NPV) allocated to NOx reduction

Cost-Effectiveness:

$ 15.06 million / 33,760 tonnes NOx =

= $ 446 / tonne NOx reduced from baseline

Assuming costs are distributed according to % of emissions reductions in total. This approach assumes the impacts of these emissions are valued by society the same per unit of reduction and ignores the relative impacts on health, aesthetics, visibility etc.

APPENDIX B)

Burrard Thermal Generating Plant rebuild

Estimate of costs for retro-fitting BTGP with SCR technology if the base case scenario is no rebuild and continued operation as is, in other words the status quo. The base case scenario may be unlikely over the 25 year time frame as the current rate of emissions output may exceed future levels set by regulatory bodies. However, this approach provides a solid example of incremental value and emissions changes when compared against alternatives outside the BC Hydro System.

The rebuild entails that all 6 boiler units to be replaced @$12 million dollars each + $1 million /year in extra operating costs for the plant (page 10, Burrard Utilization Study Report.) This assumes that the electricity output and operating and maintenance input remains the same (except for the $1 million extra operating costs.) (There are also efforts to increase power output from Burrard by increasing the boiler output from 150 MW to 160MW on five of the six units. This entails separate costs and associated benefits that have no bearing on the NOx reduction costs and benefits considered in this paper.)

The proposed time frame has the first unit to be installed by 1995, and the remaining 5 units completed by 2001.

Some basic assumptions: firstly, BC Hydro will apply the same technology to all remaining units, secondly, assume one unit completed per year after 1995, (start and complete one unit before moving on to the next), thirdly, there is no change in technology, or costs of technology and labour .

Cost Estimates:

To calculate net present value, the information in the cells below plus the Net Present Value of $ 1 million in extra operating costs per year from 2002 to the year 2018.

time frame	1994	1995	1996	1997	1998	1999	2000	2001
units installed	0	#1	#2	#3	#4	#5	#6	
extra operating costs	0	0	$1million	$1million	$1million	$1million	$1million	$1million

NPV = sum Pt/ (1+i) to t power (Davis pg. 120) (I = 8%)

= $ 88.527 million (1994 Canadian dollars @8%)

NOx Emissions reductions:

Calculate NOx reduction based on yearly emission reductions information from Appendix 5 (a and b) of The Burrard Utilization Study, Task Force Report, 1993.

Table A-2. Emissions BTGP, operating at 4,500 GW.h (electric power generation)

Emissions	**status quo (tonnes/ year)**	**with SCR (all 6 units)(tonnes/yr.)**
SO_2	27	27
NOx	2,430	486
VOC's	54	54
Particulate	32	32
CO	927	927
NOx as a percentage of total emissions	70.03%	29.9%

Due to the phased installation, emissions must be calculated for each year. At 4500 GW.h , each boiler unit equipped with SCR will reduce 324 tonnes of NOx per year from baseline .

Table A-3 NOx Emissions reduced per year (@ 4500GW.h) to 2001(During Installation of SCR)

	1994	1995	1996	1997	1998	1999	2000	2001
NOx Emissions	2430	2430	2106	1782	1458	1134	810	486
change (t / yr.)	0	0	324	648	972	1296	1620	1944

The change in NOx emissions to 2001 equals 6804 tonnes. Assuming the NOx reduction is then 1944 tonnes a year from the baseline, the total reduction becomes 39, 852 tonnes of NOx to the year 2018.

Since the installation of SCR reduces NOx emissions only, 100% of emissions control costs must be attributed to NOx reduction. Therefore cost effectiveness of NOx reduction :

=$ 88.527 million / 39,852 tonnes NOx

= $ 2,221 per tonne of NOx reduced

APPENDIX C) Purchase of 25 Natural Gas Buses instead of 25 Conventional Diesel Buses

Estimate Net Present Value of purchasing 25 natural gas buses instead of 25 conventional diesel buses (and resulting emissions reductions). Key assumptions:

- price relationship between the two types of buses and the associated fuels type remains constant over the 25 year time frame.
- new capital investment required after every 8 years (no salvage or overhauls).
- maintenance schedules and costs are the same for both types of buses.
- emission reductions remain constant regardless of technological advances or standards.

Table A-4 Comparison of Natural Gas and Diesel Buses

	NATURAL GAS BUS CUMINS L10- no converter	DIESEL BUS Detroit 6V92, no converter
Capital costs (1993, Can $)	$ 300,000 / bus	$ 247,000 / bus
Fuel requirements	1.2 km / l	1.4 km / l
Fuel cost (to BC Transit)	$ 0.2650 / l	$ 0.4098 / l
Fuel cost/year/ bus (100,000km)	$ 22,083.00	$29,271.00
Fuel cost: 25 buses for one year	$ 552,083.00	$ 731,785.00

NPV = Capital costs + fuel costs /year (up to and including 2018)

(includes capital investments in 9th and 18th year)

(Fuel cost saving from using natural gas instead of diesel is approximately $180,000 per year.)

NPV of purchasing buses (first, ninth, and eighteenth years)	= $ 2,319,410
NPV of fuel cost savings for 25 years	= $ 2,075,167
NPV Incremental costs	= $ 244, 243

Table A-5: Emissions Reductions:

tonnes of emissions per bus per year (based on 100,000 km/ year operation)

	Conventional Diesel (no converter)	Natural Gas Bus
HC	0.075	0.085
CO	1.072	0.263
NOx	1.230	0.532
PM	0.104	0.010
total per bus	2.481	0.890
25 buses	62.025	22.25

(adapted from table 9, page 16 of McDaniels 1993).

Difference in emissions = 39.775 total tonnes of pollutants per year eliminated by 25 natural gas buses.

tonnes of NOx generated per bus (based on 100,000 km operation/ year):

conventional diesel bus (1.230) X 25 buses = 30.750 tonnes

natural gas bus (0.532) X 25 buses = 13.300 tonnes

change in emissions **= 17.450 tonnes/ year**

Change in NOx emissions as a percentage of total: 17.45 tonnes NOx / 39.775 total tonnes of emissions **= 43.9 %**

Share of Costs attributed to NOx Control:

Allocating NOx control costs is based on the actual amount of emissions reductions, (not the social value of those reductions.)

43.9% x $244,243 = $ 107,222 allocated to NOx control

Cost effectiveness: $ / tonne of NOx reduced

= $107,222 / (17.45 tonnes x 25 years.)

= $107,222 / (436.25)

= **$245 / tonne NOx reduced from the base case scenario.**

APPENDIX D: Vanpooling

Estimate of emissions reductions and costs associated with operating a 100 vehicle vanpool. The base case scenario is that no vanpooling is in operation and all potential vanpoolers (900 commuters) use SOV's to travel a minimum of 40 kilometers per day. Since it is difficult to foresee if commuters would get rid of their vehicles due to a successful vanpool operation, any costs attributed to use of private vehicles outside of the vanpooling operation must be ignored. Therefore, the costs will be based on the vanpool operation itself (for 100, 9 passenger vans). The riders fare rate (about $90 per month) will pay for the leasing (to repay capital costs), fuel and maintenance of the vans. It is assumed they would have to pay this amount (at least) on a SOV basis for insurance, fuel, maintenance). The financial account from a societal perspective is therefore attributed to administrative costs and would either be covered by the GVRD (as in option C of the Trip reduction Working paper relating to vanpooling) (GVRD, 1994 b), private corporations or a combination of both.

Assumptions for vanpooling scenario:

- $ 2 million dollar loan interest free to purchase 100 vans (JBF)
- financial account taken from viewpoint of society as a whole
- riders fares ideally pay all capital and operating costs, only administrative costs are borne by society
- total annual operating costs taken from Option C (GVRD, 1994 b): Fully Funded and Operated by the GVRD: $255,000 (this includes staff costs, annual operating costs such as administration and advertising)
- the vans will operate for eight years before capital reinvestment is required (no salvage)
- vans purchased in the future will be paid for by the riders fares over the life of the vehicle.

An assumption is that capital costs, fuel costs and depreciation will be covered by the fares and that the commuters would have to pay this much (probably more) if they went on a single occupant basis any way. Therefore the incremental costs will include only the program operating costs.

Cost Estimates:

Administrative costs are $255,000 per year (I = 8%)

NPV = Sum Pt / (1+i) to the power t: i= 8%, t=25 years

= $ 2,812,271 (1994 Canadian Dollars at 8%)

Emissions Reductions:

Estimate using data from the GVRD AQMP Working Paper : "Regional Trip Reduction Programs" page 6, figure 2.

Table A-6 : Emissions reductions

	9 passenger Vanpool	Single Occupancy Vehicle
passengers	9	1
return trip distance (per day)	40 km 25 miles	40 km 25 miles
Emissions (g/ pass/ mile) NMHC (VOC's) CO PM SO2 NOx	 0.36 3.05 0.01 0.03 0.23	 2.57 20.36 0.04 0.14 1.61
grams / vehicle / mile	33.12	24.72
daily grams(for 25 miles)	828	618
grams/ day for equivalent SOV's	828	5562

4734 grams of emissions reduced per 9 passenger vanpool per day.

NOx % = .23g / 3.68g = 6.25 %

6.25% x 4734g = 296 grams of NOx reduced per day

= 74 kilograms of NOx eliminated per van, per year, based on 5 return trips per week of 40 km each for 50 weeks per year

= 7.4 tonnes of NOx eliminated for 100 vanpools per year

= 185 tonnes of NOx reduced for 25 years of vanpooling versus the 900 single occupancy vehicles, assuming reductions, ridership and costs remain constant.

Allocating costs of NOx control:

Share of Costs allocated to NOx control:

6.25 % x $2,812,271 = $175,767 allocated to NOx control

Cost Effectiveness

$175,767 /185 = $ 950 per tonne NOx avoided

Another scenario, although unlikely is a government funded vanpool operation (where society as a whole picks up the costs for new capital investments of vans). The riders fares then only pay for fuel and maintenance and the taxpayer pays for capital and administrative costs. In this scenario, the total costs NPV of vans and operating costs becomes $6,313,271. The resulting cost effectiveness of NOx reductions becomes $2132 per tonne.