Evaluation of the British Columbia Photo Radar Program

by

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ABSTRACT

This dissertation assesses the photo radar program, a world-wide emerging but controversial automated police traffic speed enforcement program, as it was implemented in British Columbia. The dissertation is composed of three separate and related impact analyses: a macro study to assess the overall impact of the BC photo radar programs on speed and safety on BC highway systems, a site-specific study to verify the internal validity of the province-wide study, and a cost-benefit analysis to summarize the economic impact of the program to society.

The study found that the BC photo radar program was implemented through an extensive publicity campaign and the deployment of 30 photo radar units across the highway system in the province. The impact of the program on traffic speed was dramatic at photo radar deployment sites and limited at non-photo radar deployment sites, monitored across the province. At the photo radar deployment sites, on average, the proportion of speeding vehicles decreased from more than 60% in the warning letter phase to 37% in the first year and to 29% in the second year. The proportion of excessive speeding vehicles decreased from more than 10% in the warning letter phase to 3% in the first year and to 2% in the second year. At the non-photo radar monitoring sites, the proportion of speeding vehicles declined from 78% in the pre-PRP period to 73% in the first year and then increased slightly to 74% in the second year. The proportion of excessive speeding vehicles declined from 27% in the pre-PRP period to 22% in the first year and rebounded slightly to 23% in the second year.

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Corresponding to the reduction in speed and speed variance, the program is found to be associated with a yearly reduction 2,220 collision injuries, and 79 collision fatalities across the province. These numbers represent 14% and 26% reductions in traffic injuries and fatalities respectively. The site-specific analysis of the program corroborated the results of province-wide study.

The cost benefit analysis concludes that the program produced a net benefit of close to $120 million dollars per year from the societal perspective. The result is robust except for potential estimation errors of program safety effects. The estimated net benefit becomes negative if the real safety effect is one standard error below its expectation.

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1. INTRODUCTION

Unsafe speed is a major contributing factor to traffic collisions in British Columbia. During 1995 “unsafe speed”, as judged by police attending traffic collisions, was involved in 37% of all fatal collisions, 15% of all personal injury collisions, and 9% of all property damage only collisions. More than 8,000 people were injured and 184 people killed in the 10,564 unsafe speed related collisions in 1995, resulting in severe social and economic cost to British Columbians. It is generally acknowledged that speeding may also play a role in other collisions, not specifically identified by the police as involving “unsafe” speed.

In response to this problem, the provincial government and the Insurance Corporation of British Columbia (ICBC) sponsored introduction of the Photo Radar Program (PRP) in 1996. The goal of the Photo Radar Program was to achieve a 3 per cent reduction in mean traffic speed on roads throughout the province, presumably through a generalized deterrence effect. It was assumed that a reduction in speed would lead to a decrease in the number and severity of traffic collisions. This study set out to assess the effectiveness of the program.

This study represents an initial attempt to evaluate the program as it was implemented in British Columbia. The study is intended to serve both practical and theoretical purposes. Practically, it addresses the accountability issue often raised in public administration, especially in the current political and economic environment. The knowledge learned could be used for informed decisions on the continuation, or termination, of the program. Theoretically, the study tests the linkages between program intervention, driver behavioural change, and the resulting impact on traffic safety. The information obtained could advance our collective understanding of the forces, individually or interactively, underlying and shaping the observed traffic safety.

The paper is divided into seven chapters after this brief introduction. The first chapter compiles and summarizes the current knowledge of the photo radar program and its effects by an extended literature review. The review covers both substantive and economic evaluative studies across motorised countries over the last 30 years since the program's inception. The second chapter describes the design and implementation of BC photo radar program. It provides a program logic model, which leads to the specification of the research questions. The third chapter assesses the implementation of the program. This chapter provides the foundation and basis for the outcome/impact assessment of the BC photo radar program. The fourth chapter presents a substantive evaluation of the program at the macro level. It assesses the impact of the photo radar program in speed and traffic safety across the province. The fifth chapter addresses a site-specific effect of the program at selected BC highway sections. This chapter is to verify, and potentially reinforce, the internal validity of the provincial study with better evaluation control and greater knowledge of the program implementation details. The sixth chapter presents the results of a preliminary cost-benefit analysis. This economic study of the program integrates all the major impacts of the program, and reduces them to a common monetary scale for comparison. The seventh chapter summarizes the results of substantive and economic studies and discusses the limitations inherent in the study design and data availability.

2. LITERATURE REVIEW

This chapter compiles and summarizes current knowledge of photo radar program and its evaluation. The literature review is divided into two main parts. The first part reviews theoretical issues and empirical evidence of the speed and safety effects of photo radar programs as they are applied in other jurisdictions. The review critically examines the methodologies used in previous studies and summarises program impacts from studies deemed to be of valid. The second part surveys current theories and practices of cost-benefit analysis methodologies. It then narrows down to its application, mostly in the transportation and traffic safety area. Studies on speed enforcement and especially photo radar enforcement, are pursued, and to the knowledge of the author, exhausted, given their relevance to the current study. This literature review leads to the construction of the program logic model.

SPEED AND SAFETY EFFECT OF PHOTO RADAR PROGRAM

This section reviews the theory and practices of photo radar programs across jurisdictions in the world over the last 30 years. It presents the information in two sections: first, the theoretical foundation of traffic speed, traffic safety and speed enforcement programs, and second, the existing photo radar enforcement and their speed and safety effects.

Theoretical foundation

The rationale of using automated speed enforcement devices, including photo radar, is founded mainly on theories of physics, psychology, and economics. To understand the reasoning underpinning the use of photo radar program, a chain of links between traffic speed and traffic safety, between traffic enforcement program and traffic speed, and between the required level of enforcement and the available resources, needs to be explicitly articulated. This section surveys the conceptual frameworks of automated speed enforcement, especially of photo radar enforcement, and assesses their construct validity. The next section summarizes the empirical evidence accumulated in previous studies in other jurisdictions.

A number of theories postulate relationships between speed and collisions (Shinar, 1998). The simplest and relatively robust ones are based on physics, stipulating that a vehicle's stopping distance increases exponentially with speed and that the energy dissipated upon collision is proportional to the square of spot speed. The higher the speed of a vehicle, the less time the driver has to respond to unexpected circumstances, and the more likely the vehicle is to be involved in a collision. The higher the speed of a vehicle, the more severe the collision when it occurs. These highly plausible predictions have been supported (or at least not rejected) by most empirical laboratory and field studies in traffic safety (Nilsson, 1981; McKnight and Klein, 1990; Fildes et. al., 1991; Rock, 1995). As summarised by Finch et al. (1994), in general, for every 1- km/h increase in mean traffic speed, collisions rise by about 3%.

The speed variance in the traffic affects collisions through its impact on potential inter-vehicle conflicts. It seems reasonable to theorize that a larger dispersion in traffic speeds tends to result in a greater number of overtaking manoeuvres, which in turn increase the likelihood of traffic conflicts and collisions. Empirically, this has been demonstrated by Hauer (1971) and supported by many other empirical studies. The empirical evidence was summarized by the much-quoted U shaped curve between collision involvement and deviation from mean speed (Solomon, 1964; West, Dunn; 1971; Shinar, 1998). The risk of collision increases with the speed differential of a vehicle from the median speed of the traffic. If the photo radar program reduces the mean and variance of speed, then, it is predictable, based on the above hypothesis, that it will likely reduce the frequency and severity of traffic collisions.

The theoretical foundation for traffic law enforcement and its effectiveness on reducing traffic collisions is based on the general deterrence theory. General deterrence is described by Ross (1982) as: “the effect of threatened punishment upon the population in general, influencing potential violators to refrain from a prohibited act through a desire to avoid the legal consequences” (page 8).

The general deterrence theory recognizes that the effectiveness of traffic law enforcement depends on a number of factors and conditions. Operationally, three main factors: certainty, severity and swiftness were postulated to influence the intended behaviour change induced from traffic safety enforcement. The higher the likelihood of apprehension, the heavier the fines, and the quicker the punishment, the more effectively the program affects driver behaviour and improves traffic safety (Ross, 1982).

Not all speed enforcement strategies produce the certainty, severity, and swiftness required to generate general deterrence effects. Conventional enforcement methods require police officers to stop the speeding vehicles and manually issue tickets to offending drivers. This method is time consuming and it often puts police officers in dangerous situations. The decreasing resources in police forces in recent years further dampened their impact. New and automated technologies such as photo radar provide the potential for improved efficiency, and should be considered among the potential tools for the police to combat traffic safety problems (Goldenbeld, 1995).

It could be posited, therefore, that a photo radar enforcement, coupled with the publicity campaign, would reduce traffic speed not only at the photo radar deployment sites, but also at other locations in the province, if the photo radar device is mobile and the deployment sites somewhat unpredictable. In this case, the photo radar can theoretically reduce speed and collisions at the enforcement sites by its presence and reduce speed and collisions at other places by the heightened perception of detection and punishment attributable to the efficiency and unpredictability of the automated system.

In summary, relatively strong theories are available to substantiate the links between traffic speed and traffic collision, and between speed enforcement and traffic speed. Traditional methods of speed enforcement proves to be inefficient and ineffective, however. Therefore, it is conceivable, and to a large extent plausible, that an automated speed enforcement program, such as the photo radar program, could reduce traffic speed and speed variance, which would in turn lead to a reduction in traffic collisions and injuries, i.e., the improvement of traffic safety.

Existing photo radar programs and their speed and safety effects

Various types of photo radar devices and programs have been tested and implemented in many jurisdictions across the world in the past 30 years. Europe is the pioneer in adopting this technology for managing traffic speed and collisions. The Netherlands has used photo radar successfully and extensively as an enforcement tool. Germany and Sweden have also used photo radar devices but with limited success. The difference has been attributed to the presence or absence of enabling legislation in the respective countries (Coleman et. al, 1995). Laws in Germany and Sweden require that tickets be issued to the driver, while other more successful jurisdictions allow the ticket to be charged to the owner of the offending vehicles, regardless of the identity of the driver who committed the offence.

Swali (1993) assessed the speed and safety effect of speed cameras on a major highway in West London. A speed camera was deployed at selected sites based on collision history and deployment suitability. The study found a 97% reduction in the proportion of speeding vehicles, travelling at 60-mph or faster speed in a 40-mph speed limit zone. The mean speed was reduced by 5 mph and the 85th percentile speed was reduced by 7 mph. Using other trunk roads as controls, the analysis revealed a 19% reduction in collisions, a 20% reduction in casualties, and a 29% reduction in serious and fatal casualties.

The largest operation of photo radar units is found in Victoria, Australia. In September 1989, Victoria introduced its photo radar program with expanded use of 60 speed cameras. The objective was to reduce travel speeds across all speed zones by 10-15 km/h in 6 to 12 months, and thus reduce the number and severity of collisions by 10% (Hitchens, 1994). The level of program delivery was high as indicated by greater than 4,000 camera hours per month as of 1994.

Since the introduction of the program, Victoria has experienced a significant reduction in traffic speed. The proportion of speeding vehicles in the traffic flow was decreased by 85% (Hitchens, 1994). The reduction in traffic speeds was followed by a reduction in traffic collisions. In combination with a night time drinking driving program, the traffic enforcement program clamed a reduction of collisions by 16%, injuries by 21%, and fatalities by 30% in the first year of program operation (Hitchens, 1994).

In an attempt to separate the photo radar program effect from that of other traffic safety initiatives, Cameron, Cavallo and Gilbert (1992) analyzed the collisions and casualties in “low alcohol hours” over a nine-year period, using New South Wales as the comparison jurisdiction. Using an interrupted time series analysis approach, they found a significant drop in collisions from what would have been expected in the number of casualty crashes across all treated areas.

New Zealand is another country where photo radar has been extensively used in traffic speed management. Led by a one-month amnesty period (no fines levied), the New Zealand photo radar program commenced on November 15, 1993. Altogether, fifteen mobile cameras were deployed at more than 800 sign posted sites. Deployment of close to 4,000 camera hours per month was reported in 1994, indicating a high level of program delivery (New Zealand Traffic Camera Office, 1996).

The implementation of the photo radar program in New Zealand was followed by a reduction in traffic speed and collisions. Based on a one-year simple before and after comparison between 1992-93 and 1993-94, the total number of traffic injuries was reduced by about 5% and the total number of traffic collisions by about 3%. The validity of the study is questionable however, given the lack of control implemented in the analysis. The study did not control the regression to the mean effect nor time effects due to changes of influential variables.

Limited uses of photo radar in the United States have been reported and even less information is available on the effectiveness of these programs in reducing traffic collisions and casualties. Two examples of the applications are from Paradise Valley, Arizona and Pasadena, California.

Paradise Valley, Arizona deployed the Traffic Monitoring Technologies (TMT) system. It was reported (Lynn, 1992) that speeds on most roads in the town were markedly decreased but safety impacts were not the subject of the report. The program has survived a constitutional challenge and several state law challenges.

The operation of photo radar equipment in the city of Pasadena, California started in 1988, following a 1987 testing project (Lynn, 1992). As in Paradise Valley, Pasadena adopted the TMT systems. Unlike Paradise Valley however, the photo radar program was not viewed as a success due to an apparent lack of understanding and co-operation on the part of various stakeholders (Lynn, 1992). The city did not witness an improvement in traffic safety, after an increase in hours of enforcement.

Photo radar devices have been tested and implemented in a number of Canadian jurisdictions. Reports of three applications were found from Calgary and Edmonton in Alberta and selected major highways in Ontario. Calgary introduced its first Multanova photo radar devices in the early 1990s. It added a second photo radar unit in 1994. Since the deployment of the devices, the city has experienced an apparent reduction in traffic speed and collisions. Measured by the 85^{th} percentile speed, Calgary Police Service (1996) reported speed reduction at selected deployment sites. There was also a continued decline in the total numbers of collisions, coinciding with the photo radar program. No controlled analysis was provided, however. Consequently, the observed continued reduction in collisions cannot be attributed solely, or even in part, to the photo radar program.

Edmonton started its photo radar program in March 1993. The program deployed photo radar units at over 300 locations in the city as of April 1995. The site selection criteria include 1) high collision area, 2) posted speed limit of 80 km/hr and 3) location too risky for conventional radar enforcement. Church (1995) analyzed the impact of the photo radar on driver behaviour. Simple pre-post comparison of speed measures was used as the basic study design. No control was employed in the analysis except the consideration of the influence of weather and construction.

The analysis revealed a decrease of between 2 and 4 km/h in average speed at the selected locations. The author concluded that photo radar in combination with other factors increased the perceived risk associated with exceeding the speed limit, which produced the reduction of speed.

Ontario started a photo radar pilot project in August 1994. The purpose was to assess its impacts on traffic speed and road safety. Four mobile photo radar cameras were deployed on designated sections of major Ontario provincial highways. Speed loop data from three photo radar sites and three comparison sites were collected on a continuous, 24-hour basis. An impact evaluation after four months of operation revealed that the mean speed of traffic at the photo radar sites was reduced. Speed reduction was found at both the photo radar sites and the comparison sites, but the decrease was substantially greater at photo radar sites (Safety Research Office, 1995).

The rate of speed reduction also varies with other road and traffic variable. Greater reductions were found on highways of higher posted speed limits, of higher real traffic speed, and of larger traffic volumes. Although these other uncontrolled factors in this study could have influenced the change of traffic speed, the additional reduction in speed was attributed to the photo radar program. No report was found of the traffic safety effect of the photo radar program as it was applied in Ontario. This is probably due to the short-lived nature of the program. The Ontario photo radar project was cancelled soon after the election of the conservative government in the province in 1995 (Safety Research Office, 1995).

Cooper (1988) assessed the effectiveness of a Multanova Photo Radar Unit in reducing traffic speed in the city of Victoria, BC in March 1988. Three sites, covering playground, school zones and regular city streets were selected. The study found a reduction in traffic speeds at the study sites both when the use of photo radar and only the "threat" of use of the detection devices were in effect. No constant, beneficial effect on collisions was discerned in this evaluation. The author cautioned that a longer-term deployment and investigation would be required to assess properly the photo radar's capability in reducing traffic collisions.

In a pilot study of the photo radar program in BC in 1994, Pedersen and McDavid, J.C. (1994) also investigated the traffic speed effect of the photo radar program. Using a time-series comparison site quasi-experimental design, they concluded that vehicle speed was significantly reduced after the introduction of the photo radar program. The authors, however, cautioned that the variables unique to the officers implementing the photo radar units were not controlled in the analysis. Therefore, the reduction of speed should not be attributed only to photo radar technology itself. Again, due to the short time pilot nature of the program, no analysis of traffic safety impact was reported.

A limited number of studies have been found to address the corridor-specific effects of photo radar programs. Elvik (1997) conducted a before-after study of the effects of the program on collisions, controlling for general trend and regression to the mean of a Photo Radar program introduced in Norway in 1988. Empirical data from 64 road sections were collected and Bayes method was used in model construction and analysis. The study found a statistically significant 20% reduction in injury collisions associated with photo radar. Further analysis revealed that the effect varied with prior frequency of collisions at different sites. The higher the number of collisions before the program, the greater the effect. As insightfully pointed out by the author, the study did not investigate the change in speed as an intervening effect of the program. Nor did it address the hypothesis that drivers slow down at the photo radar site, only to speed up after passing the site, causing migration of collisions to the next section of highway.

London Accident Analysis Unit (1997) conducted a before-after study on the West London Speed Camera Demonstration project. The study examined the collision data on trunk roads three years before and three years after the introduction of the project. The remaining roads in the area were used as the control sites. The studies revealed an 8.9% reduction in total collisions and a 12.1% reduction in fatal and serious collisions attributable to the photo radar program. The study is limited by its design. No control for regression to the mean effect was implemented. Limited control for passage of time effects was introduced by the use of the other roads in the area as comparison groups.

Rogerson, Newstead, and Cameron (1994, phase 3) assessed the localized influence of the photo radar program in Victoria, Australia. To alleviate the potential contamination of overlapping alcohol-related interventions, the study used low-alcohol-time collisions as the outcome measure. The study did not find clear evidence of a localized safety impact of the photo radar program. The only significant effect was found at high alcohol hours, when the program is confounded with enhanced drinking-driving enforcement. There was no reduction in the number of collisions on the actual day when the speed camera was used or on the following 6 days within a 1-km radius of the deployment sites.

Recently, Oei (1998) reviewed studies of speed enforcement (conventional and electronic), its effects on speed behavior and traffic safety and the potential halo effects based on studies in Europe, Australia and North America. At the location or route level, Oei concludes that traffic speed is reduced substantially as a result of speed enforcement. However, the evidence for a safety effect is sparse and unreliable, due to the lack of control for regression to the mean, the time effect, and the large random variation inherent in collision counts. It appears that further research on speed, safety and the halo effect of photo radar programs, using stringent methods and sufficient data, is needed.

Summary

In summary, photo radar as an automated speed enforcement device has been tested and implemented in a number of jurisdictions. Numerous studies have been conducted to assess its impact on traffic speed and safety at both the jurisdictional (the macro) or corridor (site-specific) levels. The majority of studies suggest that photo radar can be effective in reducing traffic speed at the photo radar deployment sites. Few studies have been found to assess drivers' speeding behaviour at non-photo radar sites, which constitute a key link in the general deterrence framework and should be the final instrumental goal of the program.

Moreover, limited studies have been found in the review, which assessed the traffic safety impact of the program. The few safety impact studies are of qualified validity, due to the lack of controls in study designs. Consequently, the interpretation and the use of the existing knowledge of the effectiveness and efficiency of photo radar program require caution and discretion. Given that speeding causes tremendous human and economic consequences and society needs more effective and efficient ways, such as photo radar program, to control driving behaviour on public roads, and that reducing traffic speed may have negative impacts to society and photo radar enforcement as a control mechanism, touches upon sacred values of liberty and privacy of so many citizens in a democracy, stringent scientific studies to further the knowledge of the overall inputs and impacts of the program is required. It is the hope of the author, that the accumulation of comprehensive and objective information on the program could improve the status and credibility of knowledge and that the knowledge is used to inform the debate on the overall value and the desirability of photo radar program to individual, institutions and the society as a whole.

COST-BENEFIT ANALYSIS

Very few reports were found in the literature of cost-benefit analysis as it is applied to traffic safety. Even fewer papers were obtained which specifically address economic evaluation of photo radar programs. This is not totally unexpected, given that photo radar speed enforcement technology is still relatively new, and that its physical effect on traffic safety has not been fully established. This section extends the literature review of available reports of cost-benefit analysis to the field of transportation in general, although special attention is given to traffic safety, including photo radar programs. To facilitate the discussion, a survey of the history and the theoretical foundation of cost-benefit analysis is first conducted and presented below.

Theoretical foundation

Theoretically, cost-benefit analysis is rooted in applied welfare economics (Layard, 1972; Mishan, 1988). Welfare economics is concerned with the evaluation as to how the workings of the economic system lead to desirable results in reference to generally accepted social goals (Clower, Graves, & Sexton, 1989). Welfare economics usually assumes three desirable social goals: 1) maximum freedom of choice for individuals, consistent with rights for others; 2) maximum satisfaction of wants, which requires use and allocation of resources in such a way as to permit the maximum per capita real utility (often proxied by income), and 3) a pattern of distribution of income regarded as equitable in terms of the standards of contemporary society (Clower, Graves, Sexton, 1989).

However, as a normative theory, welfare economics has not been able to provide a comprehensive framework to incorporate all generally accepted social goals of contemporary societies (Dworkin, 1980; Posner, 1981; Arrow, 1984; Williams, 1992). Efforts such as the attempt to construct social welfare functions faced complex ethical and logical difficulties (Harberger, 1978; Just, Hueth & Schmits, 1982; O'Connell, 1982). At present, in comparison to other areas in economics, welfare economics is less developed and still evolving. Many theories in this area are subject to subjectivity and, consequently, controversy. Please refer to Harberger (1978) for a critical and comprehensive review in this regard.

Given the limitation of theoretical development, cost-benefit analysis, as an application of welfare economics, is built mainly on four derived or related principles: consumer sovereignty, welfare maximisation, valuation of goods according to willingness to pay, and neutrality with respect to distributive outcomes (Elvik, 2001). Most cost-benefit analysis uses the potential Pareto improvement rule, i.e., Kaldor-Hicks criterion, a one-dimensional efficiency rule, in evaluating proposed projects. The Kaldor-Hicks, potential Pareto efficiency rule adopts policies that have positive net benefit, regardless of whether compensation from the gainer to the loser will actually be realised.

Cost-benefit analysis is originated in the United States (Nas, 1996). Formally, it became part of the US Flood Control Act of 1936. In 1950, the Federal Interagency River Basin Committee report established it as a standard guide for water resources planning practices. The most systematic use of the method occurred in the 1960, when the Planning, Programming, and Budgeting System (PPBS) was introduced in the US Department of Defence (Nas, 1996).

Since the 1960s, the U.S. Office of Management and Budget has been instrumental in integrating the principle of CBA in the decision-making process in US federal agencies. Circular A-94 from OMB clearly states the purpose of CBA to be the promotion of efficient resource allocation through well-informed decision-making by the Federal Government. It stresses that the guideline to be followed in all analysis submitted to OMB in support of legislative and budget programs (Nas, 1996).

Similar to the U.S., in the 1960s, economists in many English-speaking countries had strongly advocated the use of cost-benefit analysis. But growing attention has been paid in the subsequent years to its shortcomings and limitations. Although new theories and practices are being developed in recent years to incorporate equity and compensatory concerns (Brent, 1996), cost-benefit analysis does not yet lend itself well in addressing issues relating to competing, and sometimes conflicting, values other than economic efficiency. Most cost-benefit analyses explicitly limit their scope to economic efficiency, leaving the task of combining and weighing all relevant information and concerns in policy making to decision-makers and/or to political processes (Williams & Giardina, 1993; Fuguitt & Wilcox, 1999). The method by itself does not provide a comprehensive rational framework for public decision-making.

Cost-benefit analysis, as a normative theory and practical tool, can be used to assist public decision-making in three main areas: regulation, taxes and subsidies, and public production (Layard, 1972; Brent, 1996). Although in the past the applications are mostly concentrated in public production, more and more applications are found in regulation, and taxes and subsidies over time.

Many scholars have described and/or defined cost-benefit analysis (Prest & Turvey, 1965; Mishan, 1988; Elvik, 2001). In an early study, Prest and Turvey (1965) defined cost-benefit analysis as "a way of setting out the factors which need to be taken into account in making certain economic choices". These choices refer to public decision making with a societal perspective. Choice is about maximisation. Based on Prest and Turvey (1965), the aim of cost-benefit analysis is to maximize the present value of all benefits less that of all costs, subject to specified constraints.

Eckstein (1961) classified the constraints into categories. The main categories in his scheme include physical constraints, legal constraints, administrative constraints, budgetary constraints, and distributional constraints. Physical constraints refer to production functions. One particular input may be in totally inelastic supply, or two projects may be mutually exclusive. The legal constraints refer to the legal framework under which the society operates. In the Canadian context, individual rights and freedoms under the Constitution should always be considered and protected when designing government intervention programs.

The administrative constraints relate to what can be handled by the capacity of the organization. Overstretched, a sound and promising program can turn out to be a failure due to the inadequacy in administration. The budgetary constraints refer to the fact that decisions are taken within the existing budgetary limitations. They are of special relevance in the present fiscal and political conditions facing governments in both the developed and developing countries. Few parties or governments would like to run the risk of political retribution by increasing taxes, even if optimisation can be demonstrated with extra funds.

The distributional constraints stem from the fact that government interventions produce gainers and losers. The lack of compensation between the groups raises issues of equity or fairness. This issue introduces a different dimension into cost-benefit analysis, which cannot be easily accommodated within efficiency considerations. Thorough exposition of the issue is beyond the scope of this work. In theory, two approaches, weight and multi-dimensional analysis, could be used to release this constraint. However, in practice, the majority of cost-benefit analysis adopts the Kaldor-Hicks criterion, an explicitly defined condition, keeping the analysis practical and manageable.

More recently, Fuguitt and Wilcox (1999) described cost-benefit analysis as: "a useful approach to assess whether decisions or choices that affect the use of scarce resources promote efficiency". In considering a specific policy and relevant alternatives, cost-benefit analysis involves systematic identification of policy consequences, valuation of social benefits and costs of consequences, and application of the appropriate decision criterion". In Canada, the Treasury Board Secretariat has issued guidelines for the use of CBA in the appraisal of government programs. The guideline simply defines CBA as a procedure that evaluates the desirability of a program or project by weighing the benefits against the costs.

Steps in conducting cost-benefit analysis

Procedurally, cost-benefit analysis can be broken down into discrete, however, interrelated steps (Drummond, 1984; Boardman et al., 1996; CCOHTA, 1997; Treasury Board of Canada Secretariat, 1998; Fuguitt & Wilcox, 1999). Examining various classification schemes in the literature, a list of common and essential steps are identified and listed in Table 2.1.

Table 2.1 Steps in conducting cost-benefit analysis

1	Demonstrate effectiveness
2	Decide whose benefits and cost count (standing)
3	Determine the perspectives to be considered
4	Select the portfolio of alternative projects
5	Catalogue potential (physical) inputs and impacts, and select measurement indicators
6	Predict quantitative impacts over the life of the project
7	Monetize (attach dollar values to) all impacts
8	Discount for time to find present values.
9	Sum: add up the benefits and costs
10	Perform sensitivity analysis.
11	Recommend the alternative with the largest net social benefits.

Some of the steps in Table 2.1 are rich in concept. These steps are discussed further in detail in the following subsections. Two steps in the Table: adding up the benefits and costs, and recommending the alternative with the largest net social benefits, are self-explanatory. They are excluded from further deliberation.

Demonstrate effectiveness

A prerequisite of a meaningful cost-benefit analysis is the effectiveness of the program. Effectiveness is used in this study interchangeably with impact, which is the difference between what happened with the program and what would have happened without the program. If a program does not make a difference in its intended goals and objectives, its efficiency assessment through a cost-benefit analysis becomes irrelevant and unwarranted on cost-benefit grounds. As

Drummond (1984) put it: "If something is not worth doing, it's not worth doing it well." Consequently, a procedure to assess the effectiveness (impacts) of a program should be identified and implemented prior to (or concurrently with) any well-intentioned and well-designed cost-benefit analysis.

The approach to establish program effectiveness depends on the subject area of concern. In relatively matured areas of scientific inquiry, the effectiveness of a program could be obtained by systematic literature reviews. Meta-analyses in various subject areas, such as in medicine, have generated an inventory of convincing evidence of program effects for a wide range of programs. These resources should be exhausted before new, original, however repetitive, studies contemplated.

Other areas of scientific inquiries can be new and the knowledge accumulated in the area lacking. Stringent studies, employing all available data and the best designs should be conducted to estimate the effectiveness of the intervention, prior to its cost-benefit analysis. However, no matter how well the study is construed and implemented, caution should be exercised in the use and interpretation of the results. No one single study should be treated with absolute confidence in its results. Only the accumulation of studies can cross-validate study results and solidify knowledge. For a single, however, comprehensive study covering both effectiveness and efficiency, a sensitivity analysis should be incorporated to test the robustness of conclusions. The sensitivity analysis is further elaborated in the sensitivity analysis subsection later.

Decide whose benefits and costs count (standing)

Cost-benefit analysis inherits its societal perspective from its social welfare economics origin, wherein society tends to be defined globally (Fuguitt & Wilcox, 1999). The issue of standing is important, as it can materially affect the results of a cost-benefit analysis. The potential Pareto improvement as a criterion to judge the merit of a policy is based on the aggregates of the net benefits of the people who are presumed to have standing.

There are three main issues in defining standing: the jurisdictional definition of society, the exclusion of socially unacceptable preference, and the inclusion of the preference of future generations. Current thinking of society is comprehensive, towards a global perspective. At minimum, a national standing should be used in cost-benefit analysis. Sensitivity analysis should be constructed if there are concerns (Boardman, et al., 1996).

Socially unacceptable preference should not have standing as they are against the widely accepted social values as demonstrated in culture and formalized in legal systems. For example, convicted criminals, who benefit from trafficking drugs, should not have standing in cost-benefit analysis. The dominating social value should be treated as a social constraint, similar to physical constraint and budgetary constraint, limiting the optimisation space of cost-benefit analysis (Trumbull, 1990).

The inclusion of the preference of future generations is a legitimate claim in theory. But it should not be a major issue in practice in most of the cost-benefit analysis. Their preference is partly represented by current generation and partly by potential improvements in technology and resources. However, guard should be always in place so that irreversible environmental and other long-term negative consequences are not inflicted by current generation (Daly & Cobb, Jr., 1989).

In practice, standing does not seem to have received its appropriate attention. There is no consistency in government guidelines in cost-benefit analysis in addressing this issue. The Treasury Board Secretariat of Canada guidelines for cost-benefit analysis (1998) suggests that standing issues be clarified at the beginning of the study. The Transport Canada guidelines (1994), however, do not address the issue of standing, relying on the analysts to infer its national perspective. The current practices as reflected in published reports in cost-benefit analysis in transportation and traffic safety tend not to specify standing (Ran, et. al., 1997; Lacey, Jones & Stewart, 1991). As a matter of fact, various different standings, the government, the province, the nation, or the globe are reflected explicitly or implicitly at different places in various reports.

Determine the perspectives to be considered

Although closely related, perspectives are different from standing substantively. Standing defines whose costs should count in a cost-benefit analysis from a social perspective, while perspective differentiates the points of views from various stakeholders, institutions, and the society as a whole. For instance, criminals may not have standing, but their perspective might be important to show if we want to know how they will respond to some crime-prevention program. Although cost-benefit analysis should always report from a comprehensive societal perspective (CCOHTA, 1997), other perspectives, such as the government or funding organizations, when the government does not fund the program, are legitimate, and sometimes important perspectives, worthy of assessment.

For the current study of BC photo radar program, which is initiated by the BC provincial government but funded directly by the Insurance Corporation of British Columbia, the perception, opinions, and the behaviour of ICBC, the funding agency, is of great interest. Apparently ICBC has its own unique perspectives of the program. To address this issue, this analysis is to assess the cost and benefit of the program from both the societal and ICBC perspectives. It was the hope of the author that the inclusion of the ICBC perspective would enrich the current study and provide AN explanation of the potential differences in opinion as to the worthiness of the BC photo radar program.

Select the portfolio of alternative projects

Cost-benefit analysis is in essence a comparative framework for selecting among alternatives. It requires first of all the justification and specification of options, within constraints, from which the most efficient project could be selected. It seems only logical then that all feasible options should be identified and compared. Only when all the options are considered, could the best project in terms of optimal resource allocation be possibly identified.

It should be noted however that full optimization, in terms of ranking all government policies in terms of efficiency is impossible and probably not always desirable, especially for ex-post cost-benefit analysis. Policy priorities are derived legitimately from political processes. It may not be unreasonable to restrict the comparisons of projects in terms of efficiency in a specific area of priority concern.

In practice, not many options are often considered in the selection of alternative projects, especially in ex-post studies. These are probably due to financial, technical, or time constraints. Transport Canada (1994) suggests a baseline approach. A base-case provides the common point of reference against which to measure the incremental benefits and costs of other options (Transport Canada, 1994).

The basis for the evaluation is often the status quo. The state of affairs of "status quo" however, should be modelled appropriately. Things would still change had the project not been implemented. The expected state, as opposed to that in the before implementation period, should be used for the baseline for the comparison to assess the merit of the option concerned. The base-case is, in effect, the "no policy change" case, not the "no change in state" case.

The base-case should be designed to make the most out of existing facilities. It should reflect the action that management and users would likely take in response to the deficiencies/opportunities identified in the problem statement. Adjustments to present operations or facilities, consistent with ordinary managerial discretion in maintaining efficient operations, should be assumed.

Reported studies in transportation and highway safety varied with the extent to which they identify multiple options. Although some researchers and institutions use more than 2 options (Ickovich, 1998; Bein, 1996), many other cost-benefit analyses, especially the ones of ex-post nature, are based on comparisons between a proposed project and the baseline status quo (Hadrovic & Weiss, 1986; Moses & Savege, 1997; Lacey, Jones & Stewart, 1991). The reason for the discrepancy could be inferred from the nature and time of the study. Ex-ante cost-benefit analysis allows the analyst to survey and investigate the potential alternatives, while ex-post study is to assess the efficiency, as in cost-benefit analysis, of a fixed, implemented, program.

Catalogue potential (physical) input/impacts and select measurement indicators

As a comprehensive comparative framework, an appropriately designed CBA strives to identify and assess all meaningful categories of input and impacts. Transport Canada guidelines (1994) recommend typical input categories for highway improvement and traffic law enforcement projects. It classifies project inputs based on the four main phases of a project's life: planning, development, operational, and post forecast (terminal value). The project-related costs in planning phase include all costs incurred prior to procurement or construction. Typical costs are those for planning, project engineering and project design. These include costs associated with any project teams.

Transport Canada (1994) suggests that the potential costs associated with Construction and Development Phase include:

- Land acquisition or opportunity costs of land used;
- Construction costs. Include all such costs, whether incurred for the construction of a new facility or for the modernization or refurbishment of an existing facility. Note that this should include any costs to expand or refurbish a building necessitated by the implementation of a project.
- Equipment purchase and/or lease, including spares;
- Vehicle purchase and/or lease;
- Project-related training. Include initial training costs for staff, for example, to learn how to operate new equipment. This should include not only the costs of the training programs but also related travel, accommodations and productivity forgone (i.e., staff labor costs);
- Other capital expenditures. Include all capital not elsewhere accounted for (e.g., general furnishings);
- Transition costs, including those resulting from disruptions during the implementation of the project;

- Construction management;
- Contingencies; and
- Costs to other parties, including capital and training necessary to implement the project.

Transport Canada (1994) suggests that the project-related costs incurred over the operational life of a project include:

- Direct operating costs. The labor component includes regular salaries and wages, overtime, bonuses, allowances and fringe benefits;
- Maintenance costs;
- Overhead and other supporting costs;
- On-going training;
- Periodic capital outlays, such as to mid-life refits over and above regular maintenance; and;
- Operating and maintenance costs incurred by other parties (e.g., snow removal on new access roads).

The last component, i.e., the Post Forecast Phase, represents the process to determine the terminal value of the project. When the investments contained in the options do not have the same operational life, an adjustment is made to take account of the fact that one or more options have value extending beyond the analytical period. This value is the residual value of the assets involved. Typically, it is reflected as a reduction in costs in the final year of the analysis. A market price for the asset at the end of the analytical period is the preferred basis for valuation. In many cases, this price is not available, leaving the net book value of the asset as the only practical measure of residual value.

A better approach may be to use annual costs for all capital assets, with the "payments" calculated at the discount rate and over the particular asset's expected life. This method would provide some economic basis for estimation, as opposed to using the accounting book value, which may not reflect the market value at all.

With regard to impact categories, Transport Canada (1994) classifies program intended effect, the main program benefits, into three major categories: safety, efficiency, and productivity. These terms can be operationally defined as:

- Safety: Society benefits from a reduction in the number and severity of accidents;
- Transportation efficiency: Society benefits from a reduction in the resources consumed in transportation. Such benefits accrue to the operators of transport services and the users of transport services (e.g., passengers, shippers, consignees); and
- Productivity gains: Society benefits from improvements in the efficiency and/or effectiveness of government operations.

There are also environmental impacts associated with transportation projects. Sometimes, they are the main intended benefits. Other times, environmental benefits follow from the intended safety benefits of a project. For example, the introduction of Vessel Traffic Services in a particular waterway would reduce the risk of accidents, thereby lessening the possibility of a major oil spill from a tanker.

In addition, there are other benefits associated with such difficult-to-quantify intangibles as comfort, convenience, aesthetics, travel time predictability and contribution to social objectives (e.g., national unity).

In reality, all the potential impacts are not identified nor quantified in transportation cost-benefit analysis. Blanchard (1996) reviewed and summarized current practice in Canadian jurisdictions in cost-benefit analyses conducted over the period 1982 to 1993. Table 2.2 listed the impact categories in these studies, which bears relevance to the present evaluation.

Table 2.2 shows that at present, the main effects accounted for in cost-benefit analysis include highway transportation time cost, vehicle operating cost (VOC), traffic safety, environment and travel enjoyment. Table 2.2 indicates that environment impact and travel enjoyment, although identified, are not usually quantified in current practice. This is mainly due to the lack of data and consensus in methodology (Blanchard, 1996).

Table 2.2 Impact Categories in Transportation and Highway Projects (1)

CATEGORY	SUB-CATEGORY	DATA USED
Highway transportation cost - Time	Business	x
	Non-business	x
Highway transportation cost - VOC (2)	Fuel and oil	x
	Labour	x
	Maintenance	x
	Depreciation	x
Highway safety	Fatality	x
	Injury	x
	Property damage	x
Environment	Emission	
	Noise	
	Habitat	
	Vibration	
	Urban sprawi	
	Highway runoff	
	Aesthetics	
	Socio-economic	
	Wildlife	
	Depletion of non-renewabie resource	
	Highway product life-cycle management	
Travel enjoyment	Improved aesthetics	
	Reduced stress	
	Improved ride	

Predict quantitative impacts over the life of the project

Accurate estimation of program impact is the prerequisite of a valid cost-benefit analysis. Without accurate estimate of program effects, cost-benefit comparison is groundless and possibly misleading. Estimating physical impact of a program is arguably the most technically demanding part of a comprehensive evaluation. The methods and procedures in estimating impacts depend on the timing of the study, relative to the stage of program development and implementation.

For ex-ante cost-benefit analyses, the impacts over the life of the project have to be predicted, as the planned program has not yet been implemented and the results are apparently not yet observable. The prediction of impacts is often difficult, given that, in most of the cases, a host of factors, in addition to the planned project, will affect the outcome of the program (Graham, 1981). Often assumptions are made to make analysis possible. Risk assessment and management techniques, such as sensitivity analysis, in that case, should always be used to estimate the robustness of the study conclusions and to explicate the possible scenarios and consequences, had the major assumptions not materialised (Boardman et al., 1996).

For in-medias-res or ex-post studies, the concerned program has been partly or wholly delivered and the physical impacts, if there are any, should be potentially observable. In these cases, to the extent possible, project impacts should be measured and assessed, as opposed to projected or modelled, in a cost-benefit analysis. The estimation of program physical effects requires a thorough understanding of the particular field of study and the relevant research methodologies. Each evaluation is idiosyncratic in this respect. For the present study, these issues are addressed in the methods section in each of the chapters for the province-wide and the site-specific studies.

Monetize (attach dollar values to) all impacts (Valuing input - opportunity cost)

Almost inevitably, the implementation of public policies requires the use of resources, the program inputs. These inputs, if not used for the particular policy under consideration, could be used to produce other goods or services. Consequently, the resources used as inputs for government policies should be valued at their opportunity cost, the value that could be realised in the next best use. Opportunity cost measures the value of what society must forgo to use the input to implement the policy or program. Opportunity cost is the theoretically appropriate method to value inputs (Boardman et al., 1996).

Theoretically, the area under the market supply curve represents opportunity cost of the input under valuation (Mishan, 1988). If the market is efficient and the government purchase is small relative to total market output, then the government expenditure for the input approximates its opportunity cost. For an efficient market with noticeable market price effects or for an inefficient markets, the opportunity cost of inputs is complex and estimation methods have to be adjusted individually. For example, in factor markets in which supply is taxed, direct expenditure overestimates opportunity cost. In factor markets in which the supply is subsidised, expenditure underestimates opportunity cost. In factor markets exhibiting positive externality of supply, expenditures overestimate opportunity cost. In factor market exhibiting negative externality of supply, expenditures underestimate opportunity cost. The general rule in these cases is that opportunity cost equals direct expenditure on the factor input plus its impact on the changes in social surplus occurring in the factor market (Boardman et al., 1996).

Transportation Canada (1994) claims that the direct expenditure of a project option usually reflects the value of the resources (e.g., goods and services, labour and capital) consumed in its implementation in transportation related projects. However, Transport Canada (1994) requires that careful consideration be given in valuing opportunity cost under three circumstances. First, many projects consume resources that are not reflected in incremental cash expenditures. Typically, these consist of existing resources (people, facilities or equipment) for which there would have been a valuable alternative use. Use of these resources implies a lost opportunity to put them to such other uses.

Second, some of the resources consumed in a project have been subsidized. Consequently, the prices of these resources do not reflect the true social opportunity cost. In all such cases, the subsidies have to be estimated and added to the prices.

Finally, sales or excise taxes may form part of the expenditures to be incurred in a project account. Such taxes, including the federal excise tax on fuel, provincial fuel taxes, provincial sales taxes and the GST do not represent resources consumed in a project. Accordingly, they should be excluded from project-related costs (Transport Canada, 1994). This suggestion is supported by studies in the fields (Gan, 1995), and echoed in BC Ministry of Transportation and Highway cost-benefit guidelines (1997).

Monetize all impacts (Valuing output - willingness to pay)

Theoretically, willingness to pay method is the appropriate method to value the impacts of government policies. For goods and services that are traded in a well-functioning market, the demand curve estimated from market studies could be used to assess the willingness to pay value of marketed goods (Fuguitt, 1999).

For goods and services not traded in the market, willingness to pay measures as reflected in consumer expenditure and consumer surplus are no longer available. Other inferential methods have to be developed and used. Two main approaches are used in current practices, inferring the value from observed behaviour - the revealed preference approach, or inferring values from public surveys - the contingent valuation approach (Fuguitt, 1999).

The observational approach comprises a number of methods in valuing various aspects of impacts. These include using revenues as the measure of benefit, market analogy method, intermediate good method, using differences in asset values, the hedonic pricing method, travel cost method, and defensive expenditure method (Boardman et al., 1996). For the present study, the most relevant applications of the revealed preference approach are the valuation of time and human life. For the valuation of time saved due to improvement of transportation and highways, an obvious analogy is the labour market, where people sell their time for wages. In theory, the social value of an additional hour of work equals the wage rate. Furthermore, all other things being equal, when people can choose the number of hours they work, and there is no unemployment, the wage rate (net of tax but including benefits) also equals the marginal value of their time. In other words, the value of an additional hour of leisure to the person equals the wage rate.

In reality, people are unlikely to be able to choose the number of hours they work and there is unemployment. The assumption that people in general would be willing to pay the market rate of their wage to save an hour in travelling or waiting in line is very strong. Weighted averages between the work and leisure hours seem to be more plausible to assess time value in transportation study context. Consequently, weighted-averages of time values are estimated in various jurisdictions and often used in cost-benefit analysis in transportation and traffic safety at present time (Transportation Canada, 1994; BC Ministry of Transportation and Highways, 1997).

With regard to life saved, the market analogy principle gives rise to three applications: the forgone earning approach, the consumer purchase studies, or the labour market studies method. The forgone earning approach is based on the same logic for the estimation of value of time. If one accept that a person's value to society for one hour equals that person's wage, then one might reason that the value of that person to society for the rest of his or her lifetime equals the present value of his or her future earnings (Bergstrom, 1982).

This discounted future earnings method, or the human capital approach, as it is often referred to, is not appropriate for the valuation of human life in cost-benefit analysis for public policies for two main reasons. First, it is unfair ethically. It places very low values on children and seniors. It values women less than men. It ignores pain, suffering, and loss of quality of life (Miller, 1991). Second, it is unfounded methodologically. It does not account directly for the society's willingness to pay to avoid or reduce the risk of being injured or killed in traffic collisions. As noted by Boardman (1996), "There is no reason to suppose that a person's future earnings bear any particular relation to what he, or others, would be willing to pay to reduce the chance of his own death."

The consumer purchase studies method is based on willingness to pay principle. It imputes the value of life from the observed amount a person is prepared to pay to reduce an expected risk to life. An example can be found in the purchasing of safety equipment, such as air bags in new car sales. This method is better than forgone earning, thanks to its closer adherence to willingness to pay principle. The problem associated with this method is technical. Often it suffers from lack of information and selection-bias if information is available. It is conceivable that those who buy safety equipment tend to value safety and, therefore life, more than those who do not.

The labour market study method examines the additional wage people require in compensation for exposing themselves to greater risk of death on the job. In general the imputed value of life varies according to the initial levels of risk. A primary problem associated with this method is the unsustainable assumption that people are fully aware of the risk on their jobs. A secondary problem is related the assumption that the market is efficient, while in reality, bargaining powers of the union may impact the wages substantially, irrespective of the level of risk associated with the job.

The survey method, also called contingency valuation method, is not deemed as reliable as the revealed preferences in the observational studies. However, it supplements the observational studies, and more often than not, it represents the only way to estimate the value people assign to impacts attributable to social programs (Boardman et al., 1996).

In transportation and road safety, as in some other fields of studies such as healthcare, costs of highway crashes are often classified into direct cost and indirect cost. The direct cost includes crash clean up, injury treatment, property damage, and insurance claims process, including legal proceedings and public program administration (Ted Miller, 1991). The indirect cost includes forgone productivity, and sometimes, pain and suffering in a more comprehensive assessment framework.

There are three main approaches to value traffic collision cost, combining direct costs and indirect costs: year loss plus direct costs, human capital, and willingness to pay (Miller, 1991). The year loss plus direct cost method is a partial valuation of crash cost. It estimates the years of life lost to fatal injuries and the years of functioning lost to nonfatal injuries, in addition to direct cost. By doing that, it avoids placing a dollar value on lost life and functioning. But by the same token, it ignores quality of life completely. Consequently this method is limited to cost-effectiveness analysis as opposed to cost-benefit analysis (Miller, 1991).

Human capital costs, called economic cost by some people, is more than 200 years old (Miller, 1991). Arguably, the recent, more structured exposition of the concept was developed by Rice (1965, 1966, and 1967). In this framework, individuals are seen as producers and consumers of a stream of output throughout their lifetime (Rice, 1989). Injured persons are considered part of total societal impact; hence, the value of their decreased production and their decreased consumption is included in total cost. The resources consumed in response to any injury or crash that might otherwise be used for increasing the general state of wellbeing in society also are counted in total cost (Blincoe, 1994).

This human capital costing method is widely used in valuation of collision cost in traffic safety and in the judicial systems, the courts, to decide appropriate compensation for injuries (Rice, et. al. 1989; Blincoe, 1994). The method assigns a dollar value based on lost income over the lifetime.

Willingness to pay method includes the effects of injury on people's life, in addition to monetary matters. It is estimated by examining risk reduction values, the amount people pay for small decrease in safety and health risks. From the risk reduction value, the approach infers the amount of money a large group of people would pay for an expected saving of one anonymous life. As an example given by Miller (1991), suppose 10,000 people each spent $220 on an airbag that reduced their chance of dying in traffic collision by 0.01%. Then statistically, the total of $2,200,000 investment will save one life. Thus, this dollar figure of $2,200,000 is assigned as the value of an anonymous statistical life.

Note that the above calculation assumes a linear relationship between the probability of harm and its worth, when in reality the relationship is clearly asymptotic. As the probability increases, people will pay proportionately more to avert a bad event; the value of certain (or near-certain) is essentially infinite (bounded only by ability to pay). Simple linear extrapolations are therefore likely to be misleading. For example, a person who would pay $1 to avoid a 1/1,000,000 chance of death would very likely pay much more than $1 million to avoid certain death.

Over the past 30 years, more and more economists and institutions have become interested in, or turn to, the willingness to pay method in the valuation of traffic accident cost. The UK department of Transportation used willingness to pay method to value road accident fatalities since 1988 (Hopkin, J., M.; Simpson, H. F., 1995). Ontario conducted a comprehensive analysis of the social cost of motor vehicle crashes (Vokken, K., et. al., 1994). New Zealand also retained Miller for a thorough study of value of life in the New Zealand setting (Miller, 1991b).

Willingness to pay values can be inferred from observable behaviours or solicited by contingency valuation. The most used methods are wage premium for risky jobs; willingness to pay for safety equipment, willingness to use safety equipment/speed choice, and hypothetical survey methods. Miller (1989) summarised existing studies of different method across a number of jurisdictions, attempting to arrive at a common value of life with narrow variations. Using criteria such as the quality of the survey design, sample size, and the inclusion of appropriate risk variables, he reviewed 49 studies that estimated the value of life. Based on his review, 29 studies were deemed satisfactory. He re-estimated the values using a consistent discount rate and 1985 after-tax dollars.

Many economists and researchers have attempted to define and measure human life (Byer, 1980; Byrne, 1985; Harris, 1985;). In the area of transportation and traffic safety, Miller (1989) found that the value of human life estimated by various willingness-to-pay studies across many jurisdictions is convergent. The mean value of life across the 29 studies is $1.95 million, with a standard deviation of $0.5 million. He concluded that there is enough consistency across the studies to suggest that this mean is quite plausible. He points out that the evidence also suggests that individuals value life similarly whether the risk is largely voluntary (for example, auto driving behaviour) or involuntary (for example, the risk of a nuclear accident) and whether the potential death is slow and painful or sudden and quick.

Elvik (1995) recently surveyed the official economic valuation of traffic accident fatalities in 20 motorised countries. Part of the information was obtained from the Commission of the European Communities. For countries outside of the community, data were acquired from individual countries. Attempts were made to specify three components of the total economic valuation of traffic accident fatality: the value of lost output or lost productive capacity, direct cost, consisting mainly of property damage and administrative cost, and lost quality of life, which is the economic valuation of pain, grief, and suffering associated with death or stated differently, the value of living per se in addition to that generated by producing and consuming material goods. The cost figures are initially in Norwegian Kwoner in 1991 price level. The figure is converted to U.S. dollars, by multiplying a factor of 0.139, the estimated exchange rate in 1991.

The review reveals that seven out the 20 countries do not include lost quality of life in the total economic valuation of a traffic fatality. Consequently, there is a substantial difference between the values estimated in the two groups of countries. While the value of traffic accident fatality is valued at between $0.1 million to $0.5 million in countries where no valuation or valuation based on court awards through mainly human resource methods, the value of traffic accident fatalities is valued about $1.5 million when valuation of lost quality of life is based on road user willingness to pay method (Elvik, 1995).

In summary, it seems reasonable to conclude that at present there are different methods in valuing human lives across jurisdictions. Over time, there seems to be a trend to accept willingness to pay methods. However, some transportation experts reject the concept on theoretical soundness and ethical integrity ground.

Discount for time to find present values.

Discounting future benefits and costs to derive their present values for policy valuation is a relatively straightforward, mechanical process. However, the selection of an appropriate social discount rate is much more theoretically involved. The question of what is the appropriate social rate of discount is complex and continues to be the subject of controversy among professional economists (Lind, 1982). This section surveys the discounting methods in general and their applications in traffic safety particularly.

Social discount rates are problematic, mainly because they are derived from different theoretical foundations. The various discount rates can be traced back to two origins: the individual time preference principle and the opportunity cost of private investment foundation (Boardman et al., 1996). The individual time preference is rooted in the premise that individuals tend to prefer to consume more immediate benefits to ones occurring in the more distance future. The opportunity cost origin refers to the fact that one forgoes interest in real terms if one consumes now as opposed to investing the dollars for future use.

In practice, various social discount rates are used under different circumstances. They can be classified into groups. In an earlier study, Lind (1982) identified five categories of discount rates: the social rate of time preference, which is the rate at which society is willing to exchange consumption now for consumption in the future; the consumption rate of interest, which is the rate at which individual consumers are willing to exchange consumption now for a consumption in the future; the marginal rate of return on investment in the private sector; the opportunity cost of a public investment, that is, the value of the private consumption and investment forgone as a results of that investment; and risk, which is related to the degree to which variation in the outcome of a public project will affect variation in the payoff from total investment.

It was concluded (Lind, 1982) that if one were to establish the social rate of discount so that it properly reflected the differences in the opportunity cost and riskiness of different projects and so that it properly reflected the social rate of time preference as well, one would have to set a different rate for almost every project, and the choice of the social discount rate for each project would depend upon many things. There would be no single rate that could be applied to government projects, such as those required by Office of Management and Budget in the US and the Treasury Board in Canada.

It was also concluded (Lind, 1982) that in a world of perfect competition and certainty, social rate of time preference will equal the opportunity cost of capital measured by the marginal return on private investment and the consumption rate of interest and that both rates will equal the market rate of interest. Therefore, the market rate of interest should be used as the discount rate for evaluating public as well as private investment decisions.

However, the world is not certain and market is not perfectly competitive. How to choose a suitable discount rate is far from resolved (Lind, 1982; Boardman et al., 1996).

In the absence of perfect markets, Boardman (1996), in a more recent survey, summarised discount rates into four categories: Marginal social rate of time preference (SRTP), Marginal Social Opportunity Cost of Capital (SOC), Weighted Average Method (WAM), and Shadow Price of Capital (SPC).

The Marginal Social Rate of Time Preference (SRTP) is the rate at which society is willing to exchange consumption now for more consumption in the future. The SRTP measures tend to be lower than individual rate of time preference. The individual rate of time preference is estimated to be between 0 and 4 percent (Boardman et al., 1996).

The Marginal Social Opportunity Cost of Capital (SOC) is based on the argument that government and private sector compete for the same pool of funds. Efficient allocation of resources requires that, at the margin, investment in the public sector should yield the same return as investment in the private sector. The SOC can be approximately estimated by the marginal real before-tax rate of return on private investment. The average real, before-tax rate of return on investments during the 70s and the 80s was more than 10 percent.

The Weighted Average Method (WAM) is calculated in terms of the source of the resources that is used in a particular project. If the resources come entirely at the expense of current private consumption, then the marginal social rate of time preference is appropriate. If the sources of resources are entirely at the expense of current private investment, then the marginal rate of return on private investment is appropriate. In general, based on WAM, the social discount rate equals a weighted average of the SOC and SRTP in proportion to the source of the resources.

The Shadow Price of Capital (SPC) is based on the conception that all costs and benefits can be converted into their corresponding change in consumption and then use the marginal rate of time preference as the discount rate. This process involves finding the shadow price of capital, as the price of capital in terms of consumption. The shadow price of capital cannot be directly observed in a market but instead must be inferred.

A further consideration of discount rate stems from the propensity for individuals to be risk averse. The private sector has been clear on the principle that the cost of capital, corresponding to the discount rate in cost-benefit analysis, depends on the risk of the investment. The cost of capital depends primarily on the use of the funds, not the source (Ross, et. al., 1996). It is based on the premise that individual investors and firms are risk averse. They demand higher returns for riskier projects. The capital asset pricing model (CAPM) can be used as the basis to estimate the risks and returns of an asset, and therefore, can provide information to assist the determination the appropriate discount rate associated with a risky project.

However, as in the application of other theoretical work in defining social discount rates, the incorporation of risk considerations in the development of the social discount rate is hindered by practical difficulties. The CAPM model is primarily developed for a two-period time horizon. It does not provide assistance in calculating benefit and cost in long term project. Moreover, the risk factor is hard to estimate. This further limits its use in cost-benefit analysis given the time limits often associated with policy analysis and decision making.

As discussed in Bailey and Jensen (1972), the social discount rate in actual practice often diverges substantially from theory. Most practitioners realize that future costs and benefits should be discounted in some way. Standard practice ignores the distinction between increments to consumption and increments to capital, i.e., setting the shadow price of capital to one. For government projects, the social discount rates are often set by government agencies, although different opinions occur within government departments.

In explaining the different opinions in selecting discount rates, Boardman (1996) classified people working in government into three groups, the spenders, the guardians, and the analysts. In general, guardians, those who work in government central agencies, tend to view government expenditures as crowding out private investment; consequently, they tend to argue for a social discount rate approximating SOC, the rate of return on private investment. Spenders, who often reside in government line ministries/executive departments, view government expenditures as reducing current consumption, therefore, they tend to argue for a social discount rate approximating the marginal rate of time preference. As in most of the cases the people in central agencies control government finance, and influence decisions on government expenditure, government discount rates tend to be on the higher end of the spectrum derived from theoretical considerations.

For example, the U.S. government uses different social discount rates for government projects. The Office of Management and Budget (OMB) requires a 10% real rate for general public investment, taking a stance that public investment crowds-out private money therefore, social discount rate should reflect pre-tax rate of return on private investment. The Congressional Budget Office (CBO) recommends 2%, plus or minus 2%, for the social discount rate, based on the view that the marginal rate of time preference should be used as the appropriate discount rate. The General Accounting Office does adopt a more flexible approach, basing its discount rate on the real rate of interest on federal borrowing. This approach uses the cost of the source of the fund as opposed to the use of the funds.

Treasury Board Secretariat of Canada, as a guardian, has required, since 1976, that benefit-cost analysts use a social discount rate of 10 per cent 'real' per annum - that is, a 10 per cent discount rate applied to real dollars (constant, inflation-adjusted dollars). This rate is a stable one because it reflects an opportunity cost in the private sector where the average rate of return to investment (over the whole economy) changes very slowly over the years, if at all. The government's estimate of the social discount rate has been robust, despite some challenges over the years. Social discount rates as low as 7.5 per cent real and as high as 12 per cent real have been proposed and supported by various economists. Estimates by the Department of Finance, however, have consistently supported the 10 per cent real estimate of the social discount rate (Treasury Board Secretariat of Canada, 1997).

Transport Canada (1994), as a spending department, seems to argue that the 10% real discount rate should be adjusted downwards in the case of certain future benefits and other effects involving a significant degree of judgement in their valuation, namely fatalities, injuries and environmental damage avoided. The issue is one of intergenerational equity -- does a 10% discount rate result in too little weight being given in the investment decision to the value of these benefits and other effects to future generations?

Crown Corporations Secretariat and Treasury Board stipulated the discount rate in British Columbia. At present it is set at 8% (BC Ministry of Transportation and Highways, BC Transportation Finance Authority, 1997). Notwithstanding, BC Ministry of Transportation and Highways, and BC Transportation Finance Authority recommended that sensitivity analysis be conducted using 6% and 10% to examine the performance of the project under different assumptions. Theoretically, they believe a 6% social discount rate is more reasonable for transportation related projects in British Columbia (BC Ministry of Transportation and Highways, 1997).

There seems to be some agreement among theorists and practitioners that the guardians have inflated the real social discount rate. Daly and Cobb (1989) in their early book on environment and sustainable futures claim that the capital discount rate is unsustainable. If, they argued, cooked goose could provide a larger stream of benefits in the present than a stream of eggs would provide in a discounted future, then it is efficient to kill the goose that lays the eggs.

Houston (1995) summarised recent development in the theories of discount rate to conclude that the standard discount rates used in many Canadian and American jurisdictions are unreasonably high. These high discount rates could jeopardise sustainability, the environment, and intergenerational equity.

The above analysis suggests that discount rates at present are not objectively and uniquely defined based on theoretical considerations. Instead, they are prescribed by the government, especially by the "guardians" in the central agencies. These rates tend to be higher than most theories would suggest. In conducting a cost-benefit analysis, given its significance in affecting the results of the study, it is therefore paramount that the author select a reasonable range of discount rates based on theoretical considerations. At a minimum, sensitivity analysis should be built on all the plausible cases to estimate reasonable benefits and costs of the project concerned.

Perform sensitivity analysis

Sensitivity analysis should be included in all cost-benefit analysis. This is mainly due to three main concerns: the unpredictability of future event and program effects, the uncertainty affecting the valuation of the impacts, and the theoretical debate concerning the correct social discount rate.

Boardman (1996) describe three different ways to conduct sensitivity analysis: partial sensitivity analysis, the best and worst case analysis, and the Monte Carlo analysis. Each of the methods can be used for different purpose under different circumstances. In assessing the impact of different assumptions of the important parameters, the partial sensitivity analysis varies one factor at a time, assuming other factors remain constant. It is relatively easy to conduct and easy to comprehend for decision-makers. This is the most used method in current practice.

The drawback of the partial sensitivity analysis has to do with its inability to investigate the joint impact of total changes. More often than not, in reality, parameters change simultaneously and interactions of the effects are not estimable within the framework of partial sensitivity analysis.

The total variation method can be used to check for risks and consequences if contingencies of combinations of the factors put the program and the impact in its extreme cases. This method also generates the most likely cases people could envisage as the probable impact of the program, if the circumstance evolves and plays out as anticipated.

The problem of the extreme case analysis has to do with the lack of quantification of the probabilities of the extreme cases. If the worst case scenario has no practical probability in reality, then the concerns of this case and the effort to asses its impact will be worthless. Moreover, there are many scenarios that could determine the results of a policy. Brute force analysis with this method is both inefficient and impractical.

The Monte Carlo method uses modern computing techniques to simulate a program's net benefit as a function of all plausible variations of the parameters concerned. It is an improvement on the partial and extreme cases sensitivity analysis in two dimensions. It makes use of any available distributional information of the parameters and it derives a probability distribution of the net benefit of the project under consideration.

One of the major limiting factors for the use of the Monte Carlo method is the need to know the probability distribution for uncertain variables. Moreover, Monte Carlo analysis could be time consuming and confusing if many parameters are considered as variables or as parameters in model formulation. Analytical resources required may prove to be beyond the institutional capacity available for quick, field applications. However, if possible, effort should be made to conduct sensitivity analyses using Monte Carlo method, given its ability to generate fuller policy relevant information in risks and expectations.

Parameters selected in sensitivity analysis could differ, depending on the ex-ante, ex-post distinction. For ex-ante analysis, the uncertainty in the predicted program impact takes priority over other concerns, including the valuation of the impacts. This is due to the fact that the future is not reliably predictable and deviation of the prediction and the real future state could substantially alter the conclusion of the cost-benefit analysis. Consequently, a carefully designed sensitivity analysis could provide some confidence and comfort for decision-makers in rendering a decision, knowing that major risks are considered in the analysis.

In transportation and traffic safety, factors to be involved in sensitivity analysis vary with the nature of the projects. Transport Canada (1994) requires that the following risks should be checked in a cost-benefit analysis, using partial sensitivity analysis technique:

- **Demand**. Traffic forecasts are always key variables;
- **Prices**. For example, fuel prices have shown unexpected and significant movement in real terms several times in the past two decades;
- **Technology**. There may be unexpected advancements in vehicle, vessel, or information technology;
- **Logistics**. Changes may occur in trade flows, traffic growth and mix, scheduling patterns or modal preferences;

- **Technical performance**. For projects involving new or advanced technology, there may be a significant design risk associated with the estimates of cost and performance;
- **Cost estimates**;
- **Standard values**. These values include the value of fatalities, injuries and environmental damage avoided and the value of time savings;
- **Timing**. Changes in the implementation schedule of a project may have a material impact on project benefits and costs;
- **Discount rate**. Results should be tested using real discount rates of 7.5% and 12.5%;
- **Conditions for the accrual of benefits**. Assumptions affecting the accrual of benefits, including the behaviour of stakeholders or the presence of certain conditions or complementary actions, should be tested; and
- **Accrual of full benefits**. In some circumstances, it may be appropriate to test the sensitivity of results to the accrual of less than full benefits.

Sensitivity analyses on the final two factors is particularly important for dealing with uncertainties arising from conditional benefits.

In addition to these partial sensitivity analyses, a number of scenarios for the best-worst case analysis are also recommended. For example, an alternative scenario for a port development project might involve a major shift in global shipping patterns combining changes in traffic volume, traffic mix, vessel technology and fuel prices (Transport Canada, 1994).

A review of uncertainties may prompt a quick look back at discarded options to be sure that they have not regained their feasibility under some "what-if" conditions being considered.

The conclusions of a sensitivity analysis should focus on whether the selection of the preferred option is robust. If not, then the risk factors and the range of values or assumptions, which affect the selection of the preferred option, should be identified (Transport Canada, 1994).

Sensitivity analysis has been gradually incorporated into regular cost-benefit analysis in various sectors of government organizations (Beshers, 1997). However, a number of major cost-benefit analyses conducted for transportation and traffic safety projects did not include sensitivity analysis (Castle, 1976; Lacey, Jones, Stuwart, 1991; Moses, Savage, 1997; Ran, Yee, Lee, Dong, 1997). This is disheartening, given the significant role that sensitivity analysis plays in dealing with uncertainties and managing risks.

Existing cost-benefit analyses in traffic safety and photo radar programs

To a limited extent, cost-benefit analysis has been applied to set priorities for road safety measures in the last 30 years (Elvik, 2000). Over time, improvements have been made in the application of this analytical framework in two dimensions. More impacts have been incorporated into the analysis and extended studies were performed in the economic valuation of non-market goods, such as human lives. Notwithstanding strong and well-articulated criticism from prominent researchers in the field (Hauer, 1994), the use of the technique has been increasing. It is now being prescribed by many jurisdictions as a prerequisite for application for major transportation and traffic safety investment (Transport Canada, 1994; BC Ministry of Transportation and Highways, 1997).

However, as for transportation projects, quantification of impact in traffic safety programs is wanting. Numerous impacts, such as environmental impacts and travel enjoyment, are ignored due to the lack of theoretical framework or the difficulties of precise estimation (Elvik, 2000; Transport Canada, 1994). Substantially work need to be done before the method could be considered comprehensive in assessing transportation in general and traffic safety in specific, programs.

Extensive literature search on cost-benefit analysis in the area of traffic safety in general and in photo radar program in particular did not produce many sound studies. No standard method was observed in conducting cost-benefit analysis.

The following section reports on selected studies found from this review. Only studies with adequate information on methodology and data to allow an assessment on validity and reliability were included in the review.

The earliest qualifying CBA study found in the review compared the cost and benefit of a large-scale US traffic speed intervention. It assessed the impact of the Federal Law of 55-mph speed limit imposed on all rural and interstate highways across the United States, following the oil crisis in the early 1970s. Taking a societal standing, Castle (1976) assessed the speed and safety effect of the regulatory intervention and evaluated its economic consequences before and after its inauguration. The benefits included the values of gasoline saved, lives saved, and injuries averted. The cost was the value of the time lost as a result of the change of speed limit from 70 mph to 55 mph.

The study calculated the savings on gasoline by multiplying the quantity of gasoline saved, measured by the differences in the quantities of gasoline required to travel the save distance before and after the intervention, with the prevailing gasoline price at the time. The study assessed the value of lives saved and injuries averted by multiplying the estimated numbers of lives and injuries saved with their respective estimated social cost. The average hourly wage of a US worker was used in the valuation of time lost due to lower speeds attributable to the speed intervention.

The study revealed that the total savings of the speed limit change did not compensate for the cost due to the increase in travel time. The study found a cost-benefit ratio of 0.8 for the statutory intervention as a whole.

One of the major drawbacks in this analysis has to do with the way it handles temporal issues of cost and benefit over the life of the program. The study did not make allowance to discount and the study did not provide a net present value in its conclusion. The lack of discounting and standard reporting renders the study incomplete and the results incomparable to other studies.

A more thorough study was conducted by Australia Bureau of Transport and Communications Economics (1995). The study assessed the traffic safety effect of the Black Spot Program of the Australian Federal Government, using a before-after with control design. Eight types of engineering improvement of the road ways were included in the project, including new traffic signals, modified traffic signals, roundabouts, intersection channelisation, provision of medians, protected turning bays, shoulder sealing, and protected right turns (equivalent of left turn in Canada). A total of 254 sites were included in the study. The average of three years of data (1988-90) are used for the before period and the 1992 data was used for the after period.

The study revealed an overall reduction of collision and injuries across the study sites. It was estimated that the Black Spot program reduced the injury collisions by 46%, property damage only (PDO) collisions by 30%, and person injured by

61%. Among treatments, the high cost roundabout generated the highest traffic safety effect, while the shoulder sealing (paving) the least in terms of percentage reductions.

The cost-benefit analysis section of the study summarized the economic impact of the program from a societal perspective. The benefit of the program was measured in terms of collision cost avoided (Australia Bureau of Transport and Communications Economics, 1995). The willingness to pay approach was characterized as more theoretically sound but hard to implement. The human capital cost was classified by both collision type and collision severity. The cost by severity is listed as Fatal collision: $780,416; Hospitalization collision: $111,419; Medical treatment collision: $11,707; and Property damage only collision: $4,848.

Three impacts of the program on road users are listed: the net changes in crash cost, the operating cost, and travel time. Due to the lack of the data, only the change in crash cost was considered in the study.

The capital and recurrent cost are the economic or resource costs. Taxes and subsidies, as transfer payments, were therefore not included. The service times are between 5 to 30 years depending on the project. The projects were assumed to have zero residual value at the end of service term. A benchmark discount rate of 8% was used in the CBA. A sensitivity study compares the result of changing the discount rate between 6% and 10%. The program is evaluated in terms of its net present value.

Recognizing the difficulties and compromises in design validity and data availability, using a human capital approach as the major costing model, excluding travel time consideration, the CBA revealed that the Black Spot Program has delivered net benefits to the Australian community of at least $800 million, generating benefits of around $4 for each dollar of expenditure.

A major concern of the study arises from the use of the human capital valuation method for lives saved and injuries averted. Although still used extensively in transportation, insurance, and judicial systems for specific purposes, this method is gradually losing its prominence. This is due to the recognition that the human capital valuation method places a lower value on infants, women, and the elderly. Moreover, it does not reflect the value that the society places on human lives as reflected in the willingness to pay method. In a policymaking and program evaluation context, the use of the human capital approach unduly reduces the potential allocation of public funds in the area of traffic safety in competition with other spending priorities.

By contrast, the omission of travel time lost due to the reduction in traffic speed could have likely introduced an underestimation of the negative economic impact of the program, opposite to the underestimates of benefit in the valuation of the savings in human lives and injuries. Depending on the degree of impact of traffic speed, the time lost in travel for both passenger vehicles and trucks can be small or substantive, under or over correcting the valuation error in the human resources method in valuing human lives. The omission of major impact categories from the cost-benefit analysis and the incorrect valuation of major benefit items deprived the researcher and the reader from judging the bias of the resulting estimates, let alone obtaining with confidence the real net social values of the program.

Recently, Elvik (1997) conducted an evaluation of the photo radar program in Norway. He studied the traffic safety effect on 64 road sections where photo radar devices was installed. He found a statistically significant reduction in collisions and injuries in these sites. He estimated that the program reduced injury collisions by 20% at program treatment sites.

Elvik (1997) extended his study to a brief cost-benefit analysis, wherein he compared the program cost with the saving in collision cost. The investment cost for each of the 64 road sections is estimated to be U.S.$49,000. The annual operation cost of the program was estimated to be $2.45 million. The investment cost was included in the form of an annual capital cost assuming a 10-year service life for each photo radar unit and a 7% annual interest rate in real term. No clear indication was given on how the valuation of the collision reduction savings was calculated.

Under this framework, Elvik (1997) found an annual saving of 19.54 million in collision cost. He claimed a benefit-cost ratio of about 8 (19.54/2.45). Apparently, the program produced a positive return on the resources that the society had forgone for other uses. The study did not count the time lost due to the reduction of speed and no sensitivity analysis was attempted to assess the robustness of the estimated values.

The UK Home Office Police Research Group commissioned a cost-benefit analysis of traffic light and speed cameras (Hooke, Knox, Protas, 1996). The cost-benefit analysis was carried out between November 1995 and March 1996 by Price Waterhouse. The data collection exercise focused on ten police force areas which were selected in accordance with a range of criteria including number of cameras, experience of their use, force size, degree of urbanisation, road length and number of traffic officers. Detailed information was also collected from local authorities, magistrates' courts and CPS branches in each of these ten force areas.

The types of costs considered relevant included:

- the costs of purchasing, installing, operating and maintaining the cameras,
- the costs to the courts and the Crown Prosecution Service (CPS) resulting from the use of the cameras, and
- the costs of associated publicity campaigns.

The types of benefits considered relevant included:

- savings in human lives and injuries, as well as those associated with reduced damages to properties,
- savings experienced by the police and emergency services as a result of attending fewer road accidents,
- savings experienced by the health service as a result of dealing with fewer road accident victims,
- fine income generated as a result of camera use, and
- improved traffic flow, reduced travel times and an "improved environment".

The study found that the number of police forces using speed and traffic light cameras has increased steadily in recent years. In 1994, it was estimated that just over half of all police forces were using cameras. The number of cameras in use then was still relatively small with just over 30 speed cameras and 54 traffic light cameras. Data from the current study indicates that by March 1996, in ten forces alone, there were 102 cameras servicing more than 700 sites (475 speed cameras plus 254 traffic light) - confirming the continued growth in the use of camera technology.

The majority of the cameras in use, at the time of the study, were wet film cameras, which are usually unmanned and mounted on fixed roadside poles. Some cameras were mounted on portable tripods to allow them to be shifted between sites and a small number of video cameras were found to be in use.

Data was collected in the ten force areas on the costs associated with the installation (fixed costs) / operation (recurrent costs) of speed cameras and with related prosecutions.

Costs of cameras:

- The average fixed cost per site for a speed camera was £12,500 and average recurrent costs were just over £8,500 per annum for each site.
- Each site generated an average of 316 speed-related prosecutions per annum, although there was considerable variation between sites. The average cost per prosecution was £27. (86% of these offences were dealt with by way of fixed penalty.)

Benefits of cameras:

- Accidents fell by 28% at speed camera sites or by 1.25 accidents per site per year
- Speeds were reduced by an average of 4.2 mph per site

Cost-benefit analysis:

The costs of installing and operating speed cameras were contrasted with the monetary value of benefits brought about by accident reduction and prosecution. This showed that a significant net benefit was generated for speed cameras. The study concluded that:

- The £5.3 million investment made to install speed cameras generated a return of five times this amount after one year and more than 25 times the amount after five years. All areas achieved a positive return after one year and, in nine out of ten forces, fine income covered the "cost" of operations;
- Modelling with more pessimistic assumptions (e.g. decline in incident reductions, reductions in fine income) still produced a substantial net benefit for both speed and traffic light cameras.

Apparently, this study did not separate the traffic violation fine revenue from traffic safety benefit. From a societal perspective, traffic fines collected from speed camera enforcement does not generate extra benefit for the society, assuming all the fines are paid by people with standing in the study. From this perspective, revenues from traffic fines is more appropriately treated as a transfer as opposed to a benefit to government and a cost to offenders. By including traffic fine revenue, the cost-benefit analysis over estimates the benefit and biases the results of the study.

Moreover, the study did not consider lost travel time due to reduction in traffic speed. The omission could further bias the cost-benefit estimates towards producing a more positive economic impact estimate of the program than it really is.

Summary

In summary, extended theoretical work has been done in welfare economics in general and in cost-benefit analysis in particular. Based on consumer preference, within the domain of economic efficiency, cost-benefit analysis could be used as an analytical framework to support policy-making and resource allocation. The limitation of cost-benefit analysis centres on efficiency vs. multi-goals incongruence. The majority of practitioners adopt Kaldor-Hicks criterion to overcome this contention. Political processes, based on citizen preference (Fuguitt & Wilcox, 1999), could be used, in conjunction with cost-benefit analysis, to tackle issues of competing values in our multicultural democratic society.

Cost-benefit analysis has received mixed acceptance in the field of traffic safety, however. Placing a dollar value to human life cannot be accepted by a number of prominent researchers and engineers on philosophical or technical grounds (Harris, 1985; Hauer, 1994). However, unless left unattended, any attempt to choose between two competing investment options implies valuation, no matter whether the subject is time, human life, or whatever is of concern (Williams, 1993). Given that public administrators are supposedly making decisions in the best interest of the public and the public is demanding more transparency and accountability in public decision-making, explicit valuation of all impacts, including human lives, as used in cost-benefit analysis, should be promoted.

Recently, a trend is forming toward the extended use of cost-benefit analysis. Elvik (2001) examined the applicability and controversies of cost-benefit analysis as an aid to policy making for road safety measures. He concluded that rejecting the basic principles of cost-benefit analysis is not defensible as these principles are simply a re-statement in economic terms of very general principles of rational choice. These principles are part of the normative basis of all formal techniques designed to aid policy making as well as the democratic system of government. There are disagreements with respect to the perception of a specific policy issue in terms of whether it is mainly about rights and fairness or mainly about the effective use of policy instruments to solve a social problem.

The practical application of cost-benefit analysis in traffic safety, especially in speed enforcement, has been very limited, based on this literature review. The quality of the studies varied substantially. The conclusions from the studies are hardly comparable, given the variation in the applications of the technique. It seems reasonable to conclude that high quality cost-benefit analysis, using theoretically sound methods and reliable data, are still a rarity in this field of traffic safety. In the context of increasing government fiscal constraints, further work to extend the knowledge of the technique and to increase the application of the decision tool seems to be worthwhile.

3. BC PHOTO RADAR PROGRAM AND PROGRAM LOGIC MODEL

This chapter is to lay down a framework for the evaluation of BC photo radar program. It attempts to identify and relate main constructs and theories of photo radar program in a program logic model. The model is then used as the basis to form evaluation questions, select variables, and clarify limits and assumptions. It postulates causal links between program intervention, driver behavioural change, traffic safety improvement, and the benefit and cost to the society. It also identifies unintended outcomes, which should be considered in the overall assessment.

The program logic model dictates that the study, first of all, ought to examine the implementation of the program. It raises the issue of the level of program delivery in terms of communication campaigns to educate the public and publicize the program, and the level of enforcement in terms of hours of photo radar deployment, and the numbers of violation tickets issued. Only when program delivery is confirmed, should the study continue to pursue a full-fledged outcome evaluation (impact assessment).

The program logic model suggests three main outcome impact studies: a province-wide speed and safety analysis, a site-specific speed and safety study, and a cost-benefit analysis. These studies, with their individual study method, results, summaries, and conclusions constitute the main body of the thesis. These studies are presented in the following three chapters.

BC PHOTO RADAR PROGRAM

The BC Photo Radar Program was developed and implemented to reduce traffic speed, and therefore improve traffic safety. The official goal of the program is to achieve a three per cent reduction in mean traffic speed on roads throughout the province, presumably through a generalized deterrence effect (Park, 1995). It was assumed that a reduction in speed would lead to a decrease in the frequency and severity of traffic collisions.

The BC photo radar program consists of a number of components: a province-wide deployment of 30 mobile speed monitoring camera units, the processing of the traffic violation tickets generated by the program, the additional support from the provincial judicial systems to handle appeals, and a major communications effort to publicize the program.

The mobile photo radar unit includes a cross-the-road Doppler radar, a camera with a flash, and a laptop computer, all mounted on an unmarked mini van. The vans are various colours but all the same model and body style. The vans are parked in easily visible locations, although there is nothing to distinguish them as police vehicles. The radar unit is visible only after vehicles have passed the van. The camera and the computer system record the license plate and speed of the speeding vehicles detected by the radar. The device has a margin of error of 1 km per hour.

The photo radar unit was designed to operate at sites of high accident history. It could also be used at sites requested by the local community where speeding was perceived as a safety problem. The sites are surveyed to examine the suitability of photo radar operation and to set the trigger speed. The trigger speeds are based on 85th percentile speed or 11 km over the posted speed at the discretion of the police officers. The location selection and implementation procedure was outlined in a Guideline developed by the Integrated Traffic Camera Unit (ITCU), the newly established police force to operation the BC photo radar program, prior to the implementation of the program (ITCU, 1996).

The communication component comprises all the effort by the government and ICBC, to inform the public of the photo radar program and educate the public of the consequences of speeding. The program does not include regular traffic safety programs initiated and sponsored either at the provincial or at the local level.

PROGRAM LOGIC MODEL - PROGRAM THEORY OF BC PHOTO RADAR PROGRAM

Theoretically, the BC photo radar program can be diagrammed in a program logic model. The model postulates a number of causal links, whereby the BC photo radar program could modify speeding behaviour of the motorist, and therefore reduce the number of collisions and injuries. There are two main hypothesized relationships in the model, the relationship between the newly introduced photo radar enforcement and driver behaviour change, and the relationship between driver behavioural change and traffic safety improvement.

The association between photo radar enforcement and driver behaviour change could be established through two possible mechanisms. First, it is possible that the knowledge acquired through the program's education campaign could inform the drivers of the danger of speeding and change their attitudes (i.e., "speed kills" and “if I speed, I am part of the problem”). The attitudinal change could lead to the reduction in the propensity of speeding.

Second, If the educational effort failed to produce the attitudinal change, or if the link between attitude and behaviour is weak, (which is probably the case), increased probability of being detected and punished for speeding as a result of the newly implemented photo radar program could probably persuade the potential speeders to drive within the speed limit.

The reductions in traffic speed and speed variance are expected not only at the photo radar deployment sites, but also at non-photo radar locations across the province, due to the mobility of the photo radar vans. The rates of speed and speed variance reduction were expected to be substantially greater at photo radar enforcement site than at non-photo radar enforcement sites. The speed and speed variance reduction were expected to be immediate and sustainable, as long as the program is in place, based on enforcement theory and previous experience from other jurisdictions.

BC PHOTO RADAR PROGRAM LOGIC MODEL

INPUT

Resources
- Human
- Financial
- Time

Target
- Group: Speeding vehicles
- Loc.: Province wide
- Time: Mainly daytime

ACTIVITIES, OUTPUTS

Communication
- Communication campaign
- Staged community events
- News release

Enforcement
- Deployment of 30 cameras
- Processing tickets and fine
- Incremental court cost

PROCESS

Awareness of Program
- Awareness of program
- Support of program

Threat of Punishment
- Photo radar traffic fines
- Increase in Insurance cost

INTERIM OUTCOMES

Driver Behaviour Change
- Reduced mean speed
- Reduced speed variance

LONGTERM OUTCOMES

Traffic safety effects
- Reduced crashes
- Reduced injuries
- Reduced fatalities
- Reduced property damages

Potential Unintended Consequences
- Increased court cost due to dispute of photo radar tickets
- Migration of collision to adjacent highway sections
- Longer travel times
- Fuel savings
- Environmental benefits

Benefit-Cost Comparison
- Benefit : (savings on societal cost due to collision reduction)
- Cost: (development, operating, negative unintended consequences)

The linkage between speed and speed variance reduction and traffic safety improvement is based on collision physics. As summarized in the literature review, the higher the mean speed and speed variance of the traffic, the greater the likelihood of traffic collisions. If the photo radar program reduces the mean and variance of speed, then, the program is expected to reduce collision frequency and improve traffic safety.

Moreover, the lowered speed reduces the amount of energy to be released if a collision occurs, and therefore affects the severity distribution of collisions. In other words, it was expected that photo radar would have a greater relative impact on fatal collisions and severe injuries than on minor injury and property damage only collisions.

Competing theories exist with regard to the effect of photo radar enforcement on the highway segments adjacent to treatment segments. The BC photo radar program is based on the assumption that there will be a beneficial spill-over effect in speeds and collisions primarily due to the mobility of the photo radar units and the resulting unpredictable nature of enforcement. However, a reasonable competing proposition is that drivers will slow down at the PRP locations only to increase speed at non-PRP sections of the highway to compensate for time lost. This compensatory behaviour could result in the unintended collision migration to untreated sites. A study to empirically test the validity of these positions is of practical and theoretical significance.

The economic impact of the program to the society depends, on the one hand, on the effectiveness of the program in reducing the frequency and severity of traffic collisions, and on the other hand, on the resources consumed both in terms of program input and its negative outcomes. The economic impact of the program to the society is real and the only issue is its valid and reliable quantification. The accuracy of an economic evaluation depends on many factors, including the accuracy of safety impact assessment.

PLANNED STUDIES AND RESEARCH QUESTIONS

In line with this conceptualization, the evaluation is designed to comprise three main components: a province-wide impact analysis to assess the extent to which the program achieved its intended goals (reduce speed and collisions across the province), a site-specific study to verify the internal validity of the province-wide study and to test the competing theories, and a cost-benefit analysis to combine all the impacts and to determine the economic worthiness of the program to the society.

To verify and quantify program delivery, prior to the main impact analyses, an implementation assessment was conducted. The implementation assessment examines the level of program delivery in terms of the communication campaign to educate the public and publicize the program and the level of enforcement in terms of hours of photo radar deployment and the numbers of violation tickets issued. If the program delivery can be shown to be in line with expectations, then there is a sufficient basis to support the outcome evaluation (impact assessment).

As outlined in the program logic model, the outcome evaluation measures and assesses two main constructs, traffic speed and traffic safety. The program impact on speed will be analyzed at the photo radar enforcement locations to assess direct deterrence and at locations where police enforcement was not likely to occur, to assess the general deterrence. Speed data are analyzed primarily by descriptive methods, due to the nature of the research question and the data collection schemes.

Improving traffic safety is the ultimate physical goal of the BC photo radar program. Consequently, every effort is made to improve its validity and reliability, within administrative, budgetary, and time constraints. The analysis is inferential in nature, attempting to gauge the amount of change in traffic safety measures, which could be attributable to the photo radar program. Quasi-experimental designs and various statistical analysis techniques were employed in this effort.

A number of techniques, such as cost-benefit analysis, cost-effectiveness, and multi-goal analysis can be used in assessing the economic effect of the BC photo radar program. Cost-benefit analysis was selected, recognizing its comprehensiveness and thoroughness in quantification. Two major risks of using cost-benefit analysis are the potential strong objections from some traffic safety experts and practitioners on placing dollar values on human lives from a philosophical viewpoint, and the evolving valuation methods and practices of willingness to pay as they are applied in transportation from the implementation perspective . However, seizing the opportunity to address the issue could provoke meaningful discussion and advancement in the application of economic evaluation in traffic safety specifically and in government programs in general. Comparing the potential benefits and the costs, relative to other economic evaluation method, the cost-benefit analysis method was selected.

Based on the above considerations, the specific research questions by in the three main studies are specified as follows.

Study I: Province-wide, speed and safety effects of BC photo radar program

- To what extent are traffic speed and speed variance reduced at the photo radar deployment sites?
- To what extent are traffic speed and speed variance reduced at the non-photo-radar monitoring sites?
- To what extent are traffic collisions, injuries and fatalities reduced as a result of the photo radar program in the province?

Study II: Site-specific, speed and safety effects of BC photo radar program

- To what extent is traffic speed and speed variance reduced at photo radar deployment locations and at a speed monitoring location on the highway, 2-km from the nearest deployment location, as a result of the photo radar program?

- To what extent are traffic collisions reduced at PRP deployment locations and at non-PRP interleaving locations along the study corridor as a result of the photo radar program?
- Does the evidence support the traffic collision migration hypothesis? Or, conversely, does the evidence support the beneficial spill-over effect of the program?

Study III: Cost-benefit analysis of BC photo radar program

- How does the benefit of the program compare with its cost?
- How robust are the results of the cost-benefit comparison?

4. IMPLEMENTATION ASSESSMENT

A prerequisite for a valid impact assessment of a program is, first of all, the implementation of the program. The overall construct reliability is enhanced if the delivery of the program is empirically measured and confirmed. Consequently, an implementation assessment was conducted, preceding all the other evaluation effort.

The implementation of BC photo radar program was assessed along two program delivery component dimensions: the major communication effort to publicize the program and the province-wide deployment of 30 mobile speed monitoring camera units. The publicity program component includes government and ICBC efforts to inform the public of the photo radar program and to educate drivers of the consequences of speeding. The enforcement component further composes picture taking, the ticket procession and down stream adjudication. A chronicle and logical description of the program delivery output is presented below.

COMMUNICATION AND PROGRAM PUBLICITY

A major education and communication campaign for the PRP program long preceded its deployment. The communication effort of the government and the opposition against the program from various groups stimulated media coverage that further enhanced program publicity. The following is a chronological list of major events before and after the inception of the program.

In early March 1995, the Transportation and Highways Minister Jackie Pement announced the Traffic Safety Initiatives, including the photo radar program.

In July 1995, the BC legislature debated the photo radar program. With the projection that the program would increase traffic ticket revenues by $1.6 million, the "Cash Cow" debate heated up. This triggered major media coverage of the photo radar program.

In February to March 1996, announcements of the photo radar fair warning phase preceded program start-up. The decision by some municipal councils (e.g. Surrey, Cranbrook, West Vancouver) to withdraw from photo radar participation also received news coverage.

In the first week of March, major news coverage ensued as the photo radar fair warning phase began, followed by weekly announcements of deployment sites.

On July 26, 1996 the government announced photo radar with violation tickets to start on the August long weekend. Major news coverage continued during the following weeks.

Apart from the government announcement of the program, ICBC advertising, including the "Speed is Killing Us" campaign started long before the program initiation and continued throughout photo radar's development. The "Speed is

Killing Us" campaign is aimed to educate the motorist and the general public the consequences of speeding and the prevalence of the problem in British Columbia. Also, extensive community consultation/education, mainly by the police, was on going during and after the commencement of the program.

The communication component of the Photo Radar program seems to have achieved its goal of publicizing the program to British Columbians. An overwhelming majority of the public (over 95%) were informed of the program prior to its inauguration (Viewpoints Research, 1995). The majority of people in BC supported the program. Two-thirds of the people surveyed believed that the photo radar program was a good way to reduce traffic collisions and the resulting injuries and fatalities (Insurance Corporation Of British Columbia, 1997). The support for the program continued in the second year of operation.

PHOTO RADAR DEPLOYMENT

The photo radar program started operation officially on March 1, 1996. It was implemented in two phases: the warning letter phase and the violation tickets phase. From March to July, the owners of the speeding vehicles were issued warning letters. Starting from August 2, 1996 the owners of speeding vehicles began to receive mailed violation tickets. The photograph taken by the photo radar device is printed on the ticket along with the date, time and place of occurrence, and the recorded vehicle speed. The tickets carried a $100.00 to $150.00 fine, depending on the extent of the offence (BC Ministry of Transportation and Highways, 1996). The level of photo radar deployment is measured by the total deployment hours and the total number of tickets issued to the registered owners of the offending vehicles.

Deployment hours

The BC photo radar program was introduced in a phased-in fashion. At the onset, equipment and human resources allocated to the program were limited. As the program developed over time, more and more resources became available. Figure 4.1 shows a continuous increase in the hours of photo radar deployment in the warning letter phase and the first year of the violation tickets phase. The vertical line in the figure indicates the beginning of the violation ticket phase. The figure did not present data for March and April of the warning letter phase, as the hours of deployment in that period are minimal and mostly deployed for survey and testing purposes.

Figure 4.1 Photo Radar Deployment Hours

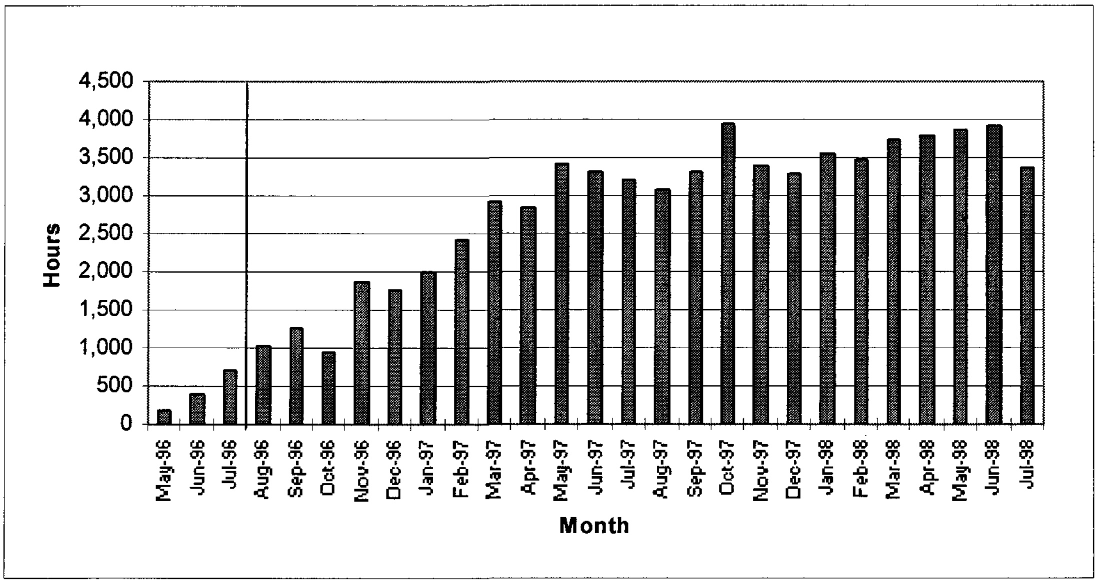
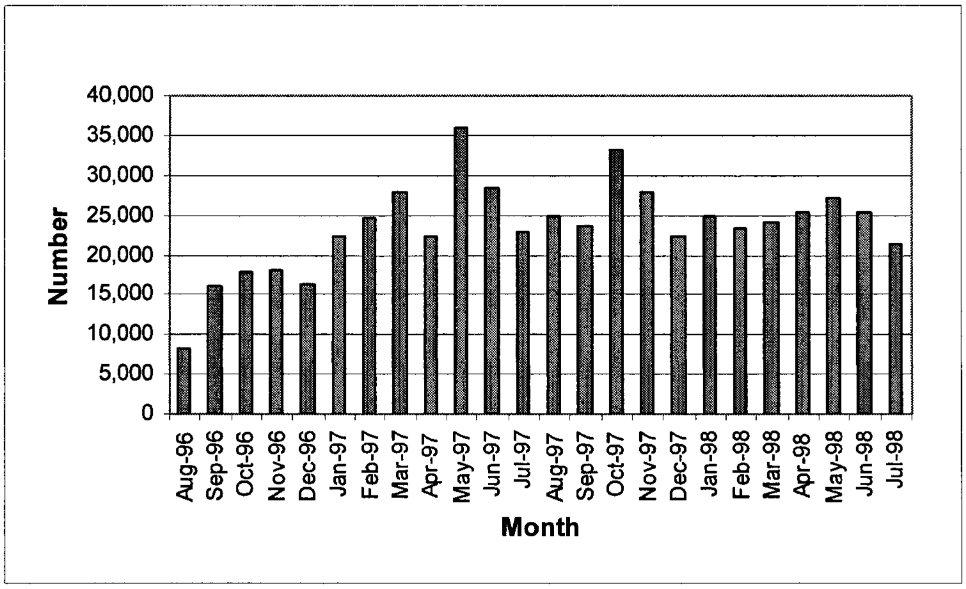


Figure 4.1 shows that by the end of May 1997, the level of photo radar deployment had been increased to 3,000 hours per month. Deployment hours stabilised at the 3,000 to 3,500 hours per month level afterward. In total, photo radar operated approximately 70,000 hours on BC roads over the five month of warning letter phase and the subsequent 24 month violation tickets phase wherein this study concerns.

Violation Tickets

The photo radar program takes photographs of the alleged offending vehicles at the sites of photo radar deployment. Traffic violation tickets were generated after charging officer from the Ministry of Attorney General reviewed and verified the validity and submissibility of photograph to withstand legal challenges. Tickets were mailed to registered owners of the vehicles irrespective of who was driving at the time when the offence was detected. Meanwhile, records of violations were registered against the registered owners of the vehicles in the Contraventions database at ICBC. The numbers of photo radar violation tickets mailed to registered owners of the offending vehicles by month are shown in Figure 4.2.

Figure 4.2. Number of Photo Radar Violation Tickets by Month



As can be seen in Figure 4.2, the number of photo radar tickets increase over time in the first year of the violation tickets phase of the program. The number of tickets increased from below 9,000 when the violation ticket phase started in August 1996 to over 35,000 in May 1997.

Figure 4.2 also indicates that corresponding to the pattern of deployment hours, the number of photo radar violation tickets stabilised in the second year of the violation ticket phase. The average number of tickets levelled off at approximately 25,000 per month level. The total number of tickets mailed or personally delivered to registered owners of alleged offending vehicles accrued to 564,863, over the first 24 months of program violation tickets phase.

It is interesting to note that although the level of enforcement was higher in general in the second year, the number of tickets issued in the period declined slightly. As evident and further explained in the next section, this reflects the fact that the number of vehicles exceeding the trigger speed further declined in the second year of the program, after an initial abrupt fall in the warning letter phase. The summary data for the numbers of photo radar enforcement hours and the numbers of violation tickets issued to the registered owners of the alleged violation vehicles are listed in Appendix A.

SUMMARY

The implementation assessment confirms that the BC photo radar program was delivered as planned. The BC government, ICBC, and the police, in conjunction with other safety partners in the province, conducted an extensive communications campaign to raise awareness of the program and to educate the public of the safety consequence of speeding. Approximately 95% of BC residents were aware of the program, before the commencement of the warning letter phase of the program in March 1996.

On a phased-in basis, the police deployed 30 radar cameras across most parts of the province. The hours of deployment increased steadily from the start of the violation ticket phase to more than 3,000 hours per month since May 1997. The number of tickets sent to the owners of the offending vehicles increased to more than 30,000 per month in May 1997 and sustained at 25,000 per month level in the two years of violation tickets phase under this investigation. Given the information of program implementation, the impact assessment of the program was deemed meaningful and conducted. The results are reported in the following chapters.

5. IMPACT ASSESSMENT I: PROVINCE-WIDE, SPEED AND SAFETY EFFECTS

This chapter presents the method, results, and discussion of the province-wide speed and safety evaluation of the BC photo radar program. As stated in the program logic model chapter, this macro level assessment is intended to address the following specific research questions:

- To what extent were traffic speed and speed variance reduced at the photo radar deployment sites?
- To what extent were traffic speed and speed variance reduced at the non-photo-radar monitoring sites?
- To what extent were traffic collisions, injuries and fatalities reduced following the introduction of the photo radar program in British Columbia?

RESEARCH DESIGN

The main purpose of the research design in an evaluative study is to improve internal validity. This is achieved primarily through experimental or statistical controls over potential confounding variables. Confounding variables are not the main interest of the investigation, nevertheless they could affect the traffic speed and traffic safety at the same time. In other words, design in this study addresses the issue of attribution: to attribute the appropriate portion of the effects to the photo radar program, after removing the portion of the effect accounted for by other influencing covariates.

For the province-wide evaluation of the photo radar program, a quasi-experimental, interrupted time series analysis design was selected. The reason for selecting this design is to take full advantage and opportunities of the circumstance. Given that a randomised experimental design could not be applied to a provincial law enforcement program, and that the outcome measures are available at the provincial level over years in time series form, the best design options available to the researcher is a quasi-experiment, time series analysis. This design was safeguarded by various considerations of potential threat to internal validity. These considerations are built into various types of adjustments, which is implemented in both the data collection and analysis stages.

First, adjustment was applied to a number of exogenous variables that have documented impacts on traffic safety. The factors initially considered include the condition of the economy as measured by employment rate, the amount of driving as measured by provincial motor vehicle gasoline sales, and drinking driving behaviour as measured by draft beer consumptions. By including these variables as covariates in the time series model, the effects of these extraneous variables were accounted for.

Second, consideration was given to other concurrent traffic safety programs. Two drinking and driving programs, the Enhanced Impaired Driving Road Check and the Administrative Driving Prohibition/Vehicle Impoundment programs could confound the effect of the photo radar program. The potential contamination of these traffic safety programs was addressed by using only daytime collision data. As the photo radar program is operated primarily during daytime hours and the impaired driving road check exclusively at night, it was assumed that any safety effect of on day time collisions should be attributed to the photo radar program. It was recognized, however, that the impact of photo radar could spill over to nighttime as a consequence of its general deterrence effect - the program can and does operate in darkness (usually early evening) and is not publicized as a daytime only program. Therefore, the estimated effect from the daytime data only is conservative, probably erring in the direction of underestimating the traffic safety effect.

Other potential endogenous influences, such as trend and seasonality were statistically accounted for over and above the exogenous covariates by the application of ARIMA modelling techniques. The principles and procedures of these statistical adjustment are presented in the modelling process section.

Although other small scale, conventional speed enforcement programs, such as school zone and long weekend enforcements, were present over the time when the photo radar program was implemented, the impact of these programs was considered as localised and routine. No other major province-wide traffic safety program was implemented in the study period, which could conceivably and empirically affects the overall safety on BC highways, and therefore contaminate the results of the current study. Consequently, the change in traffic safety, after controlling for major, known confounding factors, is attributed to the photo radar program tentatively.

It is recognised that, in general, no quasi-experimental study could ensure complete internal validity of a study. The omission of local safety programs in this study, recorded or not, and the numerous other changing factors could possibly render each of the analyses in the current study invalid. Acknowledging this limitation in each individual study, effort was made to extend beyond the concept of validity of individual investigation, to the concept of credibility and confidence based on corroboration of evidences from the accumulation of empirical results from various studies across conditions and over time. In line with this reasoning, this analysis uses multiple measures of traffic safety to independently assess the impact of the program. Moreover, a site-specific study, using comparison groups design and Empirical Bayes method was performed, supplementary to the province-wide analysis. The method and the result of the site-specific study are presented in the next chapter.

DATA DEFINITION, COLLECTION, VALIDITY, AND RELIABILITY

Based on theories of traffic safety and law enforcement, and experience from other jurisdictions of similar programs, variables considered relevant to address the research questions were selected and data sought in various administrative data sources in government agencies across the province. The program outcome measures, the criterion variables, selected for the study falls into two categories: traffic speed and traffic safety. Table 5.1 provides selected attributes of the variables. The data for the most relevant variables are presented in Appendix B. Each variable is further discussed separately in the following sub-sections.

Table 5.1 Study variables and selected attributes

Category	Variable	Definition	Source	Range
Criterion: Speed	% Vehicles speeding (PRP sites)	Averaged over sites by month	ICBC	May 96 - Jul 97
	% Vehicles exceeding limit by 16 km/hr (PRP-sites)	Averaged over sites by month	ICBC	May 96 - Jul 97
	% Vehicles speeding (Non-PRP sites)	Averaged over sites by month	ICBC	Sep. 95 - Jul 97
	% Vehicles exceeding limit by 16 km/hr (Non-PRP sites)	Averaged over sites by month	ICBC	Sep. 95 - Jul 97
Criterion: Safety	# of daytime traffic injuries	Monthly total	Ambulance	Jan. 91 - Jul. 98
	# of daytime traffic fatalities	Monthly total	Police	Jan. 91 - Jul. 98
Covariates	Employment rate	Monthly rate	BC Stats	Jan. 91 - Jul. 98
	Alcohol sales	Monthly total	BC Stats	Jan. 91 - Jul. 98
	Motor gas sales	Monthly total	BC Stats	Jan. 91 - Jul. 98
Other safety program	Enhance Speed Enforcement program	Ramping*	ICBC	May 97 - Jul. 98
Photo Radar Program	Warning letter phase	Indicator	ICBC	Mar - Jul. 96
	Violation ticket phase	Indicator	ICBC	Aug. 96 - Jul. 98

* The ramping effect is a linear incremental indicator variable, identical to a record identification variable, used in SAS modelling and forecasting terminology to represent incremental effect.

Criterion variables - Traffic Speed

The photo radar program is designed to improve traffic safety by reducing traffic speed. As outlined in the program theory and logic model section, reduction in mean speed and speed variance is thought to lead to an improvement in traffic safety. Consequently, mean speed and speed variance would be the most sensitive, sensible, and constructively valid measure for this purpose.

However, when evaluated at the province level, mean speed and speed variance cannot be easily defined, understood, and communicated. Different types of highways have different posted speed limits. Speed variance across many locations along the highway systems in the province is confusing, if not meaningless. Consequently, other related measures should be identified.

The alternative measure for driver speeding behaviour in this context is the proportion of speeding vehicles. Proportions of speeding vehicles are deemed simple and unifying summary measures of driver speed behaviour for province-wide speed study with diverse highway types and varying speed limits. This measure to some extent hinges on the assumption that posted speed limits reflect the real safe driving speed, given the geometry and environmental condition on the particular highway. This measure is selected for the current study.

Two proportions, the proportion for all the violation vehicles and the proportion for excessive speeders as defined by exceeding the posted speed limits by 16 and more km/hr, are calculated and reported to reflect the change in mean and in variance. These measures are also reported in the only other comprehensive photo radar evaluation found in the literature. (Cameron, M., Cavallo, A., and Gilbert, A. 1992).

The separation of the excessive speeders as a group in this study is of theoretical implications. This subpopulation deserves special attention, as they are more likely to be involved in traffic collisions. A different rate of reduction in the proportions of speeding vehicles indicates a reduction in traffic speed variance. A greater observed reduction in this group would strengthen the linkage between speed reduction and collisions reductions, improving the construct validity of the overall evaluation design.

Two distinct types of instruments were used to collect traffic speed data: the photo radar devices and the speed induction loops. Photo radar units automatically collect data when the program is in operation. Speed data from the photo radar units were used to examine the speed effect in the presence of program enforcement.

Unobtrusive induction loops embedded in pavement were used to collect speed data to obtain information of program generalized speed effect. Induction loops were installed at 16 sites on selected highways and streets across the province, where photo radar deployment was not operating.

The selection of sites for induction loops was not strictly random. Selection criteria included non-congestion and distance to traffic control devices to ensure free-flowing conditions. Geographic and speed limit representation for the province was another factor considered.

The majority of the devices started collecting data in September 1995, before the location of the photo radar sites was known. Eight days of speed data were collected every month, ensuring that each eight-day period included the same number of weekdays and weekends. At minimum, more than 10,000 vehicles were observed in each observation period each month. Due to the virtually undetectable nature of the device, the speed data collected should reflect the free driving behaviour of motorists independent of police presence.

Criterion variables - Traffic Safety

The ultimate goal of the photo radar program is to improve traffic safety. Traffic safety can be measured in a number of ways. For a province wide, longitudinal study, traffic safety is conventionally and reasonably measured by monthly frequencies of traffic collisions, injuries and fatalities. Each of the safety measures has its advantages and disadvantages. Two main factors, the validity and the reliability were considered in the selection process.

The monthly count of police reported traffic collisions seemed to be the most valid and direct measure of traffic safety. It is based on the most comprehensive traffic collision database, including the time and location of the collisions, contributing factors based on the judgement of the investigating police, environmental factors which could affect the likelihood of collision, etc.

The reliability of traffic collision data in British Columbia, however, is compromised by the change of police data collection practices in the late 1990s. Due to resource reductions, the police decreased investigating and reporting traffic collisions since July 1996. The majority of police detachments reduced or stopped reporting property damage only collision (PDO), focusing instead on injury and fatal collisions. For a limited time period, eight police forces stopped reporting any collisions to the Traffic Accident System (TAS), the provincial central database completely. The lack of reliability precluded the use of the total number of police reported traffic collisions as the sole measure for traffic safety in the impact analysis of traffic safety programs. Other measures have to be included to corroborate the result of this measure.

The number of persons killed in traffic collisions is the most accurate measure of traffic safety in the sense that all fatal collisions are investigated by the attending police and corroborated by the coroner's office. The definition of a traffic collision fatality is less open to dispute and interpretation. However, the monthly total of traffic fatalities is small. Consequently, this measurement is subject to substantial random fluctuation in the time series framework, wherein data were summarized on a monthly basis.

The number of injuries due to traffic collisions is a valid and reliable measure of traffic safety, as injuries tend to be validated by medical professionals. The monthly numbers of traffic injuries are large and therefore lend themselves to more powerful statistical analysis. However, the number of injuries from police report suffered the same reliability problem as the number of collisions. Other source of information need to be collected to cross validate the data and corroborate assessment results.

Recognising the pros and cons of safety measures and data sources, this study used two indicators: traffic collision fatalities and traffic collision injuries. The data were obtained from two independent data sources: the police and the BC Ambulance Services. The traffic fatality data were obtained from police traffic accident investigation reports, stored and managed in the Traffic Accident System (TAS) at ICBC. The numbers were considered reliable, except those from eight relatively small police detachments where change of reporting was indicated. Data from these eight detachments were removed from the entire time series. Although complete fatality data were available from the Office of the Chief Coroner, these data did not provide a distinction between daytime and night-time collisions, which limits its utility in reducing the threat of contamination from other traffic safety programs.

The traffic injury data were obtained from Ambulance Services of BC Ministry of Health. Ambulance data were considered a relatively independent and generally reliable data source. No change of administrative data collection process was obvious to the author and further telephone interview of the personnel from Ambulance Services confirmed that no change took place in the time period this study concerns. Although the data from Ambulance Services is not as comprehensive as the police data, in terms of highway geometry and inferred contributing factors by investigating police office, the data does provide the time and location of the collision, the initial identification of injury, and the medical facilities to which the victim is sent. The Ambulance Services kept a complete record of every dispatches of Ambulance, using standard procedures in the process. The number of trips of Ambulances, which did not pick up victims, is also recorded, so that they can be excluded in counting the number of traffic injuries. The disadvantage of the Ambulance data is related to its incompleteness in terms of documenting all injuries on BC highways. Only the more serious injuries tend to be picked up by Ambulance and sent to medical facilities. This phenomenon could result in an underestimate of the effect of the safety program, if the counts are used in absolute terms. However, given its independence from the traffic safety program, its undisturbed data collection process, and its medical expertise in verifying injuries, consistent with the conservative stance, the injuries data from Ambulance Services is used in this study as the main indicator for the assessment of safety impact of the photo radar program.

Although no single measure of traffic safety is perfect in this evaluation, as in almost all other field-oriented, evaluative studies, it is argued that the potential corroboration of investigation results, using data from various independent sources would improve the credibility of the study. If similar patterns of program effect in traffic safety were found in the various measurements used, the confidence in the overall assessment of the program impact would be increased.

The consideration of other traffic safety programs have led to a further refinement of the measures. The province-wide enhanced drinking and driving program was in operation when the photo radar program was implemented. However, the enhanced drinking and driving program was delivered mostly at night time. The photo radar program, on the other hand, operates predominantly during daytime hours. Given that the level of the enhanced drinking and driving program changed over time, the potential effects in collisions and collision injuries reduction could be confounded by the two programs . To reduced the potential contamination due to the enhanced drinking and driving program and to improve sensitivity of the measures for the impact of the photo radar program, day time collisions, (those occurring between 0600 and 2059 hours) were separated from night time collisions and used in this study.

Covariates

A number of covariate variables that have documented impact on traffic safety were considered for inclusion. After reviewing data availability, quality, and intercorrelations, three variables, motor gasoline sales, unemployment rates, and Draught beer sales, representing vehicles miles travelled, state of the economy, and amount of drinking-driving were initially selected. Motor gasoline sales was selected as a surrogate for vehicle miles travelled. The data were obtained from

BC Stats, a branch of the BC provincial government. Unemployment rate is an indicator of economic state. The data were also obtained from BC Stats. Draught beer sale is a surrogate for amount of drinking-driving (Wilson and Jonah, 1985). Draught beer is consumed mostly in bars and taverns. Some people leave the premise, driving. The aggregated amount of draft beer is found to be a more sensitive factor relating to the number of alcohol related collisions in a community than other measures of alcohol consumption (Wilson and Jonah, 1985). The data were acquired from Liquor distribution branch, BC Ministry of Attorney General. These exogenous variables were used, wherever significant, to account for the changes in the external environment before assessing the photo radar program effect.

The validity and reliability of the explanatory variables, i.e., motor gasoline sales, unemployment rate, draught beer sales, are questionable. To the extent that these variables represent the underlying constructs and that the data collection process follows industry standard, they tend to increase the internal validity of the study design. Balancing the pros and cons, given that these variables are the best measure available for the constructs, they are included initially in the models.

Other Traffic Safety Programs

As briefly alluded earlier, a number of other province-wide traffic safety programs were operational or being introduced in the similar time period as the photo radar program. The two most significant ones are the enhanced drinking and driving programs, which was in operation when the photo radar program was introduced, and which was deployed mostly at night time in major urban centres in the province; and the enhanced speed enforcement which was introduced gradually in May 1997 on selected highways corridors in the province, and which was mostly deployed at daytime hours. The impact of drinking driving program was accounted for by removing night time collisions from the time series analysis, as described in the research design section. The enhanced speed enforcement program cannot be separated by time of the day. The program was, instead, introduced as an "other program" variable, directly into the models to capture its effect. The ramp form, a simple linear indicator variable similar to a observation number variable, used in SAS modelling and forecasting procedure, was used to represent the enhanced speed enforcement program in the model, recognizing the increasing level of program delivery over the time concerned.

Photo radar program variables

The form of the program variables was selected as simple dummy indicators, denoted as 0 or 1 to reflect the presence or absence of the program over time. The photo radar program was introduced in two phases, the warning letter phase and the violation ticket phase. Consequently, two program variables are accordingly coded. These two program variables are included in the analysis to capture program effect on traffic safety measures.

The forms of the treatment conditions are based on theoretical and empirical grounds. Simple dichotomised indicator variables, corresponding to step functions in time series intervention models shown later in this section is easy to interpret and is commonly used in the intervention studies. However, it may not reflect the complex nature of the impact of the program on driver behaviour along the time dimension. More complex forms of program effects for the violation ticket phase, such as abrupt permanent, gradual permanent, and abrupt temporary, were considered theoretically and tested empirically.

Theoretically, it is conceivable that drivers could change their driving behaviour gradually due to incremental or phased-in approach of intervention programs. In fact, the BC photo radar program was introduced gradually in terms of photo radar deployment hours and the number of photo radar tickets issued.

Empirically, the BC collision data was fitted to various model forms and study results of other jurisdictions were sought for reference. T-tests for the parameters representing the complex intervention forms were reported by SAS program. The significance of the parameters was used as empirical evidence to facilitate the selection of intervention forms. Step functions were selected finally, based on the considerations of four factors: 1) statistical concerns that higher order parameters are insignificant; 2) recognition that there was overwhelming publicity of the date and, in some instances, locations of the implementation of the BC photo radar program in the province; 3) the desire for simplicity in interpretation; and 4) standardisation and comparability with previous studies in other jurisdictions.

ANALYSIS TECHNIQUES

Different analytical frameworks were applied to assess the speed and safety impact of the program. The selection of the methods depends on the quality and quantity of the data for each measure and the availability of the analysis techniques under the circumstances.

Traffic speed

Due to the lack of sufficient speed data before the implementation of the photo radar program, traffic speed and speed changes were not statistically modelled. Instead, a set of descriptive statistics of the data was produced. Graphs were generated to demonstrate the reduction in the proportion of speeding vehicles after the introduction of the program across the photo radar treatment sites and the selected monitoring sites across the province. Descriptive statistics were calculated to quantify the observed change in speeding behaviour.

The data obtained from photo radar devices are at the vehicle level. Each vehicle passing the deployment sites was monitored and the speed recorded by the photo radar unit. To summarise the speeding behaviour of the motorists at photo radar deployment sites and at the time when photo radar device were deployed, average proportions of speeding vehicles were calculated. The calculation is a simple division of the total number of speeding vehicles detected across all the deployment sites by the total number of vehicles monitored at the same photo radar deployment sites and at the same time. Due to the fact that the monitoring sites are relatively stable over time, the comparison between monthly aggregates was deemed valid for the descriptive analysis.

The data obtained from speed loops at the monitoring sites are frequency distributions in bins, used to classify speeds. The bin median was used to represent the speed of all the vehicles falling into a bin. The mean speed of the speed loop site was derived by averaging the medians in each bins, with the number of vehicles in each bin functioning as the weight. To generalize the averages at each site to the provincial averages, another round of weighted averaging was conducted. The weight for this process is the number of vehicles registered in each region, whereby each of monitoring sites is located. The overall means over time was used to study the changes in drivers' speeding behaviour in the province.

Traffic safety

The analysis of traffic safety is much more involved, given the purpose of the program and the availability of data. Interrupted time series analysis (McCleary, Hay, 1980; McDowall et. Al, 1980) was selected and applied to each of the traffic safety measures, i.e., monthly traffic victims carried by ambulance, and police reported traffic fatalities. Interrupted time series analysis is often referred to as ARMAX models, ARIMA impact analysis, or Transfer Function models. It constitutes one type of quasi-experimental design, which could be used to describe social process and assess changes in the process in response to a policy initiative or other exogenous impetus. A detailed description of the technique is presented in the modelling fitting section below.

The overall modelling approach strives to uncover as much information on the traffic safety program under investigation as the data allows, while keeping the model simple by parsimoniously selecting and including covariates, auto-regressive/moving-average (ARMA) variables. The selection process starts with all theoretically plausible covariates and empirically tests these covariates in combination with ARMA variables. The explanatory variables that pass the 0.05 significant level are included in the next step of analysis. The only exception is within groups of related AR factors (such as monthly variables). It was deemed advisable, based on econometric principles, that a lower-order AR variable should not be arbitrarily rejected if a higher-order related AR variable is significant.

The three potential explanatory variables, motor gas sales, unemployment rate, and draught beer sales were initially included in the model. Draught beer sales and the employment rate were later eliminated from the time series models due to insignificant Cross Correlation Functions (CCF).

The main advantage of interrupted time series analysis is the capacity to account for autocorrelation, in addition to other exogenous variables before attempting to assess the significance and magnitude of program interventions. Standard least square regression would underestimate the standard error of the parameter estimate and overestimate the significance of the parameters. Interrupted time series were selected over vector autoregression model (VAR) due to the consideration of independent verification of evaluation estimates (Hamilton, 1994). Recognizing the uncertainties in the reliability of any empirical data series, separate analysis of data from different and independent sources were considered to provide more confidence to the corroborated findings.

There are distributional assumptions in the modelling of traffic safety at the provincial level. First, the numbers of traffic collision injuries are assumed to follow a normal distribution. This assumption is deemed reasonable due to the fact that monthly collision injuries are aggregate counts over all highways in the province in a monthly time period.

Second, the time series are required to be stationary in variance in the ARIMA type of analysis. The potential violation of this assumption is partially overcome by explicitly modelling the effect of explanatory variables, to the extent that these variables are known, measured and data are reliable. At various stages of the model building process, the error series were tested for unit roots, using Augmented Dickey-Fuller test, to safe guard the concerns of stochastic trend.

Finally, the underlying process of traffic safety as identified by the multivariate models is assumed to be continuing. This assumption provides the foundation for forecasting the counter-factuals for illustration and testing and quantifying the intervention effect through the interrupted time series models. This assumption is justified based on the model validation process from the validation sample, and the verification of regularities of other influential variables through examination.

The analytical technique used in the study is the Multivariate Interrupted Time Series analysis, popularized by Box and Tiao (1975), Box and Jenkins (1976), McDowall et al. (1980) and McCleary and Hay (1980). The procedures delineated by McCleary and Hay (1982) were followed closely, recognizing their social science context. In addition, to test the model fit, a null ARIMA model (a model without the program intervention component) was first estimated, using data between August 1990 to July 1995. This partition of time deliberately leaves 7 months data (August 1995 to February 1996) for the testing and verification of the null model before it was applied to the after intervention data series to assess program impact.

To independently corroborate the results of impact assessment, ARIMA models were fitted to each outcome measure separately to estimate the intervention effect of the photo radar program. Each model potentially includes three main parts, a transfer function of covariates, an intervention function of the program variables, and an ARIMA noise component.

Model fitting is a dynamic, iterative process. For each safety measure, the data modelling process is comprised of three main elements: constructing a null model, testing the null model and applying the null model in the assessment of the program intervention effect. Specifically, the analysis assumes the following steps:

- preliminary univariate analysis,
- transfer function identification,
- initial noise component identification,
- multivariate null model estimation (the name of null model is used to distinguish the intervention, full model),
- noise and transfer function diagnosis,
- model validation,
- intervention function identification,
- full model estimation, and
- full model diagnostic check.

At a number of points in the modelling process, the model was checked for adequacy. Failing relevant tests, new models were identified and estimated. Descriptions for each of the steps in the process is provided in the following sections.

Preliminary univariate analysis

The raw data are previewed and univariate models were built for the criterions and covariant time series. This preliminary analysis provides a general picture of the data to be analysed and the preliminary direction of models to be contemplated.

Transfer function identification

Covariate measures were selected and transfer functions identified for each covariate as they relate to the criterion time series. The main tool for the selection and identification procedure is the bivariate Cross Correlation Function (CCF) between the criterion variable and each covariates. The preliminary models for the covariates estimated were inverted and applied to the covariate and the respective safety measures, a process often referred to as prewhitening. The step of prewhitening ensures that the prewhitened series is a white noise. The CCF of the prewhitened time series provides information for the identification of the transfer function for the covariate (McCleary and Hay, 1980). Parameter estimates approximating t-tests were used as the criterion for inclusion for the three covariates, motor gasoline sales, unemployment rates, and Draught beer sales after prewhitening. Only motor gasoline sales is significant at the 0.05 level at lag zero for the injury criterion variable. This covariate was retained in the model estimates for injuries. Motor gasoline sales and unemployment rates are not significant at any lag at the 0.05 significant level for either fatality or injury, and they were excluded from further analysis.

Noise component identification

Combining all the selected covariates and identified transfer functions from the bivariate analysis, a transfer function model for each safety measure was estimated. The residuals from each model were used to identify an ARIMA model for the noise component. The identification process follows the univariate ARIMA analysis procedure.

Multivariate null model estimation

The parameters for the covariate transfer function and noise component were then entered into the multivariate null model for estimation. The parameters were estimated simultaneously in this step. The only covariate past the test is motor gasoline sale in the traffic injury model. This variable was retained in the multivariate null model to increase its explanatory and predatory power.

Noise and transfer function diagnosis

The multivariate null models were then checked for normality through skewness and kurtosis, adequacy as manifested by white noise residuals and independence between the prewhitened input variables and the residuals. If satisfied, the null model was deemed adequate and used for forecast and model validation.

Model validation

The fitted multivariate null model was used to generate interval forecasts for the period between August 1995 to February 1996, a period immediately prior to the commencement of the warning letter phase of the photo radar program, and specially reserved for model validation purpose. The realized numbers of injuries in this period were then compared with the forecast intervals. Given that there were no other major changes that could impact on the safety measures in the 7-month period, if the realized safety measures fall into the predicted interval, it would be considered evidences to support the validity of the selected model. Point predictions of the model were then considered as the counterfactuals, reflecting the expected level of safety, had the program not been implemented. More importantly, the structure with the estimated parameters of the null model were then used as a basic building block for the construction of the full intervention model, which is then used to quantify the impact of the program.

Intervention function identification

Empirical evidence from social intervention studies shows that intervention program impact can normally be captured by one of three forms: abrupt permanent, gradual permanent, and abrupt temporary (MCDowall, McCleary, Meidinger, and Hay, 1980). The fourth possibility: the gradual temporary effect pattern, is rare and difficult to model in simple forms. In the context of current study, this representation contradicts the fact that the level of the photo radar enforcement was increasing and remaining at an escalated level in the study period, that traffic speed remained at a lower level after an initial reduction following the introduction of the program, and that the number of collision injuries and fatalities decreased and remained at the lower level, similar to the pattern of speed reduction, in the study period, which is shown in the following results and discussion section. Consequently, the gradual temporary representation of photo radar traffic safety effect was deemed implausible in the modelling of the safety effects.

The abrupt temporary impact patterns reflect an immediate response in traffic safety after the introduction of the photo radar program. However, the response gradually returns to the original level as the novelty of the program fades out. This pattern of intervention can be represented by applying the first-order transfer function to a differenced intervention function. However, similar to the comparison of the model and the empirical data for the gradual temporary case, the abrupt temporary pattern was considered not fitting the data well, recognizing that speed and safety remained at the improved level in the study period after the initial change. This pattern was therefore rejected.

The gradual permanent form of the intervention component describes a probable phenomenon that traffic safety increased gradually after the introduction of the photo radar program. This impact form can be represented as a first-order transfer function as suggested by McCleary and Hay (1980). This function can be approximated by a ramping function as implemented in the SAS ETS and the Time Series Forecasting Systems. It was initially used in the study to model the warning letter phase of the program. However, the ramping function, measuring the average incremental effect of the warning letter phase on injuries and fatalities, proved to be insignificant. Pulse functions were instead used to estimate the individual safety effect of the warning letter phase on a month by month basis.

The abrupt permanent response function reflects a phenomenon that traffic safety is improved immediately following the introduction of the program and safety stayed at the improved level over the study period. This format is commonly used in other safety studies and it is simple in application and interpretation. The pattern is represented by a zero order abrupt permanent response. Given that motorists in British Columbia was informed of the timing of the program implementation and that the empirical data on traffic speed and collisions demonstrated a stable reduction when compared between the pre-program and the violation phase, the abrupt permanent response function was selected to represent the intervention of the violation tickets phase of the photo radar program.

Full model estimation

When applicable, the full model for each safety measures includes all the three components: covariate transfer function, noise model, and the photo radar intervention function. All the parameters in the selected model form are estimated in the final model estimation stage. The empirically identified insignificant covariates were excluded from the analysis, after a careful examination on substantive and theoretical grounds.

Full model diagnostic check

Diagnostic checks were again performed in the final stage of the model building process. Each model was assessed by examining their parameters, residuals, specifications, and predictive accuracy. Model parameters were checked for stability and convertibility in both the trend and seasonality contexts through both informal review and if necessary, formal unit root test. Over differencing was considered when suspected, especially for the seasonal models, by solving the characteristic equations corresponding to the initially identified ARMA models. The residuals of the models were checked for white noise and normality. The normality was checked with Bera-Jarque test (JB test) for skewness and kurtosis (Franses, 1998). Model adequacy (while noise) was tested using the chi-square test in Ljung-Box's form (Ljung and Box, 1978). Lagrange Multiplier (LM) tests in a nested models framework were applied to test augmented models and to confirm current models. For transfer function models, the cross-correlations with the input variables were also t-tested, following Box and Jenkins (1980).

Assessing model fit

The model fit was assessed from both internal and external perspectives. Internally, when more than one model were suggested by the traditional Box and Jenkins' method of model identification, model selection criteria, such as Akaike information criterion (AIC) were applied to chose the one with better fit.

As expressed above, the modelling process followed the parsimony principle. Only significant or borderline significant variables were included in the final models. The only exception is for the program intervention variables, which are the main object of the overall study. The estimates for the intervention components in the final model were used as the measures of magnitude of the program safety impact.

Externally, the predictive ability of the model is also assessed by comparing the forecast values and intervals with the observed data between August 1995 to July 1996, which has been set aside intentionally for out-of-sample model fit assessment.

RESULTS AND DISCUSSION

This section provides the results and discussion from the province-wide evaluation of the BC photo radar program. It is organized into two main sections: speed effects and safety effects. The speed effect is further divided into the effect in the presence of the photo radar program and the effect in the absence of the program, corresponding to the program goals and the evaluation questions.

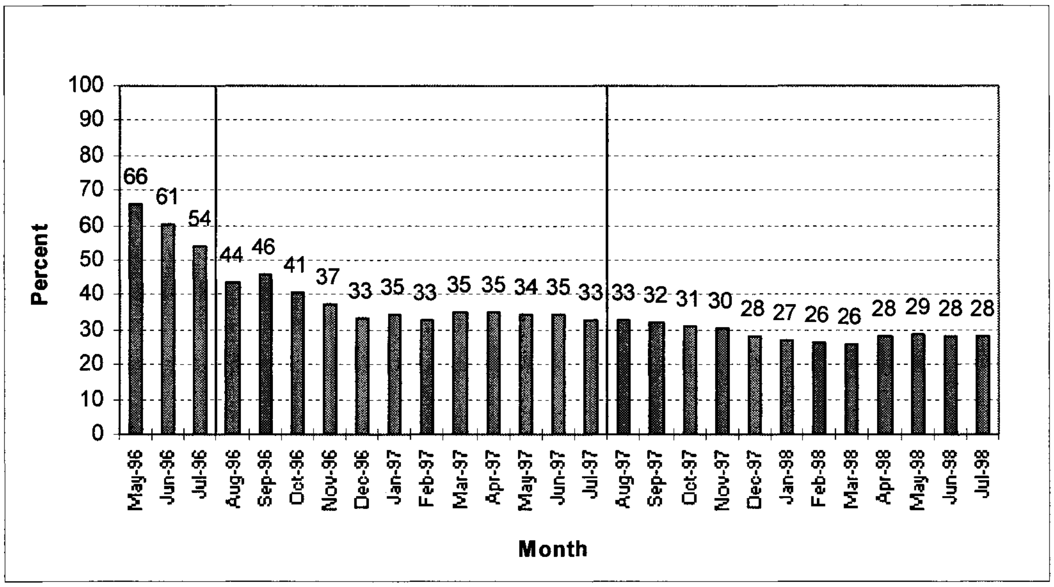
Traffic Speed Effect

It should be noted that the traffic speed data at photo radar deployment sites and non-photo radar deployment sites were obtained from different sources, using different devices, and with different time lengths. For photo radar sites, the data were obtained from the photo radar devices. Given that photo radar devices were not specially deployed to collect baseline data before the warning letter stage, and that there is very limited data before May 1996 in the early warning letter phase, only data after this point is used in the following analysis. For the province-wide monitoring sites, special arrangement was made to collect baseline data before the implementation of the photo radar program. Consequently, the data series extend back to September 1995.

Traffic Speed at the photo radar deployment sites -- photo radar data

The proportion of speeding vehicles at the photo radar deployment sites declined following the introduction of the photo radar program. Most of the reduction occurred in the warning letter phase when the drivers were informed of the pending ticketing phase of the program. The decrease continued further in the first year of violation ticket phase of the program. Figure 5.1 shows that the percentage of vehicles exceeding posted speed limits decreased from more than 60% in the early warning letter phase to an average of 37% in the first year and to under 30% in the second year. This represents a 39% reduction in the first year of violation ticket phase, and a further 21% decline in the second year, compared with the first year. The proportion of speeding vehicles remained at below the 30% level throughout the latter part of the second year.

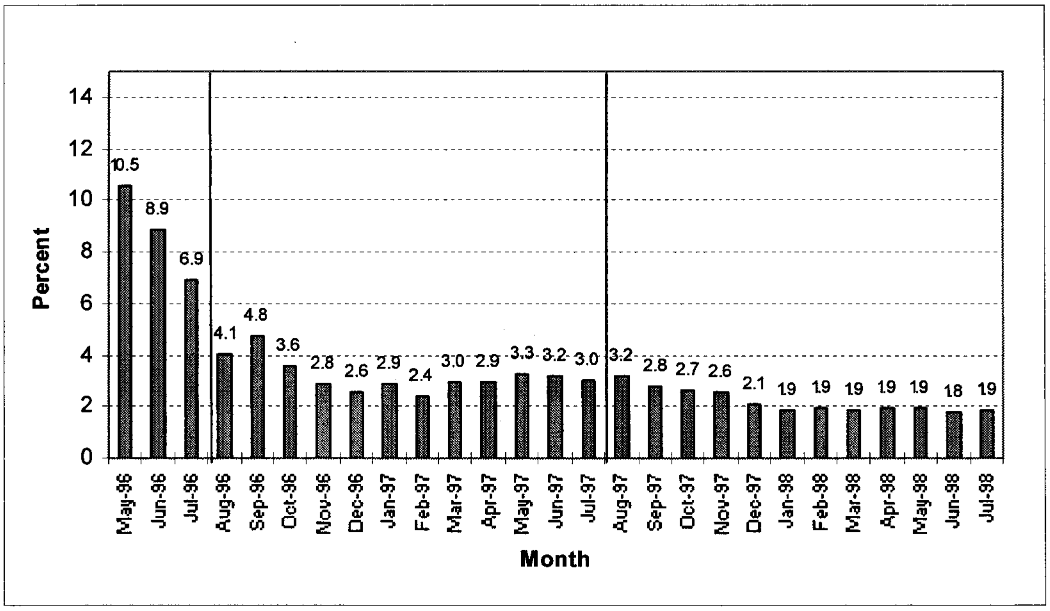
Figure 5.1 Percent of Vehicles Exceeding Posted Speed Limit at Photo Radar deployment sites



Note: The vertical lines represent the commencement of the violation tickets phase and the second year of the violation ticket phase of the program.

In the similar pattern, but at a much greater rate, the proportion of excessive speeding vehicles also declined. As shown in Figure 5.2, the percentage of excessive speeding vehicles was over 10% at the beginning of the warning letter phase. The percentage dropped to an average of 3% in the first year and to approximately 2% in the second year. This represents a 63% reduction in the first year of violation ticket phase, and a the further 34% decline in the second year, when compared with the first year. The proportion of speeding vehicles remained below the 2% level throughout the later part of the second year.

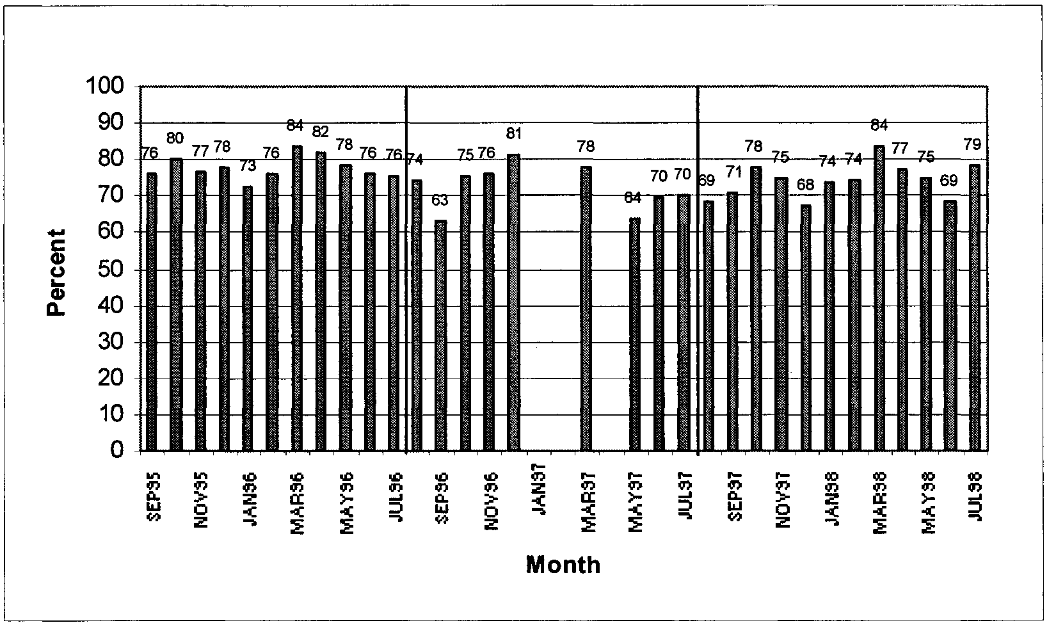
Figure 5.2 Percent of Vehicles Exceeding Posted Speed Limited by 16+ Km/Hr Photo Radar deployment sites



<u>Traffic Speed at Monitoring Sites - Induction loop data</u>

Figure 5.3 displays the average percentage of vehicles exceeding the posted speed limit across the speed loop sites during the sampling period. To estimate the driving behaviour of motorists in the province as a whole, the proportion of speeding vehicles were first calculated within a region by dividing the total number of speeding vehicles observed at the speed loop monitoring sites by the total number of vehicles monitored in the eight day data collection period each month. The regional proportions of vehicles are averaged to arrive at the provincial estimates, using the number of registered vehicles in each region as the weight.

Figure 5.3 Average Percentage of Speeding Vehicles across all Monitoring Sites, Weighted by Regional Vehicles



Note 1: Data from Sproat Lake, Maple Ridge, Westbank, Surrey, and Golden were not used in the graph due to speed limit change, inappropriate site location, and missing data.

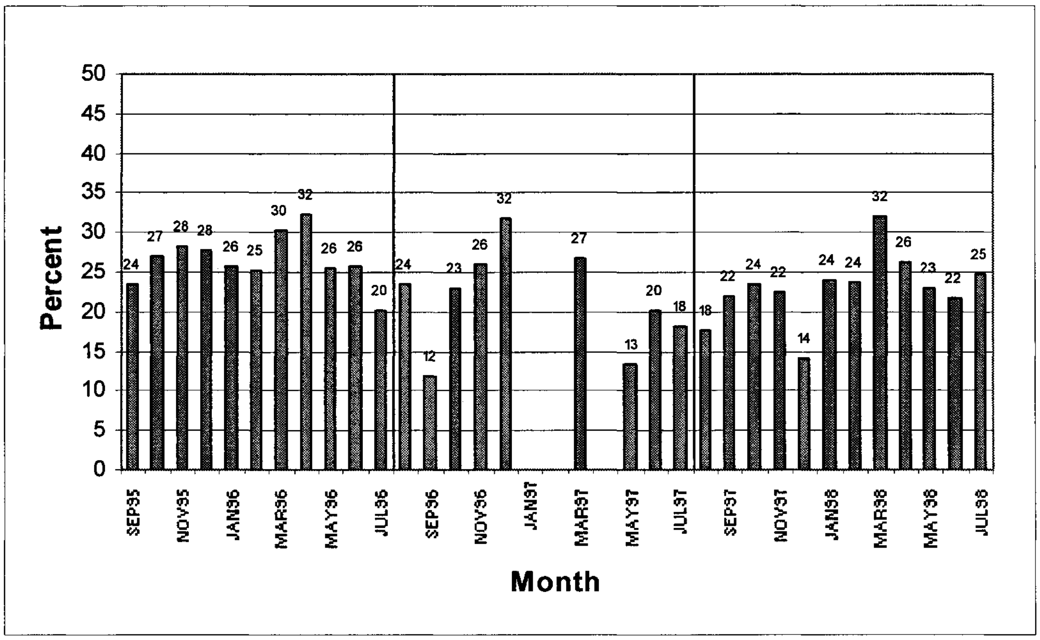
Note 2: Data for the months of January, February, and April 1997 were not collected for most of the monitoring sites. Therefore, no summaries for these months are presented in the graph.

Figure 5.3 shows that the change in the proportion of speeding vehicles followed a different pattern at the monitoring sites across the province, where photo radar device was not deployed. No dramatic reduction in the proportion of speeding vehicles was found as compared with that at the photo radar enforcement sites.

However, a close examination of Figure 5.3 suggests that a limited decline in the proportion of speeding vehicles did occur after the introduction of the program. Aggregated into three time periods: from September 1995 to July 1996 as the pre-PRP period; between August 1996 and July 1997 as the first year; and between August 1997 and July 1998 as the second year, it was calculated that the average proportions of speeding vehicles declined from 78% in the pre-PRP period, to 73% in the first year of program, and rebounded minimally to (74%) over the second year period.

Similar to the contrast between speeding and excessive speeding groups at the photo radar enforcement sites, greater reduction was observed in the excessive speeding group at the monitoring sites generally in the absence of policy enforcement. Figure 5.4 presents the average percentage by month across the monitoring sites. The average percentage of excessive speeding vehicles declined from 27% in the pre-PRP period, to 22% in the first year, and then reversed slightly to the 23% level in the second year after the introduction of the program.

Figure 5.4 Average Percentage of Vehicles Exceeding Speed Limits by 16+ km/h, all Monitoring Sites, weighted by Registered Vehicles in a Region



Note 1: Data from Sproat Lake, Maple Ridge, Westbank, Surrey, and Golden were not used in the graph due to speed limit change, inappropriate site location, and missing data.

Note 2: Data for the months of January, February, and April 1997 were not collected for most of the monitoring sites. Therefore, no summaries for these months are presented in the graph.

Traffic Safety Effect

Two analyses were conducted on the safety impact of the photo radar program, each using an independent data sources. The first study assessed the traffic safety impact in terms of daytime traffic collision victims carried by ambulance. The data is obtained from the BC Ministry of Health. The second study estimates traffic safety impact as measured by daytime traffic collision fatalities. The data were obtained from the police. The results are reported in the following sections.

Impact on Day-time Traffic Casualties -- Victims Carried by BC Ambulance

The monthly number of day time collision victims carried by ambulances is shown in Figure 5.5. A null-model forecast, had the program not been implemented is also presented in the figure for comparison purpose. The null model employed the data between January 1991 to July 1995. The method of the null model estimation is presented in the method section of the chapter.

Figure 5.5 suggests that the number of injuries decreased since March 1996, corresponding to the warning letter phase of the program and the resulting speed reduction as presented in the previous section. The number of monthly traffic collision injuries continued to decline over the two-year period after the introduction of the violation tickets phase of the photo radar program.

The magnitude and significance of the safety effect of the program was estimated with a time series intervention model, the full model, as outlined in the method section. Detailed results are presented in Appendix D. The parameter estimates are extracted and presented in Table 5.2.

Figure 5.5 Daytime traffic collision victims carried by ambulances in British Columbia, January 1991 - August 1998

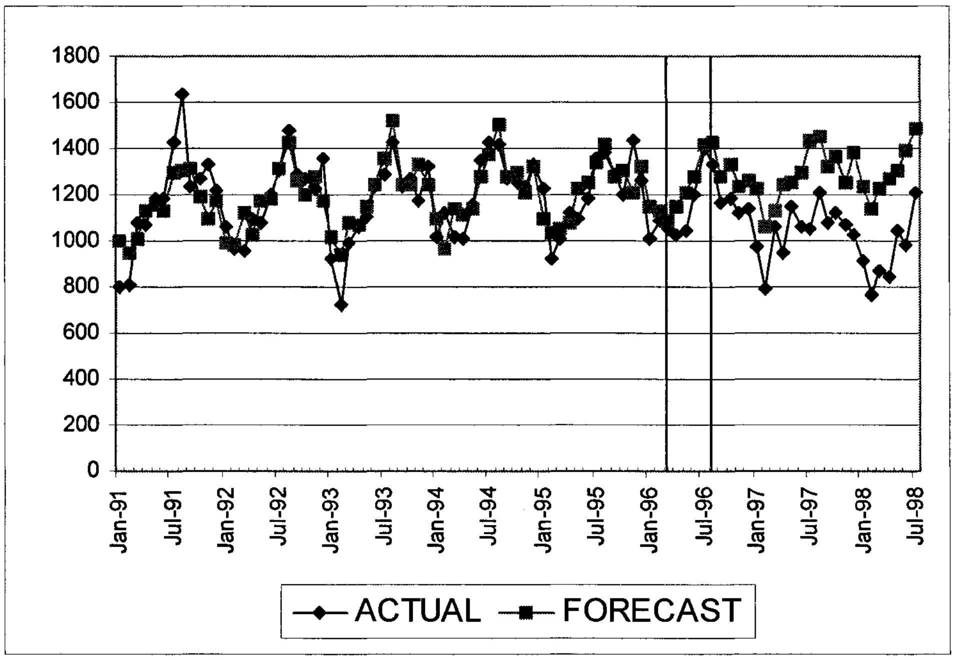


Table 5.2 employed pulse functions and step function to estimate the safety effect in the warning letter and violation tickets phases of the photo radar program respectively. A step function and a ramping function were initially constructed to test all the monthly variables in the warning letter phase together. The results of the tests were insignificant. To extract as much information as the data provide for the program intervention factors, given that the bridging factor, the traffic speed, is reduced during the warning letter phase, a more detailed but less powerful test of pulse function was kept in the formulation.

Table 5.2 and Appendix D show that the full model is adequate and fits the data well. The errors of the intervention model are stationary before the addition of the noise component, as ADF statistics are all significant, rejecting the null hypothesis of unit root. The error of the full model is a white noise as tested by LB or portmanteau test (Ljung and Box, 1978). The AIC index is the least of the tested, both alternative and augmented models. The model with all monthly variables had a lower AIC than the model omitting them, indicating that retaining these variables improves the predictive power of the model.)

Table 5.2. Model Statistics for Daytime Traffic Collision Victims Carried by BC Ambulances

Variable	Estimate	St.Error	t Value	Pr > |t|	Lag
Intercept	339.0397	172.6762	1.96	0.0531	0
Autoregressive, Lag 1	0.2836	0.1113	2.55	0.0128	1
Seasonal Autoregressive, Lag 12	0.2535	0.1175	2.16	0.0341	12
Seasonal Autoregressive, Lag 24	0.2896	0.1265	2.29	0.0247	24
GAS_SALE	0.0026	0.0005	4.95	<0.0001	0
Mar-96	-47.7786	98.9748	-0.48	0.6306	0
Apr-96	-93.0483	103.2706	-0.90	0.3703	0
May-96	-207.8516	104.8396	-1.98	0.0509	0
Jun-96	-68.1273	103.1505	-0.66	0.5109	0
Jul-96	-36.5014	100.3699	-0.36	0.7171	0
PRP violation ticket phase	-184.9803	46.5008	-3.98	0.0002	0
other programs	-13.6172	5.2710	-2.58	0.0116	0

Table 5.2 indicates that a material reduction in collision injuries occurred after the introduction of the warning letter phase of the photo radar program. It is estimated that more than 200 traffic collision injuries requiring ambulance services were avoided in May 1996 alone, three month into the warning letter phase of the photo radar program. However, the reductions are not statistically significant at the 0.05 level. They were not included in the following analysis, with potential bias of underestimating the program safety effects.

Table 5.2 shows a statistically significant ramping effect after the starting of other traffic safety programs, mainly referred to the enhanced corridor speed enforcement program. On average, about 14 incremental injuries were averted every month, due to the gradual introduction of the corridor speed enforcement program.

Substantively material and statistically significant reductions were revealed in the violation tickets phase. Table 5.2 suggest that on average, 185 injuries were avoided each month in the two-year period after the introduction of violation tickets phase of the program, over and above other traffic safety programs and the changing volume of driving. The yearly total number of injuries requiring ambulance services is therefore calculated to be 2,220. This represents 14% reduction based on the prediction of the null model, had the program not been implemented.

Traffic Fatalities

The monthly totals of day time traffic collision deaths in the province (excluding 8 police detachments) from January 1991 to July 1998 are presented in Figure 5.5. For illustrative purpose, the number of fatalities if the program had not been implemented, based on the null model as described in the method section is superimposed in the figure to provide another dimension of comparison. It is observable that the predicted number of fatalities is almost flat, lacking seasonal fluctuation as shown in the injury forecasting model.

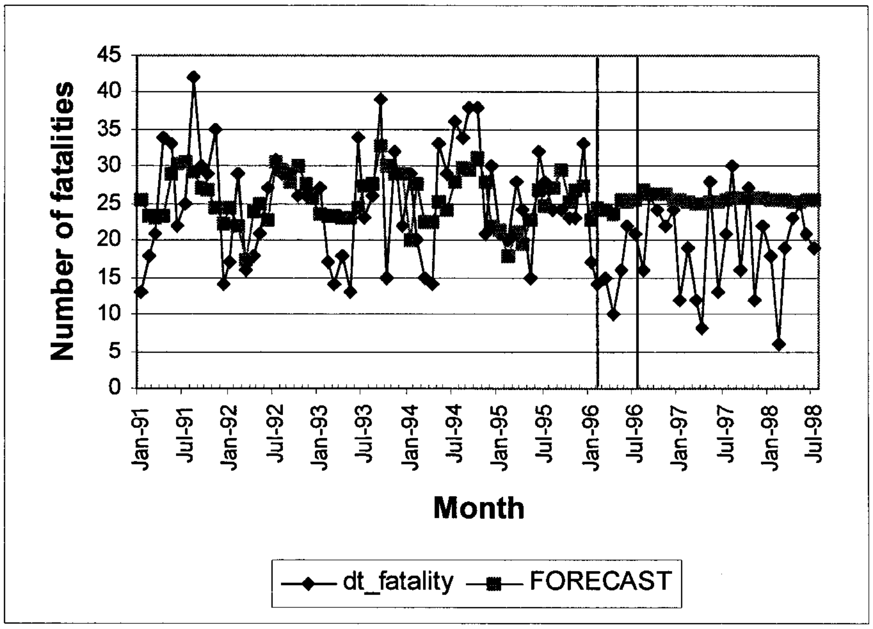
This is due to the fact that traffic collision fatalities are rare events, much more random than traffic collision injuries. This fact is reflected in time series as greater irregularities, resulting in statistically non-significant seasonal factors, which were rejected from further modelling on that basis. That is the why the prediction is a straight line while the historical data fluctuates considerably.

Figure 5.6 shows that the monthly fatalities fluctuate considerably over time. This is mainly due to the small numbers associated with traffic collision fatalities. However, a downward trend in the data series is still discernible, around the introduction of the photo radar program.

Compared with the counter-factual number of fatalities as estimated by modelling the historical data between January 1991 and July 1995, the reduction of fatalities is again apparent. Most of the data points are under the predicted numbers of fatalities, had the program not been implemented.

Overall, Figure 5.6 suggests that the number of traffic collision fatalities fell abruptly in the early warning letter phase of the program. The number of monthly traffic fatalities is under the expected numbers if the program had not been implemented in most of the months in the two year period after the introduction of the violation ticket phase.

Figure 5.6. Daytime traffic collision fatalities in British Columbia, January 1991 - August 1998



Note: traffic collision fatality data from detachments '0112', '0111', '0221', '0219', '0524', '0506', '0507', '0508' were not used in the study due to changes in collision reporting practice.

The number of fatalities saved due to the photo radar program is estimated by the interrupted time series model, the full model as described in the method section. The results of the identification, estimation, and forecast process for the full model are presented in Appendix E. Selected results, the estimates of the program effects, is extracted and provided in Table 5.3.

Overall, the model fits the data reasonably well, given the nature of fatalities as extreme rare events with an overwhelming random variation component. The residual of the intervention model is stationary, as ADF statistics are all significant, rejecting the null hypothesis of unit root. The error of the full model is a white noise as tested by LB or portmanteau test (Ljung and Box, 1978). The AIC statistic is among the least of all the tested augmented models.

Table 5.3. Model Statistics for Daytime Traffic Collision Fatalities in BC

Parameter	Estimate	St. Error	t-Value	Pr > |t|	Lag
Intercept	25.1792	0.5665	44.44	<0.0001	0
Autoregressive, Lag 1	0.0323	0.1123	0.29	0.7736	1
Autoregressive, Lag 2	0.0158	0.1102	0.14	0.8862	2
Autoregressive, Lag 3	0.1059	0.1143	0.93	0.3542	3
Autoregressive, Lag 4	-0.2107	0.1101	-1.91	0.0557	4
Autoregressive, Lag 5	-0.0273	0.1108	-0.25	0.8052	5
Autoregressive, Lag 6	-0.2182	0.1154	-1.89	0.0586	6
Autoregressive, Lag 7	-0.2505	0.1167	-2.15	0.0318	7
Point:MAR1996	-9.5414	6.5949	-1.45	0.1480	0
Point:APR1996	-13.0164	6.5571	-1.99	0.0471	0
Point:MAY1996	-7.2174	6.4777	-1.11	0.2652	0
Point:JUN1996	-4.2631	6.4844	-0.66	0.5109	0
Point:JUL1996	-4.8036	6.5247	-0.74	0.4616	0
prp_vt	-6.6106	1.5546	-4.25	<0.0001	0
otherprog	0.0934	0.2342	0.40	0.6900	0

Table 5.3 shows that substantively material reduction in collision fatalities was detected after the introduction of the warning letter phase of the photo radar program. All the months after the warning letter phase are associated with reductions in traffic fatalities. The largest reduction occurred in April 1996, when more than 13 traffic collision deaths were saved in one month. However, except for the month of April, the reductions in traffic collision fatalities are insignificant at 0.05 level, due to the same reason of lower power of tests one month at a time.

Different from collision injuries, no physically nor statistically significant effect of other traffic safety programs were revealed. The enhanced corridor enforcement program is associated with a reduction of less than one traffic death, which is by far insignificant in the statistical test.

The analysis estimates that, on average, a reduction of 6.6 fatalities per month in British Columbia occurred after the introduction of the violation phase of the photo radar program. This estimate is statistically significant.

The monthly reduction in collision fatalities was multiplied by 12 to arrive at the yearly fatality reduction. The total is therefore estimated to be 79 deaths saved. The percentage reduction is estimated by comparing the number of deaths reduced to the number of deaths predicted, had the program not been implemented, using the null model described earlier and in the method section. Using this method, it was estimated that the photo radar program is associated with a 26% reduction of collision fatalities, after removing the effects of history and other traffic safety programs.

SUMMARY

The BC photo radar program was implemented through a publicity campaign through the media and speed enforcement by the deployment of 30 photo radar units. A province-wide impact assessment shows that both traffic speed and traffic casualties declined following the introduction of the program. The proportion of speeding vehicles decreased from more than 60% in the warning letter phase to 37% in the first year and to 30% in the second year. The proportion of speeding vehicles remained at below 30% level throughout the second year. The proportion of excessive speeding vehicles decreased from more than 10% in the warning letter phase to 3% in the first year and to 2% in the second year.

Traffic speed at non-enforced locations also declined after the enforcement program. The average proportions of speeding vehicles declined from 78% in the pre-PRP period, to 73% in the first year of program, and stabilised at that level (74%) over the second year period. The proportion of speeding vehicles exceeding speed limits by 16 or more km/h across the monitoring sites declined from 27% in the pre-PRP period to 22% in the first year and then rose slightly to 23% in the second year. The proportion of speeding vehicles remained at the reduced level across the province.

The reduction in speed is followed by a reduction in traffic collision casualties. The evidence from both the police and Ambulance Services sources showed that approximately 2,220 (14%) fewer injuries and up to 79 (26%) fewer traffic related fatalities were experienced in the two-year time period after the violation phase of the photo radar program.

This impact assessment is limited in research design. It is recognised that quasi experiments do not control all the factors, other than the intervention, that could affect traffic speed and casualties. This issue is particularly disturbing when the assessment is conducted at a macro level, as is the present study in British Columbia. Detailed information on program implementation at each location and time is not included in the analysis. Driver behaviour in response to the enforcement is evaluated as aggregates. These facts diminish the ability of the study design to establish causal links between the program, driver behaviour change, and the resulting improvement in traffic safety. This province-wide impact assessment should be regarded as of limited internal validity by itself alone. To validate the province-wide study, recognising its innate weaknesses, and to corroborate the results with additional evidence, a site-specific impact assessment was conducted in selected BC highways where detailed information on enforcement, traffic speed, and collisions, are available. The process and the results of the site-specific study are presented in the next chapter.

6. IMPACT ASSESSMENT II: SITE-SPECIFIC, SPEED AND SAFETY EFFECTS

This chapter presents the method, results, and discussion of the site-specific speed and safety evaluation of the photo radar program. The specific research questions, as outlined in the program logic model chapter earlier for the site-specific study are:

- To what extent is traffic speed and speed variance reduced at photo radar deployment locations and at a speed monitoring location on the highway, 2-km from the nearest deployment location, as a result of the photo radar program?
- To what extent are traffic collisions reduced at PRP deployment locations and at non-PRP interleaving locations along the study corridor as a result of the photo radar program?
- Does the evidence support the traffic collision migration hypothesis? Or, conversely, does the evidence support the beneficial spill over effect of the program?

METHOD

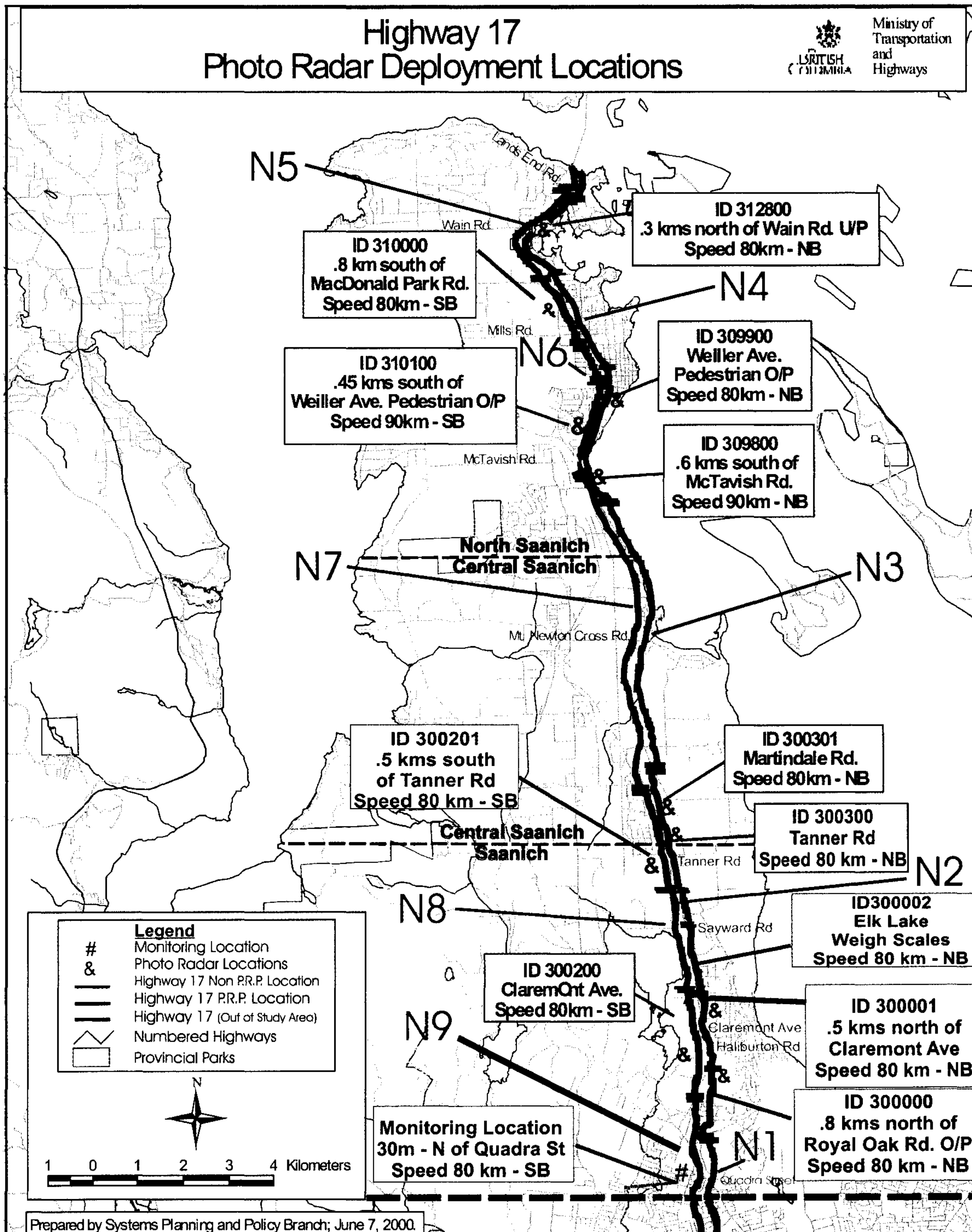
This study is designed to assess the speed and safety impacts of the BC photo radar program on selected highway sections in the province, a site-specific analysis. A site-specific study was conducted to verify the estimates of the speed and safety effect of the program obtained earlier from the province-wide impact assessment and to strengthen the causal links between the program and its traffic safety effects, the internal validity of the evaluation. Advanced research methods and statistical techniques, such as an Empirical Bayes approach was used, and adapted when necessary, to estimate program effects. The study controls for time effect, regression to the mean, distance and time halo effect, and accident migration. The comprehensiveness of technical sophistication in the design of the present evaluation was not found in any of the reported studies in traffic safety evaluation in the extensive literature review presented before.

However, similar to many other evaluative studies of government social interventions, especially with traffic safety programs, this study is plagued with inconsistency of data quality and inability to implement ideal designs. For example, the province does not have speed data at photo radar enforcement sites prior to the program implementation. Given that the limited speed data does not lend itself to a time series analysis, similar to the province-wide impact assessment above, simple before-after comparison was used to summarize the speed effect. The more involved observational before-after method with comparison groups was employed to estimate the safety effect. To deal with regression to the mean, the Empirical Bayes (EB) method was selected to estimate the expected collisions in the before period. The EB method incorporates prior knowledge of the traffic safety at similar sites and the current observation at the study sites to improve the estimate of traffic safety, relative to the observed numbers of collisions. This approach consequently reduces the potential bias in the comparison, when the sites are selected on the basis of high collision frequencies (Hauer, 1997).

Comparison groups were employed to predict the expected collisions in the after period to account for time effect. Time effect, as used in traffic safety studies, encompasses the history and maturity effects of social science studies, which are potential threat to internal validities.

The treatment corridor for the study was the 22-km length of Highway 17 extending north from Quadra Street to the Swartz Bay ferry terminal at the northern end of the Saanich Peninsula. The corridor is a four-lane divided highway with concrete barrier median and speed limits of either 80 or 90 km/h. The highway is not a completely limited access freeway, as it has a number of traffic lights along the corridor. It runs through primarily rural or light residential land. The study sites, the highway segments, and the immediate communities are shown in Figure 6.1.

Figure 6.1 Photo radar and non-photo radar deployment locations and proximity



The corridor was selected for the site-specific study of the photo radar program for a number of reasons. First, it is a corridor of sufficient length, with 12 individual photo radar locations (not all active at the same time). Second, it has been subject to photo radar enforcement since the program start date, providing two years of post-implementation data. Third, there are no realistic alternate routes for motorists travelling any distance along the corridor, making traffic migration highly unlikely. Fourth, police reporting of collisions along the highway has been consistent over the full study period, in contrast to many areas of the province, where level of reporting has deteriorated.

It should be noted that Highway 17 not is chosen for high collision history. However, the selection of photo radar deployment sites on highway 17 is based on speeding and safety problems. The number of collisions is likely to go down without any change in safety due to the regression to the means. Consequently, the Empirical Bayes method is used to prevent estimation bias due to this potential artifact.

The study corridor was divided into photo radar influence (PRP) locations and non-photo radar influence (non-PRP) locations. A PRP location is designated as a 2-km section of the highway, 1 km in each direction from the photo radar enforcement spot. The "&" and the text box in the map indicates and briefly describes the actual location of the photo radar devices. Three groups of PRP locations are separated by less than 2-km distances. They were combined as composite locations. The remaining highway sections, interleaved between the

PRP locations, were denoted as the non-PRP locations. These sections of highways were identified by cardinal numbers prefixed with "N", running from Victoria to Swartz Bay ferry terminal, and then from Swartz Bay ferry terminal back to Victoria. The length of the non-PRP locations varies from 0.4 to 5.9 km, depending on the proximity of the adjacent treatment locations.

Three police jurisdictions, Saanich, Central Saanich, and North Saanich/Sidney, are responsible for the reporting of traffic collisions on different sections of the study corridor. Other highways and roads within each of the three police jurisdictions on the peninsula, where photo radar was not deployed, were used as the comparison groups to adjust for the predicted collisions at the corresponding sections on the study corridor.

DATA

The main data items and their selected data attributes in this study are listed in Table 6.1. No missing data were recorded in any variable for the study periods.

Table 6.1 Study variables and attributes in the site-specific evaluation

Category	Variable	Description	type	Constraint	Time range
Speed	Mean speed (PRP)	Averaged across site by month on study hwy	Num.	Non negative	2-y after
	Speed variance (PRP)	Calculated across site by month on study hwy	Num.	Non negative	2-y after
	Mean speed (Non-PRP)	Averaged over 8-day sample by month	Num.	Non negative	1-y before 2-y after
	Speed variance (Non-PRP)	Calculated over 8-day sample by month	Num.	Non negative	1-y before 2-y after
Safety	Number of collisions	2-year total, all collisions, on study hwy unit.	Num.	Non negative	2-y before 2-y after
Covariate	Highway Section Length	Homogeneous sect. of hwy with regard to lane, type, etc.	Num.	Non negative	2-y before 2-y after
	Traffic AADT	Average Daily Traffic over 94-96	Num.	Non negative	2-y before 2-y after
Control	Comparison group	Same police jurisdictions, not on hwy17 nor PRPloc.	Cat.	0 or 1	2-y before 2-y after

The data for quantitative variable in Table 6.1 is presented in Appendix C. The definition, source, and quality of the data are further discussed in the following section.

Data collection, validity, reliability, and limitations

Traffic speed data at the PRP location were collected using the photo radar devices. The mean speed and standard deviation of the traffic were calculated for each deployment at each deployment location. The length of deployment and the number of vehicles in each of the deployment varied substantially. Only deployments that surveyed more than 500 vehicles were included in the analysis. It should be noted that this speed measure captures speeds only during times when the PRP units are operating at the locations. No control was applied with regard to time of day or day of week.

Traffic speed data at the non-PRP location were collected by an induction speed loop approximately 2km south of the most southerly deployment location for both the before and the after periods. The induction loops measured the traffic speed on a continuous 24-hr basis, collected over an 8-day period every month. These data were used to assess speed behaviour in the absence of the photo radar enforcement.

Police reported collision data were obtained from the Traffic Accident System, maintained by ICBC. Two-year before and two-year after collision data were used in the study. The after period extends from April 1996, when the warning letter phase of the program started, to March 1998, after which a new traffic speed program commenced operation on the same corridor. The before period is correspondingly defined as April 1994 to March 1996.

Highway characteristics and traffic volumes for the reference groups and treatment corridors were also acquired. Traffic and selected highway characteristics on all BC divided highways were obtained from the BC Ministry of Transportation and Highways for the two-year before period. Highway type, speed limit and number of lanes were used as the basis for the selection of highways and annual average daily traffic (AADT) and segment length (LEN) were used directly to model traffic collisions for the reference population.

For localized traffic speed studies, mean speeds and speed variances are valid measures for driver speeding behavior. They are the direct targets of the photo radar intervention program and they are the standard measures in the traffic safety industry as summary statistics describing traffic speed. Given the accuracy of the instrument to collect the data (1km/hr), they are also reliable for current evaluative study. Collision and injuries are widely used measures for traffic safety. However, the reliability is compromised by the change of police data collection practice. The police reduced investigating and reporting minor collisions since April 1996. The threat was reduced by the use of data from other independent sources. Collision injuries reported by Ambulance services were used to verify the assessment results using the police investigation data.

MODEL FITTING

The EB analysis is composed of a number of steps, including 1) fitting a traffic collision model to the reference groups to empirically estimate the hyper-parameters and the means of the prior parameter distribution in the before period; 2) integrating the prior mean with the observed collision count to arrive at the posterior mean as the estimated expected collisions at each location for the before period; 3) predicting the expected collisions in the after period adjusting for time effect through comparison groups; 4) comparing the predicted expected collisions with the estimated collisions as measured by observed collisions at each location in the after period; and 5) combining the estimates to derive aggregated program effects at PRP and non-PRP locations, and for the study corridor as a whole.

Fitting models to reference group to estimate hyper-parameters and prior means at each study site in the before period

The model fitting procedure followed the work of Lawless (1987), Kulmala (1995), Mountain (1996) and Sayed (1998). It is based on two main assumptions with respect to data distribution and model form. The collision count at each site in the 2-year before period, as denoted by Y is a random variable. It is assumed to follow a Poisson distribution. This assumption is based on the fact that collisions are rare events. Theoretically and empirically, the count of these events at nuclear level follows Poisson models. That is:

$$P(Y = y \mid \Lambda = \lambda) = \frac{\lambda^{y} e^{-\lambda}}{y!}$$

$$E(Y \mid \Lambda = \lambda) = \lambda; \; Var(Y \mid \Lambda = \lambda) = \lambda \qquad (6.1)$$

The mean of Y, denoted by Λ, is a between-sites random variable, as each site has its own regional characteristics. Λ is assumed to follow a Gamma distribution with parameters k and k/μ, where k is the shape parameter. This is based on its flexibility in modelling positive-real random variables and mathematical convenience as a conjugate prior, which will be shown in the following discussion of Bayes analysis. The density, expected value, and variance of the distribution are represented as:

$$f_\Lambda(\lambda) = \frac{(k/\mu)^k \lambda^{k-1} e^{-(k/\mu)\lambda}}{\Gamma(k)}$$

$$E(\Lambda) = \mu;\ Var(\Lambda) = \frac{\mu^2}{k} \qquad (6.2)$$

The marginal probability distribution of collision count, Y is derived by multiplying the conditional Poisson distribution with the probability of the condition as represented by the Gamma density function. The integration of the product over Λ gives the unconditional negative binomial distribution of Y, with the density function, expected value, and variance of:

$$P(Y = y) = \frac{\Gamma(k+y)}{\Gamma(k)y!}(\frac{k}{k+\mu})^k(\frac{\mu}{k+\mu})^y$$

$$E(Y) = \mu;\ Var(Y) = \mu + \frac{\mu^2}{k} \qquad (6.3)$$

The assumption of model formulation follows the work of Hauer (1997). Generalized linear regression model for the expected collisions, conditional on traffic volume and section length, takes the following form.

$$\mu = E(\Lambda) = E(Y) = \beta_0 \times L \times V^{\beta 1} \qquad (6.4)$$

where,

$E(\Lambda)$ = mean expected collisions-prior distribution

L = road section length

V = annual average daily traffic (AADT)

β_0, β_1 = model hyper parameters

Data from all 4-lane divided highway segments in British Columbia, except those in Greater Vancouver -- the major urban center in the province, were used as the reference group to construct the collision model. Greater Vancouver was excluded on the grounds of non-interchangeability. The study corridor is rural and suburban (Pendleton, 1991), which is different from those in Greater Vancouver. The total length of highway sections in the reference group is approximately 650 km. The collision and covariates data are presented in Appendix B.

Maximum likelihood method was used to estimate the hyper-parameters, i.e., the regression and the dispersion parameter (Christiansen and Morris, 1997). The estimation was conducted with SAS8 Genmod procedure. The study was presented in the Canadian Multi-disciplinary traffic safety conference XII (Chen, 2001). Table 6.2 provides the model parameter estimates for four lane divided highways in British Columbia as presented in a related paper published with Accident Analysis and Prevention (Chen et al. , 2001).

Table 6.2. Parameter estimates of the collision model for BC 4-lane, divided highways, Apr 94 – Mar 96

			Standard	Wald 95% Confidence		Chi-	
Parameter	DF	Estimate	Error	Limits		Square	Pr > ChiSq
Intercept	1	-6.5099	0.7637	-8.0068	-5.0131	72.66	<.0001
log(aadt)	1	0.892	0.0829	0.7296	1.0545	115.85	<.0001
Dispersion	1	0.1607	0.0461	0.0916	0.2821		

Based on the estimated hyper-parameters, the prior mean as the point estimate for expected collisions in the before period at each location conditional on length and volume is calculated through equation 6.5:

$$\mu = E(\Lambda) = 0.00149 \times L \times V^{0.892} \qquad (6.5)$$

or directly from the results of the generalized linear model with log link function in Table3:

$\log(u) = \log(b_0) + \log(L) + b_1 * \log(V)$

$= -6.5099 + \log(L) + 0.892 * \log(V)$

or:

$u = b_0 + L + V^{b1}$

as in equation (6.5).

Integrating prior mean with data for posterior mean as the estimates of expected collisions in the before period

The posterior distribution of Λ, conditional on the observed number of collisions, y, at each site can be derived from the Bayes theorem. In functional form the theorem could be expressed as:

$$f_{\Lambda|Y}(\lambda \mid y) = \frac{f_{\Lambda}(\lambda)P(Y = y \mid \Lambda = \lambda)}{f_Y(y)} \tag{6.6}$$

Substituting the prior distribution of Λ by equation (6.2), the likelihood by equation (6.1), and the marginal distribution of the data Y by equation (6.3), the posterior distribution of Λ can be derived:

$$f_{\Lambda|Y}(\lambda \mid y) = \frac{[(k+\mu)/\mu]^{k+y}\lambda^{k+y-1}e^{-[(k+\mu)/\mu]\lambda}}{\Gamma(k+y)} \tag{6.7}$$

Equation 6.7 shows that the posterior distribution of the expected number of collisions is also a Gamma distribution. This is not unexpected, as Gamma is a conjugate prior for the Poisson distribution. Specifically, $\Lambda|(Y=y)$ has a distribution of Gamma $[k+y,(k+\mu)/\mu]$. Following the relationships between Gamma parameters and moments, the expectation and variance of the expected number of collisions are calculated:

$$E(\Lambda \mid Y = y) = \frac{k+y}{k+\mu}\mu = \frac{k}{k+\mu}\mu + \frac{\mu}{k+\mu}y; \tag{6.8}$$

$$Var(\Lambda \mid Y = y) = \frac{k+y}{(k+\mu)^2}\mu^2 \tag{6.9}$$

Equation 6.8 indicates that the posterior mean of the expected number of collisions is the weighted average of the prior mean μ and the observation y. Equation 6.9 provides the variance of posterior parameters. Capitalizing on the estimated parameters, using the EB method, the point estimates and its precision of the expected number of collisions at each site in the before period are calculated by equations 6.10 and 6.11.

$$\hat{\lambda} = \frac{\hat{k}}{\hat{k}+\hat{\mu}}\hat{\mu} + \frac{\hat{\mu}}{\hat{k}+\hat{\mu}}y; \qquad (6.10)$$

$$V\hat{a}r\left(\hat{\lambda}\right) = \frac{\hat{k}+\hat{y}}{(\hat{k}+\hat{\mu})^2}\hat{\mu}^2 \qquad (6.11)$$

Predicting expected collisions in the after period

To estimate the safety effect of an enforcement program, it is necessary to predict what would have been the safety of the highway sections in the after period had treatment not been applied. There are a number of ways to predict safety with varying degree of validity. The most common ones include naïve before and after comparison, explicit data modelling with multiple covariates, and comparison groups method. The naïve before and after approach is the least valid among the three approaches. It makes a strong assumption of constancy of conditions over time. It assumes that the factors affecting traffic safety remain the same in the before and after period. Consequently, the level of traffic safety in the before period can be used to represent the level in the after period. This assumption is apparently not tenable in most of the cases in reality, considering the rapid changes in so many facets of modern life. Specifically, factors affecting traffic safety do change over time. This method is therefore excluded from consideration.

The explicit modelling with exogenous and endogenous variables would be feasible, and as a matter of fact, ideal in terms of scientific enquiry and knowledge generation, if all the influential variables were known, measured, and the impact understood. This condition is again rarely available to researchers in traffic safety field. Not all factors affecting people's driving behaviour and traffic safety are known. Not all the known factors are measured and measured reliably. For the current study, the most significant factor influencing the number of traffic collisions is traffic volume. However, even for this key traffic attribute, the measure is incomplete in BC for the current study. Traffic volume data are not available for a number of sections on the study highway for the after period (1996-98). This method is therefore not feasible for predicting traffic safety in the after period. Consequently it was excluded from further consideration.

The only method which is practical and potentially satisfactory under the current circumstance, is the comparison groups approach. However, this method is also under a relatively strong assumption. This method assumes that the selected comparison group is so similar to the treatment groups in every aspect which affects traffic safety that it mirrors the change in traffic safety in the treatment groups over the study period. This assumption however could be empirically examined by comparing the historical collision data between the treatment and comparison groups. Given that changes in traffic safety as measured by traffic collisions and injuries for the treatment and comparison groups are readily available in historical police reports, this method is considered practicable. With the adjustment of the changes in the comparison groups, the prediction of traffic safety in the after period in the treatment group could be improved. This method is implemented in the current study. More detailed description of the procedures of using comparison groups to account for the time effect is outlined further in this section.

The expected number of collisions in the after period had the program not been implemented, as represented by π, was predicted based on the expected number of collisions in the before period with an adjustment for time effect. The time effect adjustment was implemented by the use of a comparison group. As the study highway segments run through three police jurisdictions, each of the three police jurisdictions: Saanich, Central Saanich, and North Saanich/Sidney, excluding the study corridor and other photo radar deployment sites, was used as the comparison groups for the corresponding section of the study corridor respectively. The expected number of collisions and the variance for photo radar and non-photo radar locations in each of the municipalities are calculated separately based on Hauer (1997, p. 215):

$$\hat{\pi} = \hat{r}_T * \hat{\lambda}$$

$$Var\{\hat{\pi}\} = \hat{\pi}^2[V\hat{a}r\{(\hat{\lambda}\}/\hat{\lambda}^2 + Var\{\hat{r}_T\}/\hat{r}_T{}^2] \qquad (6.12)$$

r_T, is the treatment ratio, approximated by (Hauer, 1997, p. 126):

$$\hat{r}_T = r_C / \omega \doteq (N/M)/(1+1/M)$$

$$Var\{\hat{r}_T\} = r_T^{\,2}[1/M + 1/N + Var\{\omega\}/E\{\omega\}]$$

where,

r_C = Comparison Ratio

ω = Odds Ratio, estimated from historical data of treatment and comparison groups

M = Total number of collisions in the two years before period

N = Total number of collisions in the two years after period

The variance estimate in Equation 6.12 is an approximation, derived from a Taylor expansion. Expanding and ignoring higher-order terms, the estimated number of collisions and its variance can be expressed as:

$$\hat{\pi} = \bar{r} * \bar{\lambda} + (\hat{r} - \bar{r})(\frac{\partial \hat{\pi}}{\partial \hat{r}})|_{\bar{r},\bar{\lambda}} + (\hat{\lambda} - \bar{\lambda})(\frac{\partial \hat{\pi}}{\partial \hat{\lambda}})|_{\bar{r},\bar{\lambda}}$$

$$Var\{\hat{\pi}\} \doteq (\frac{\partial \hat{\pi}}{\partial \hat{r}})^2 Var\{\hat{r}_T\} + (\frac{\partial \hat{\pi}}{\partial \hat{\lambda}})^2 V\hat{a}r(\hat{\lambda}\} \qquad (6.13)$$

but

$$\frac{\partial \hat{\pi}}{\partial \hat{r}} = \hat{\lambda} = \hat{\pi} / \hat{r}_T$$

$$\frac{\partial \hat{\pi}}{\partial \hat{\lambda}} = \hat{\pi} = \hat{\lambda} / \hat{r}_T$$

Substitute into 6.13, Equation 6.12 is obtained.

Comparing predicted expected number of collisions with estimated expected number of collisions at each location in the after period

The expected number of collisions at each location in the two-year period during the program is denoted by ψ. This parameter was estimated by the police reported collisions for the period. This ψ notation is used to distinguish it (the estimated expected number of collision in the after period) from the expected collisions in the before period (λ). The expected number of collisions was then compared with the predicted expected number of collisions had the program not been introduced. The difference was attributed to the effect of the photo radar program. The reduction in the expected frequency of collisions is denoted by δ and the index of effectiveness is denoted by θ. These were calculated by equation 14 and 15, following the work of Hauer (1997, p. 64, p. 70):

$$\hat{\delta} = \hat{\psi} - \hat{\pi}$$

$$\text{var}\{\hat{\delta}\} = \text{var}\{\hat{\pi}\} + \text{var}\{\hat{\psi}\} \qquad (6.14)$$

$$\hat{\theta} = (\hat{\psi} / \hat{\pi}) / [1 + Var(\hat{\pi}) / \hat{\pi}^2]$$

$$\text{var}\{\hat{\theta}\} = \hat{\theta}^2 [(\text{var}\{\hat{\psi}\} / \hat{\psi}^2) + (\text{var}\{\hat{\pi}\} / \hat{\pi}^2)] / [1 + \text{var}\{\hat{\pi}\} / \hat{\pi}^2)] \qquad (6.15)$$

The index of effectiveness is the ratio of what safety was with the treatment to what it would have been without the treatment. When $\theta<1$, the treatment is effective; when $\theta>1$ it is harmful to safety. Also, $100*(1-\theta)$ is the percent reduction in the expected accident frequency.

Aggregating safety effect across locations

The safety effect of the photo radar program was then aggregated to the group level of PRP and non-PRP locations to test the plausibility of the competing hypotheses of collision spill over effect vs. collision migration effects. The effect was further summarized to estimate the impact of the photo radar program on the treatment corridor as a whole.

The aggregation procedure follows the method proposed by Hauer (1997). Assuming treatment was applied to n locations in a category, and ψ_i and π_i represent the estimated and predicted mean collisions for locations i, the total predicted and estimated collisions are denoted as:

$$\Pi = \sum_i \pi_i$$

$$\Psi = \sum_i \psi_i \qquad (6.16)$$

A parallel definition applied to the estimates. When the estimates are mutually independent, then:

$$\mathrm{var}\{\Pi\} = \sum_i \mathrm{var}\{\hat{\pi}_i\}$$

$$\mathrm{var}\{\Psi\} = \sum_i \mathrm{var}\{\hat{\psi}_i\} \qquad (6.17)$$

In essence, Equations 6.16 and 6.17 regard the n separate locations as one composite entity. It should be noted that it is in the nature of a total effect when δ is estimated and average effect when θ is estimated.

Assessing model fit

A feedback process for residual analysis and variable selection criteria were intentionally integrated into the model building process. All the residuals were examined for patterns and outliers. Various residuals were formally tested by using 2- standard deviation rules and informally reviewed by graphical examination. Augmented models with other potential highway characteristics, such as speed limits, were estimated and the change in deviance compared and tested using AIC as the criterion. Only after these necessary conditions are met, given full consideration in model accuracy and parsimony, industry practice and standard, and data feasibility and reliability, was the final model selected and estimated.

RESULTS

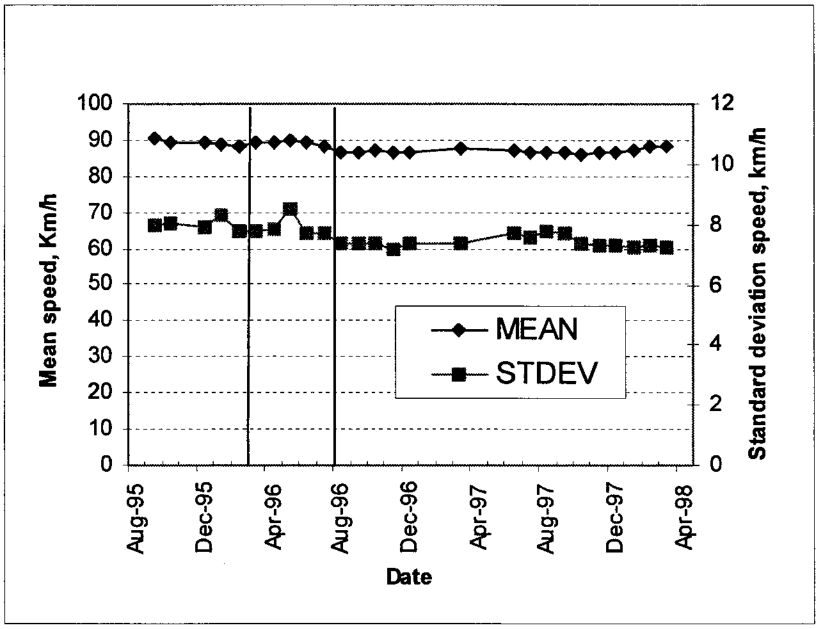
This section presents the results of the site specific assessment of BC photo radar program. It is divided into two main parts: traffic speed effect and traffic safety effect.

Traffic Speed Effect

Traffic speed and speed variance fell immediately after the introduction of the program at the photo radar deployment locations, following the general pattern reported in the province-wide analysis. By August 1996, the commencement of the violation ticket phase, the mean speed at the deployment locations had been reduced to below the posted 80 km/hr speed limits. Traffic speed remained at the reduced level over the study period.

Traffic speed and speed variance also declined at the monitoring location 2 km south of the last photo radar location on the study corridor after the commencement of the violation ticket phase of the program in August 1996. The mean and variance of speed at the monitoring site over time are presented in Figure 6.2.

Figure. 6.2 Mean and standard deviation of traffic speed at the monitoring site

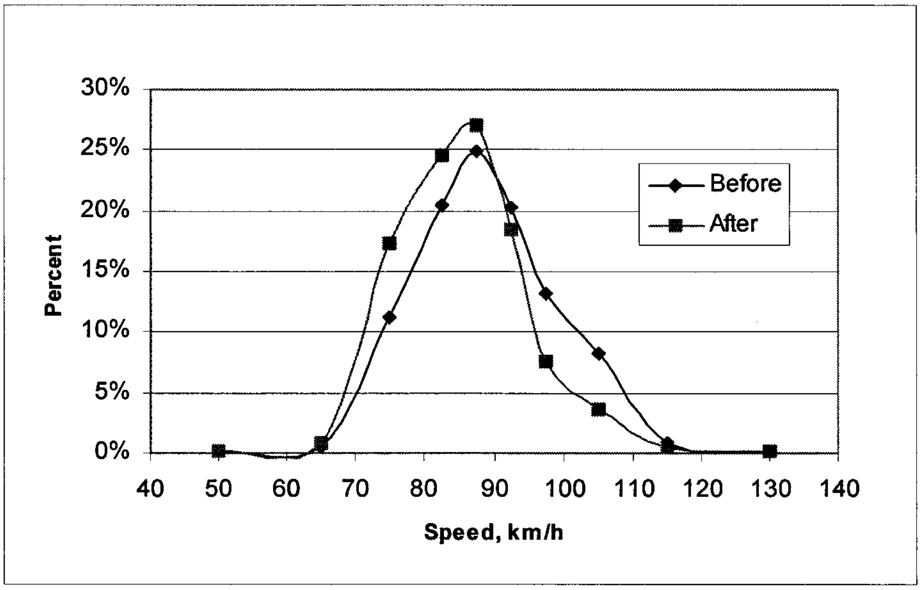


Note: Speed limit is 80 km/hr at the monitoring site.

Comparing the available data for the corresponding months in the before and the after period, the mean speed is estimated to have decreased by approximately 2.8 km/h, representing a 3% reduction. The standard deviation of speed declined by 0.5 km/h, amounting to a 6% reduction. Both reductions are statistically significant, given that millions of vehicles were observed in the study period. Although there seems to be a gradual rebound in mean speed later in the after period, the variance of speed remained lower in the period.

Figure 6.3 depicted the change in speed distribution in the one-year before and one-year after period. It can been seen that the pattern of traffic speed has been modified. Not only is there a general shift of the speeds towards the lower speed end, but the dispersion of the speed has been reduced as indicated by the taller bell shape in the after period.

Figure. 6.3 Speed distribution at monitoring site in the before and after periods



Note: Figure 6.4 is based on the total number of vehicles observed: before = 607,439; after = 585,175.

Safety Effect

The descriptive statistics for the location, length, and reported collision counts for each of the PRP and non-PRP locations on the study corridor are presented in Table 6.3. Traffic collision counts dropped after the photo radar program at both the PRP sites and the non-PRP sites along the corridor.

Table 6.3. Summary descriptive data of site-specific analysis: highway location, length, traffic volume, and collision at photo radar and non-photo radar sites

			Offset			Apr.94-Mar.96		Apr.96-Mar.98
Loc. ID	**Municipality**	**Seg.**	**Start**	**End**	**Len.**	**AADT**	**Coll.**	**Collisions**
N1	Saanich	0304	4.4	5.3	0.9	19668	1	2
300102	Saanich	0304	5.4	10.6	5.2	23634	56	64
N2	Saanich	0304	10.6	11.0	0.4	25396	3	2
330001	C_Saanich	0304	11.0	13.9	2.9	23634	12	4
N3	C_Saanich	0304	13.9	19.8	5.9	12966	39	22
39899	N_Saanich/Sidney	0304	19.9	23.3	3.4	11272	11	10
N4	N_Saanich/Sidney	0304	23.3	26.1	2.8	9617	25	11
312800	N_Saanich/Sidney	0304	26.1	27.3	1.2	6243	14	9
N5	N_Saanich/Sidney	0307	0.0	2.7	2.7	7752	18	9
310000	N_Saanich/Sidney	0307	2.8	4.8	2.0	8663	13	11
N6	N_Saanich/Sidney	0307	4.9	5.3	0.4	10046	12	19
310100	N_Saanich/Sidney	0307	5.3	7.3	2.0	10594	13	10
N7	C_Saanich	0307	7.4	15.4	8.0	13870	43	26
300201	Saanich	0307	15.5	17.5	2.0	22696	14	12
N8	Saanich	0307	17.5	19.0	1.5	22696	14	19
300200	Saanich	0307	19.0	21.0	2.0	19389	30	21
N9	Saanich	0307	21.1	21.9	0.8	17398	6	6
Total					44		324	257

Note: The number sites are photo radar deployment sites, while the N-sites are non-photo radar sites

The total number of reported collisions for the 2-year before and 2-year after periods for each of the police jurisdictions in the study area was accumulated and used as the comparison groups. The reported number of collisions increased from 101 to 111 in the Saanich study area, decreased from 202 to 177 in Central Saanich and decreased from 306 to 266 in North Saanich /Sidney. Saanich study area experienced a substantial build up in residence. The estimated increase in traffic volume, based on available data on the treated highway in the area, is about 7% in the study period. Overall, the total collisions declined from 609 to 554 in the comparison groups, representing a 9% reduction over the before and after period.

Following the steps outlined in the methodology section, the traffic safety effect of the photo radar program for PRP locations and non-PRP locations was estimated. The results for the PRP locations are presented in Table 6.4.

Table 6.4. Safety impacts of BC photo radar program at PRP sites

Site ID	ψ	VAR(ψ)	π	VAR(π)	δ	$\sigma(\delta)$	θ	% Change	$\sigma(\theta)$
3000-00/-01/-02	64	64	61.5	132.2	2.5	14.01	1.01	0.6	0.22
3003-00/-01	4	4	16.7	20.7	-12.7	4.97	0.22	-77.8	0.12
3098-00/3099-00	10	10	11.5	9.2	-1.5	4.38	0.81	-19.0	0.31
3128-00	9	9	7.3	3.2	1.7	3.49	1.17	16.7	0.46
3100-00	11	11	10.1	6.5	0.9	4.18	1.02	2.0	0.38
3101-00	10	10	10.8	7.4	-0.8	4.17	0.87	-13.2	0.33
3002-01	12	12	13.8	11.5	-1.8	4.85	0.82	-17.9	0.29
3002-00	21	21	30.0	41.9	-9.0	7.93	0.67	-33.2	0.20
All PRP	141	141	161.8	232.6	-20.8	19.33	0.86	-13.6	0.11

Note: ψ = observed number of collisions,

π = expected number of collisions, had PRP not been implemented,

$\delta = \psi - \pi$, the difference between observed and expected, and

θ = index of effectiveness

Table 6.4 seems to suggests that traffic safety is improved at five sites, as measured by the decrease in traffic collisions, and worsened at the other three sites as measured by the increase in traffic collisions. The degree of change, however, differed between the improved and worsened sites. The increase in collisions in the three sites are small in absolute or in percentage terms. The reduction in the five sites are large, relative to the worsened sites and in percentage terms. Statistically, all the worsening sites are insignificant, comparing the estimated reduction to the standard error.

The conclusion of safety improvement cannot be reached with confidence. However, when analysed across all the photo radar sites, a more reliable pattern emerges. Aggregating all the photo radar enforcement sites, the photo radar program is estimated to have reduced collisions by 14% ± 11%.

Similar to the analysis of the collision reductions for the photo radar treatment sites, the traffic safety effect for non-PRP locations and non-PRP locations was estimated. The results for the PRP locations are presented in Table 6.5.

Table 6.5. Safety impacts of BC photo radar program at non-PRP sites

Site ID	ψ	VAR(ψ)	π	VAR(π)	δ	$\sigma(\delta)$	θ	%reduction	$\sigma(\theta)$
N1	2	2	4.6	3.4	-2.6	2.31	0.37	-62.6	0.26
N2	2	2	4.6	2.6	-2.6	2.16	0.39	-61.1	0.27
N3	22	22	34.3	38.4	-12.3	7.77	0.62	-37.8	0.17
N4	11	11	19.0	15.6	-8.0	5.16	0.55	-44.6	0.19
N5	9	9	13.8	9.9	-4.8	4.35	0.62	-37.9	0.24
N6	19	19	4.1	1.1	14.9	4.49	4.31	330.5	1.39
N7	26	26	38.8	46.6	-12.8	8.52	0.65	-35.0	0.17
N8	19	19	16.1	17.8	2.9	6.07	1.10	10.1	0.36
N9	6	6	7.2	5.2	-1.2	3.35	0.76	-24.1	0.36
All NON-PRP	116	116	142.5	135.5	-26.5	15.86	0.81	-19.1	0.10

Note: ψ = observed number of collisions,

π = expected number of collisions, had PRP not been implemented,

$\delta = \psi - \pi$, the difference between observed and expected, and

θ = index of effectiveness

Table 6.5 revealed similar patterns of safety impact at the site level. Although the majority of the sites, seven out of nine, estimated lower number of collisions, as compared with no-program alternative, a couple of sites did observe higher number of collisions. This again demonstrates the difficulties in evaluating program effects when the measures of the construct are rare events and the measure, therefore, contains a major element of random variation. Integrated studies of many sites are required to obtain statistical confidence and accuracy in estimation.

At the non-PRP group level, however, statistical conclusions could be better reached. As can be seen from Table 6.5, the photo radar program is attributed with a reduction in collisions at the non-PRP sites of 19% ± 10%.

Combining the group level information, the total reduction in traffic collisions is summarized for the entire study segment of highways. The summary results of the analysis are presented in Table 6.6.

Table 6.6. Summary safety impacts of BC photo radar program

Location type	ψ	VAR(ψ)	π	Var(π)	δ	$\sigma(\delta)$	θ	% reduction	$\sigma(\theta)$
PRP locations	141	141	161.8	232.6	-20.8	19.33	0.86	-13.6	0.11
Non-PRP Location	116	116	142.5	135.5	-26.5	15.86	0.81	-19.1	0.10
Corridor	257	257	304.3	368.2	-47.3	25.00	0.84	-15.9	0.07

Table 6.6 shows the absolute and percentage reduction in collisions at PRP locations and at non-PRP sites overlap, considering the standard errors in these estimates. This fact suggests that the extent of safety improvement within the 2-km distance from the PRP deployment sites is not significantly different from that on the interleaving sections of the treatment corridor. Overall, the safety of the treatment corridor as a whole improved substantially, controlling for time effect, i.e., the changes in collision on other untreated highways in the geographic proximity. The expected number of collisions on the treated corridor as a whole decreased by 16%± 7%, compared with the expected number of collisions if the program had not been implemented. Given that the number of collisions is indicative of the number of injuries, both reflect improvement in traffic safety, the reduction in collisions is used as evidence, corroborating the province-wide study, wherein reduction in injuries was revealed.

Discussion

The study suggests that the BC photo radar program has reduced speed and improved safety at the photo radar deployment locations. The effects extended across the 22-km study corridor as a whole. At the times and precise locations where photo radar was operating, the mean traffic speeds were reduced to below posted speed limit level. Traffic speeds remained at the reduced level over the two-year study period. Moreover, traffic speed also declined nearby, in the absence of photo radar enforcement. The percentage of excessive speeding vehicles fell substantially, as indicated by the slimmer tails at the high end in speed distribution. These phenomena, in theory and practice, would suggest a more homogeneous traffic flow, thereby potentially reducing traffic conflicts and traffic collisions.

A substantial and significant decline in traffic collisions followed the reduction in speed and speed variance. Comparing the estimated safety effect of the photo radar program at PRP and non-PRP locations, no localized effect is evident. This result runs counter to the compensatory hypothesis that predicts that traffic collisions migrate to adjacent non-deployment locations to compensate for the time loss. Instead, the results support the beneficial spill over effect or generalization theory that the program extends its effect from the locus of enforcement to the whole stretch of highway. While the findings do not eliminate compensation as a reasonable explanation in other situations, where, for example temporal or spatial distances between enforcement are greater than in the present study, they do demonstrate that drivers' speeds can be modified over distances of several kilometres, with frequent intermittent enforcement.

This generalized effect is probably due to the mobile nature of the photo radar vans and the unpredictability of their deployment in both time and location. Considering that unmarked vans were used, and that deployments were rotated among 12 deployment locations along the length of the corridor (as well as on other roads), it would be difficult for drivers to discern which road segments were safe and which were unsafe, with respect to impunity for speeding. The element of unpredictability of enforcement probably has led to the desired generalized behavioral effect over time and distance.

SUMMARY

In summary, the site-specific analysis confirms that the BC photo radar program is associated with a reduction in mean speed and speed variance in the presence or absence of photo radar enforcement. At the photo radar enforcement sites, the reduction in speed occurred mostly in the warning letter phase. By the beginning of the violation tickets phase, the mean speed has been reduced to under 80km/hr, the posted speed limits.

The reduction in speed and speed variance at the monitoring sites is more fundamental, as it measures the free wills of driver in the absence of the photo radar enforcement. The analysis shows that the mean speed at the monitoring sites is decreased by approximately 2.8 km/h, representing a 3% reduction. The standard deviation of speed declined by 0.5 km/h, amounting to a 6% reduction.

The program is associated with an estimated 14%±11% reduction in collisions at the PRP locations and a 19%±10% reduction at the non-PRP locations. The extent of safety improvement within the 2-km distance from the PRP deployment sites is not different from that on the interleaving sections of the treatment corridor, considering the standard error in each of the estimates. Overall, the safety of the treatment corridor as a whole improved substantially. The expected number of collisions on the treated corridor as a whole decreased by 16%± 7%.

The present study is limited in terms of design and data. Comparison group design is not ideal for traffic safety evaluations. Given that a general deterrence effect from the BC photo radar program has been demonstrated across the province (Chen et. al, 2000), the collision experience of the three comparison groups may have been indirectly affected. The use of the three comparison groups may therefore have over-adjusted the treatment effect, underestimating the true program effect.

Collision data for the study are limited in quantity. Two year's aggregated data for the before and after period were used in the evaluation. The precision of the estimate would have been higher had longer before and after periods been available. However, the time extension was obviated by the introduction, in April 1998 of a new speed enforcement program on the same corridor. Because both programs target speeding and both were applied to the same highway corridor, it is not possible to separate their unique contributions to collision reduction. To avoid confounding effects, data after April 1998 were not used in the study.

Spatially, the site specific study was confined to one highway in the province. It should be considered as a demonstration of the benefits of photo radar speed enforcement, which could guide implementation practices in other locations. The results of this study support the earlier province-wide evaluation of the photo radar program, but should not be considered typical of all other enforcement sites. Site characteristics vary and photo radar has not been implemented identically on all treated roads and highways. Further study using reliable data from other treated highways would improve the external validity of the evaluation of corridor-specific effects of photo radar enforcement.

7. COST-BENEFIT ANALYSIS

This chapter represents the economic component of the overall evaluation of the BC photo radar program. The chapter is organised into method, results, and discussion sections. The purpose of this chapter is to address the following two main questions:

- How does the benefit of the overall program compare with its total economic costs?
- How sensitive is the result of the evaluation relative to the assumptions made in the evaluation?

METHOD

This cost-benefit analysis takes an in medias res approach, recognising that the program was in place for a few years and that it was recently cancelled in 2001 before the completion of its economic life. Corresponding to the two-year impact analysis after the introduction of violation tickets phase, the economic data were collected and used in the economic analysis. The capital cost and safety benefit incurred in the warning letter phase was annualized, over equipment economic life span to arrived at typical year estimates. Modelling is used where necessary data are not available for the BC photo radar program.

The study assumes a societal perspective, whereby all BC residents have standing. The perspective of ICBC, the main funding agency, is of special interest. Consequently, a net benefit was also calculated from the ICBC perspective. This supplementary analysis is discussed both in the base case study and in the sensitivity analysis section.

As an economic evaluation of the BC photo radar program implemented in 1996, the analysis compares the program with a no-program, status quo alternative. The comparison of the photo radar program with other traffic safety programs with the same targeted results could be conducted on an ex ante and hypothetical basis. However, this is considered out of the scope for the current study.

It should be noted that the valuation of non-marketed goods, such as safety, in this cost-benefit study is based on shadow prices developed in credible and widely referenced previous studies. No attempt was made to repeat previous studies. The multi-disciplinary nature of the study makes it not only inefficient but also technically impossible to perform original studies for every parameter needed in the evaluation. A modelling approach is therefore used for some information.

It is recognised that any estimates and unverified assumptions could introduce errors in a cost-benefit analysis. It was decided that if error is not avoidable, the estimates should be made on the conservative side, i.e., underestimating benefit and/or overestimating cost. Sensitivity analyses will be conducted to assess the impact and the robustness of the conclusions for all meaningful and plausible variations in the parameters.

To make sure that the economic valuation is conducted in the same metrics, all impacts were reduced to monetary units in real 2001 dollars. The social discount rate is selected to be 6% for the base case, based on the opinion of BC Ministry of Transportation and Highways (BC Ministry of Transportation and Highways, 1997). Sensitivity analysis for discount rates at the level of 5% and 7% were conducted to assess the robustness of the study results.

Categories of Impacts

The inputs and impacts of the BC photo radar program are divided into two main groups, cost category and benefit category. The items in the cost categories were selected based on the guidelines from Transport Canada (Blanchard, 1996) and the BC Ministry of Transportation and Highways (1997). Not all cost items in these guidelines were included for this study as these guidelines were designed mostly for transportation infrastructure projects, wherein traffic safety plays a significant, however, partial role. The cost categories, thus selected, include program development cost, program operating cost, police cost, incremental cost to court system, travel time lost cost as a result of speed reduction across the province, and the cost due to time lost in disputing photo radar violation tickets by private citizens.

The selected benefit category for this study comprises mainly the improvement in traffic safety, measured by the reductions in collisions, injuries and fatalities attributable to the program. The changes in motor vehicle operating cost and the reduction in emission to the environment due to the reduced vehicle travel speed was initially considered as benefits of the program. The savings on operating cost, (vehicle wear and tear, and gasoline consumption) due to the estimated 2.4-km/hr reduction in mean speed are deemed small (Chen, 2000). The data are unreliable. Consequently, the potential savings was not included in the main part of the report, following the current practice in transportation studies (Hooke, Knox, and Portas, 1996). However, effort was made to explore the magnitude of the potential savings. The results show that the fuel consumption savings is indeed small, even under a relatively liberal assumption, i.e., the excessive speeder increases fuel efficiency and reduces emission when they reduce their speed, while motorists on city streets and collector highways may reduce fuel efficiency when they slow down, albeit to a small degree. Due to the lack of the data and the unreliability in methodology, and to avoid introducing un-quantifiable error into an otherwise rigorous cost-benefit analysis, the fuel consumption savings impact is reported and discussed in the sensitivity analysis rather than in the base case. The final impact categories, valuation method, and data sources for the main cost-benefit analysis are presented in Table 7.1.

Table 7.1. Impact Categories

Category	Impact	Data source	Valuation method
Cost	Capital (Start up) expense	ICBC	Expenditure
	ICBC Operating expense	ICBC	Expenditure
	Police cost	AG	Expenditure
	Court cost	AG	Expenditure
Effect	Safety benefit (saving in lives, injuries, and property damages)	Police, Ambulance	Shadow price
	Time savings - collisions	MoTH	Shadow price
	Time lost - travel	MoTH	Shadow price
	Time lost - fighting ticket	BC Stats	Shadow price

Note: MoTH is the acronym for the BC Ministry of Transportation and Highways.
AG is the acronym for the BC Ministry of Attorney General.

Valuation of Costs

The social opportunity cost principle underlies the methodologies used to value the inputs to the BC photo radar program. The opportunity costs of capital and operating expenses were estimated by equating it with program expenditures in this study, however. This is based on the assumption that program equipment and services were purchased in a relatively competitive market. Given that a number of companies provide the photo radar equipment and services on the open market and that many companies have submitted their bids to provide the equipment and services for BC photo radar program, the assumption was deemed reasonable and accepted.

Shadow prices from secondary sources based on willingness to pay principle were used to value outcome cost, (i.e., increased court cost due to dispute of photo radar tickets and the time lost for citizens to dispute the alleged offence). The use of shadow prices is due to the fact that many of the impacts of the photo radar program are not traded in the market. The formula and parameters in the calculation of various costs were based on standard cost used in transportation and traffic safety economic evaluations (BC Ministry of Transportation and Highways, 1997). Simple and crude estimation methods were developed if standard methodologies are not available to fit this study. The valuation methods for a number of cost categories, including travel time lost due to speed reduction and time lost disputing violation tickets, require deliberation. They are presented in the following sections.

Capital cost and ticket processing cost - ICBC cost

The capital costs of the program include the cost to purchase photo radar equipment and software development. The tickets processing cost comprise the cost of photograph process, data management, and tickets mailing and delivery. These costs are funded by the Insurance Corporation of British Columbia (ICBC), the main beneficiary of the program.

Summary cost estimates were obtained from the corporation with regard to the above listed cost. No detailed information was made available to the author, on the detailed costing figures. Nor is the unit value and physical input to the program, which could be used to calculate standard cost. After a number of failed trials to obtain the relevant data, it was decided that the summary data would be considered true cost and used for this study. This assumption is supported by the fact that ICBC cost has been audited and accepted by the BC government.

The capital costs from ICBC were annualised for this study. This process is composed of two steps. First, all the costs were converted into 2001 real dollars. This was conducted by inflating the costs in the current year by the CPI index (BC Stats, 2002). Second, the values of the total capital costs in 2001 real dollars were discounted by a 6% social discount rate. This was done by using the PMT function in an excel spreadsheet. The calculation is presented in Appendix F - ICBC Cost Calculation.

Enforcement cost - Police cost

Standard costing method was used in the calculation and verification of police and the incremental court cost of the program. The photo radar devices were operated by uniformed police officers from RCMP and local police forces. There were also charging officers whose responsibility was to make sure that the photographs of violating vehicles are clear and otherwise admissible to the court. The office also employed four office administrative staff. The police cost was calculated by summing up the number of people in each category multiplied by their respective standard costing rate, including salaries and benefits.

$$C_E = P_P * X_P + P_C * X_C + P_A * X_A \qquad (7.1)$$

Where:

C_E = Total police enforcement cost,

P_P = Police unit cost,

X_P = Number of police officers in the program.

P_C = Charging officer unit cost,

X_C = Number of Charging officers.

P_A = Administration unit cost

X_A = Number of Administrative officers.

It should be noted that this cost estimate does not include potential incremental overhead costs, attributable specifically to the photo radar program. No official statistics were available with regard to the matter. An estimate was made by the author to compare the budgeted staff cost and the operating cost of the Court Service Branch and Criminal Justice Branch in the BC Ministry of Attorney General. Given that the operating cost of these two branches, less building occupancy charge and amortization cost, totalled $22 million with a salary and benefit expense of $106 million for 1997/98 fiscal year, a 20% additional cost was added to the total staff cost to arrive at an estimate of the total incremental cost to the police operation and court system, in the later section, due to the photo radar program. The calculation is shown in Appendix F - Police Cost Calculation.

Adjudication cost

The court system requires and obtains services from various professional groups, i.e., Prosecutor, Support Staff, Justice of the Peace, Sheriffs, Court/Registry Clerks, and attorneys. The standard incremental costs for each of the groups in the judicial system due to BC photo radar program is calculated by multiplying time spend on dealing with photo radar related cases, times the unit cost of the respective group. The time spent on processing photo radar tickets is, in turn, dependent on the total number of tickets disputed and the unit time length in treating each ticket. The total cost therefore can be derived by summing across the cost for each group, which is estimated by dividing the total disputes by productivity and multiplied by the respective standard cost rating for the group. The formula of the function is presented in equation 7.2.

$$C_C = \Sigma\ (Num\_Disp\ /\ Prod_i\ ) * C\_Rate_i \qquad (7.2)$$

Where:

C_C = Court cost incurred for a specific staff category,

Num_Disp = Number of photo radar tickets disputed,

$Prod_i$ = Number of cases processed per year for staff group i,

C_Rate_i = Standard costing rate for staff group i.

Similar to police cost, the court cost is also inflated by 20% to cover the overhead cost, imposed to the existing court systems.

Valuation of Effects

The effects of the program include the targeted program goals. It also includes side effects, positive and negative. The main effect, the intended outcome of the program, is traffic safety improvement and the resulting reduction in the clean-up time.

Reduction in collisions

The estimates of total value of the benefit depend on the valuation of human life, injury and property damages and the estimates of reduction in the numbers of collisions and injuries from the substantive impact analyses presented in the previous chapters. The total safety benefit from the program could be expressed as:

$$B_s = P_F * X_F + P_I * X_I \qquad (7.3)$$

Where:

B_s = Total safety benefit of the program,

P_F = Cost of a fatal collision,

X_F = Number of fatal collisions reduced due to the photo radar program.

P_I = Cost of injury collision,

X_I = Number of injury collisions avoided due to the photo radar program.

Similar to cost measures, the value of benefit of the program are converted into 2001 dollars, before entering into cost-benefit analysis.

Travel time savings

The amount of time saved due to reduction in traffic collisions and the resulting stoppage or slowing down of traffic depends on the severity of the collisions. In serious collisions, such as fatal collisions, the highway cleanup and police investigation can take many hours, wherein traffic is stopped or semi-stopped. The reduction of collisions, especially the major ones, will increase traffic mobility, therefore, save times for motorists.

The value of traffic stoppage due to collision reductions varies with traffic volume, as measured by Annual Average Daily Traffic (AADT), the hours of traffic impact, the composition of cars and trucks on the road, the occupancy rate, and wages for passenger vehicle and trucks respectively. A crude valuation of time saved due to reduction of traffic collisions is presented are expressed for automobile and trucks separately as equation 7.6a and 7.6b as follows:

For Automobiles:

S_A = Price_Auto * Occu_rate * Mean_AADT * %Auto * %Time * Coll (7.4a)

For Trucks:

S_T = Price_Truck * Mean_AADT * %Truck * %Time * Coll (7.4b)

Where:

S_A = cost of Automobile passengers due to reduction in traffic delay,

Price_Auto = shadow price of automobile passengers,

Occu_rate = automobile occupancy rate,

Mean_AADT = estimated mean Annual Average Daily Traffic on BC Highways,

%Auto = percent automobiles in traffic volume,

Coll = Number of serious collisions averted due to the program

%time = proportion of highway use time affected by a collision,

Stop_time = estimated mean traffic stop time due to a serious collision,

S_T = Cost of Truck Drivers due to reduction of traffic speed,

Price_Truck = shadow price of truck drivers, and

%Truck = percent trucks in traffic volume.

The travel time savings and the resulting cost savings, due to reduction of collisions, are included in the cost-benefit analysis of the current study.

Negative economic impact - Travel time lost

The objective of the photo radar program is to reduce traffic speed, whereby to reduce traffic collisions. However, the reduction of traffic speed leads to travel time lost. Travel time lost is a negative impact of the program, a cost to society, and it should be accounted for in a cost-benefit analysis. The valuation of a system-wide time losts due to speed reduction proved to be difficult to conduct. Although research results and industry standards are available for the valuation of time savings/lost for localised highway improvement, no standard method was found to quantify the time lost due to speed reduction in a whole jurisdiction, as big as a province. For this evaluation, to incorporate the cost of time lost, a very crude method was conceived and developed by the author, to approximate this time lost.

The method is based on the fact that the total hours of travels on BC highways equals to the total distance travelled in the province divided by the mean speed of traffic in the province. The time lost due to reduction in speed can therefore be approximated by the difference in the total hours of travel in the province before and after the implementation of the program.

The calculation of the value due to time lost in travel was conducted for automobiles and trucks separately, recognising the different rate of unit value of time. In functional forms, the costs are expressed for automobile and trucks separately as equation 7.3a and 7.3b as follows:

For Automobiles:

$$C_A = Price\_Auto * Occu\_rate * VKT\_Auto * ((1/MSB) - (1/MSA)) \quad (7.5a)$$

For Trucks:

$$C_T = Price\_Truck * VKT\_Truck * ((1/MSB) - (1/MSA)) \quad (7.5b)$$

Where:

C_A = Cost of Automobile passengers due to reduction of traffic speed,

Price_Auto = shadow price of automobile passengers,

VKT_Auto = Vehicle Kilometre of travel in BC, car (refer to NRCan data),

Occu_rate = the automobile occupancy rate,

MSB = Mean traffic speed before implementation of the program,

MSA = Mean traffic speed after implementation of the program,

C_T = Cost of Truck Drivers due to reduction of traffic speed,

Price_Truck = shadow price of truck drivers, and

VKT_Truck = Vehicle Kilometre of travel in BC, truck (refer to NRCan data),

Negative economic impact - cost of disputing violation tickets

The registered owners of the alleged offending vehicles have the right to dispute the speed violation tickets in court. The total time and expense consumed in disputing the tickets is lost for productive activities. These are costs to society and should be accounted for in cost-benefit analysis. The registered owners of the alleged offending vehicles may retain legal counsel in the dispute. However, use of counsel was extremely rare and no data is available to substantiate any estimate. Following the principle of materiality and keeping consistency in treating other small and unmeasured factors, such as the improvement on environment and savings on vehicle operating cost, the legal counsel cost was excluded in the analysis.

The amount of time lost in disputing photo radar tickets is calculated by multiplying the number of disputes, the average time spent to attend a court hearing, and the average wage of BC workers. The formula of the calculation is expressed in equation 7.6:

$$C_d = N_d * T_d * W \quad (7.6)$$

Where:

C_d = Total cost of citizens disputing photo radar violation tickets,

N_d = Number of citizens disputing photo radar violation tickets,

T_d = Average time spent in disputing one photo radar violation ticket,

W = Average hourly wage of BC workers.

The various cost items are reported or calculated in variance current values. To ensure that the comparison is conducted in the same metric, all the costs were converted into 2001 dollar for integration and interpretation. The cost of program is first inflated by the CPI index (BC Stats, 2002).

RESULTS

The program implementation and impact assessments as reported in the previous three chapters showed that the BC photo radar program has been delivered and the program has reduced traffic speed and traffic casualties. This section reports on the process and results of the economic evaluation. The section is divided into three main parts: the evaluation of program cost, benefit and a cost-benefit comparison.

Program cost

As outlined in the method section, the program cost for the BC photo radar program includes development and ticket processing cost, police cost, court cost, travel time lost, and citizen cost in disputing photo radar violation tickets. The following sub sections present the data obtained from various sources and estimate the total economic impacts by the cost items.

ICBC capital and operating (ticket processing) cost

The program capital and ticket processing costing data were obtained from ICBC. The capital cost includes the expenditures in purchasing the photo radar devices, software development cost, and project planning and management the costs. These are capital costs. ICBC operating cost includes ticket processing, process serving (personally delivering the violation tickets to the registered vehicle owners), and equipment maintenance costs. Table 7.2 presents the summary level program costs to the end of 1998 in nominal dollars from ICBC sources.

Table 7.2. Capital and ICBC Direct Operating Cost of Photo Radar Program ($000's, in current dollars)

	94/95	95/96	96/97	97/98	Apr-Jul 98	Total
Development/Ads.	807	10,624	16,812	3,819	865	32,927
Process Serving			364	1,471	504	2,338
Equip. Maintenance			138	144	44	326
Ticket/photo Processing			2,266	3,881	719	6,866
Sub_total	807	10,624	19,580	9,315	2,132	42,457

Source: Insurance Corporation of British Columbia (ICBC).

It can be seen that the bulk of the development cost of the program occurred between 1995 and 1997. This reflects mainly the cost of purchasing of photo radar equipment and the customising of software in the start-up stage of the program. To make sure that the program functioned as planned, initially, the program was developed in a contingency system, off line of ICBC main computer systems. A parallel operation process in two systems was set up and continued in the early stage of program development. Limited expenditure was made and shown in the table in 1998 to incorporate the system into the ICBC operating system and phase-out the contingency system. Improvement was also made in computer systems to facilitate process serving, a personal delivery to the registered vehicle owners, if mailed delivery failed initially. The development cost tapered off in 1998. Very limited cost was incurred following 1998. Small in comparison to operating cost, further investment in development cost was considered immaterial and omitted from further analysis.

The capital costs were annualized for the cost-benefit analysis. To this end, the current development costs were converted to 2001 real dollar and discounted by 6% for the 10 years of its economic life, starting from the full implementation, the violation ticket phase, of the program. It can be seen from Table 7.2 that ICBC costs are reported in different fiscal years. This is due to the official transfer of the program from the BC Ministry of Transportation and Highways to ICBC in 1997. To facilitate the analysis, all the costs and benefits are presented in photo radar enforcement years, which is defined as August 1996 to July 1997 as year one and August 1997 to July 1998 as year two. All costs were converted into 2001 real dollars. All photo radar capital cost, including warning letter phase and before are summarized and annualised to produce the photo radar typical year capital cost. The results are presented in the first row, Capital, in Table 7.3.

Table 7.3. Annualized Capital and ICBC Operating Cost of Photo Radar Program ($000's, in 2001 dollars)

Items	**Typical Year**
Capital	4,745
Process Serving	1,557
Equip. Maintenance	147
Ticket/photo Processing	3,470
Total	9,919

Similarly, the operating costs were converted to 2001 real dollars. The only difference is in the distribution. While the capital costs are annualized over equipment economic life by discounting over time, the operating cost is assigned to the specific year. The results of the operating cost in 2001 real dollars are also presented in Table 7.3.

The total ICBC direct cost increased slightly over the two-year period of full (violation ticket phase) program operation. This is accounted for mainly by the increase in photo radar deployment hours and the resulting rise of tickets issued and processed. Another reason for the cost increase is the gradual introduction of process serving and its related cost. Processing serving refers to personal delivery of violation tickets after failing to mail the tickets to the registered owners of the alleges offending vehicles. The ICBC total cost is stabilised in the later part of 1998, based on a more recent report from ICBC. This stabilization observation both in program implementation and impacts gives reason for using 1997/98 to represent the typical year in all the following cost estimations.

Police cost

A standalone police force, the Integrated Traffic Camera Unit (ITCU), was established for the deployment and operation of the photo radar devices. The Ministry of Attorney General estimated that the police cost for this office is $10,350,000 in 1998 (ICBC, 1999).

The police cost is verified, using standard costing method. The data were obtained from the BC Ministry of Attorney, via ICBC. The unit cost and the number of full time equivalent of employees of ITCU are presented in Table 7.4.

Table 7.4. Number of dedicated FTEs and costing rate for ITCU in 1998 dollars

Parameters for standard costing models		Measures
Dedicated Resources, Attorney General		*# FTE*
	RCMP	82.1
	Independent Police Forces	20.0
	Charging Officers	13.5
	ITCU Admin Staff	4.0
Standard Costing Rates, Attorney General		*$/FTE, On-Going*
	RCMP	85,000
	Independent Police Forces	73,690
	Charging Officers	43,101
	ITCU Admin Staff	71,681

Source: BC Ministry of Attorney General, via ICBC.

Using equation (7.1) in the method section of the chapter, the typical yearly police cost for the photo radar program was estimated to be $9,321,311. Adding the 20 percent overhead cost attributed to ITCU, the police cost estimated by the standard costing method is 11,185,346 in 1998 dollars, which is in line with those proclaimed by the Ministry of Attorney General. This derived figure of cost was used as the typical year annualised police cost in the following analysis.

Court costs

The number of photo radar disputes, the productivity measures, and the standard costing rates were obtained from BC Ministry of Attorney General via ICBC. The data are presented in Table 7.5 and Table 7.6.

Table 7.5. Number of photo radar violation tickets issued and number of violation tickets disputed by year

Photo Radar Program	1996	1997	1998
# Violation Tickets, Photo Radar	63,465	246,188	239,513
# Disputes, Photo Radar Program	4,511	16,388	21,681

Source: Insurance Corporation of British Columbia

Table 7.6. Productivity measures and unit costing rates in 1998 dollars

Parameters for standard costing models			Measures
Productivity Measures, Attorney General			*Disputes/FTE*
	Criminal Justice Branch		
		Prosecutor	3,000
		Support Staff	6,000
	Judiciary Branch		
		Justice of the Peace	6,000
	Court Services Branch		
		Sheriffs	15,000
		Court/Registry Clerks	2,727
Standard Costing Rates, Attorney General			*$/FTE, On-Going*
	Criminal Justice Branch		
		Prosecutor	106,844
		Support Staff	52,919
	Judiciary Branch		
		Justice of the Peace	90,252
	Court Services Branch		
		Sheriffs	47,920
		Court/Registry Clerks	46,796

Source: BC Ministry of Attorney General, via ICBC.

Using equation (7.2) in the method subsection, the incremental court cost attributable to photo radar program was calculated. The total staff cost of the court system for the photo radar program was estimated to be $1,730,825 in current dollars in 1998.

Adding 20% for the overhead cost, converting to 2001 dollars, the two year incremental court cost for photo radar program are presented in Table 7.7.

Table 7.7. Court cost by photo radar enforcement year ($000's, in 2001 dollars)

	Aug.96 - Jul. 97	Aug. 97 - Jul. 98	Typical Year
Court cost	1,416	1,954	1,954

Table 7.7 shows that court cost increased over the two years. This is due to the increase in the number of photo radar tickets disputed in the court system. The total number of tickets disputed in court is stabilised later in 1998. As a matter of fact, the total number of dispute in 1999 dropped to 10,509, halving the total disputes recorded in 1998, based on a more recent report from ICBC. This seems to indicate that the number of photo radar disputes and the total resulting incremental costs to the BC court system stabalizeing and trending downwarding after the initial surge. Consistent with the treatment of other cost and benefit, following the conservative principal, the 1997/98 court cost, which is the higher one between the two years, was selected to represent the typical year cost for the analysis.

Program effects

The benefit of the program comprises mainly the savings in collision cost, due to the reduction in traffic collisions and the savings in the resulting traffic delays at the collision sites if the program was not implemented.

Safety benefit

The total value of the benefit depends on two primary factors: the unit value per collision and the numbers of collisions averted. The value of fatal, injury, and property damage collisions are based on shadow prices derived from the willingness to pay principle. Miller (1992) provided the estimates from a societal perspective. These estimates were derived from a number of comprehensive studies in many countries across the world. These estimates are adjusted for BC settings, following Miller's investigation (Miller, 1992). The shadow prices for each category of collisions are presented in Table 7.8. These unit values were confirmed by the BC Ministry of Transportation and referred to in the Economic Appraisal of Highway Investment Guidebook (BC Ministry of Transportation and Highways, 1992). For presentation and later calculation purpose, the prices are converted into the 2001 dollars, using BC CPI numbers obtained from BC STATS.

Table 7.8 Shadow price of traffic collisions by severity from societal perspective ($000 in 1991and 2001 dollars)

Collision Severity	Cost in 1991' $000	Cost in 2001' $000
Injury	102	120
Fatality	3,870	4,578

Source: BC Ministry of Transportation and Highways

It can be seen from Table 7.8 that the shadow price for collisions varies substantially with collision severity. An injury collision is valued at only 2.6% of a fatal collision from the societal perspective.

The number of collisions averted due to the photo radar program is obtained from the two-year, province-wide safety impact assessment, reported in Chapter 5. The province-wide assessment estimates that BC photo radar program reduced 2,220 (14%) traffic collision injuries, and 79 fatalities (26%) over the expected number of collisions if the program was not implemented. The reduction in property only collisions is limited. An earlier ICBC review of property damage insurance claims revealed 1.7% reduction, compared with a predicted numbers, based on an ARCH (Autoregressive Conditional Heteroscedasticity) model (Wu and Cooper, 1998). The reduction is statistically insignificant, however. Given that the estimated reduction in property damage only (PDO) collisions is unreliable in number and low in unit value, taking a conservative stance, the possible benefit of this category was not counted in this analysis.

There is a need for conversion of measurements between the number of injuries and fatalities and the number of injury and fatal collisions due to the fact that the impact assessment and the available reliable shadow price are in different metrics. The safety impacts were assessed in the number of injuries and fatalities, while the shadow price life and injury in BC settings are measured in collisions. To bridge the different measures, the numbers of injuries are converted in the number of injury collisions by reducing injuries by a factor of 0.69. This number is the ratio of the number of injuries to the number of injury collisions as each injury collision tends to have multiple persons injured. Similarly, the number of fatalities was reduced by a factor of 0.88, representing the ratio of the number of traffic fatal collisions to the number of traffic fatalities.

The total safety benefit for a typical photo radar year is calculated by summarising the products of the number of fatal and injuries collisions reduced by the photo radar program, multiplied by their corresponding estimated unit monetary values, the shadow price. The numbers were adjusted by the observed significant reductions in collisions in the warning letter phase. Reduction in traffic injuries in the warning letter phase are not statistically significant. They are not counted as benefit in the evalution. Reduction in traffic fatalities is significant in the month of April, 1996. This month experienced 13 less traffic collision deaths than the expected number had the program not been implemented. This savings is annualized over the 10-year program economic life and added into the benefit consideration for the analysis. The resulting estimates from a societal perspective are presented in Table 7.9.

Table 7.9 Estimated yearly collision reduction, valuation of collision, and cost savings from societal perspective ($000's, in 2001 dollars)

Collision Severity	Reduction	Valuation	Cost savings
Injury	1,542	120	185,412
Fatality	72	4,578	328,518
Total savings			513,930

As shown in Table 7.9, from a societal perspective, a typical year gross safety benefit of the photo radar program is over $500 million, in 2001 real dollars, assuming the stream of benefits will continue into the ten year economic life of the equipment.

From ICBC' perspective, however, the benefit of the program is the savings on insurance claims. The outlay for each types of claims is obtained from ICBC and presented in Table 7.10.

Table 7.10 Shadow price of traffic collisions by severity from ICBC perspective ($000 in 1991and 2001 dollars)

Collision Severity	Cost in 1991' $000	Cost in 2001' $000
Injury	34	40
Fatality	42	50

Based on the number of collisions reduced by the program shown in Table 7.9 and the valuation of each collisions in Table 7.10, the annualised savings from ICBC's perspective was calculated and the results presented in Table 7.11.

Table 7.11 Estimated yearly collision reduction, valuation of collision, and cost savings from ICBC perspective ($000's, in 2001 dollars)

Collision Severity	Reduction	Valuation	Cost savings
Injury	1,542	40	61,989
Fatality	72	50	3,565
Total savings			65,554

Compared with the annualised values from the societal perspective, the ICBC gross savings is small, $65 million versus more than $500 million from the societal perspective. The additional savings on the 13 traffic collision death avoided in the warning letter phase was similarly annualized and incorporated in the above figures, shown in Table 7.11.

From ICBC perspective, the majority of the savings are accounted for by the reduction in injury collisions as opposed to fatal collisions. This is in contrast to that derived from the societal perspective, wherein the overwhelming portion is derived from the reduction in fatal collisions.

The difference can be largely explained by the difference in the value of life recognised from the two perspectives. While the society assigned more than $4.5 million in 2001 dollars to a fatal collision as shown in 7.8, ICBC pays out less than $50 thousand on average to its policyholders. This disparity could cause potentially different opinions, attitudes, and behaviours towards the BC photo radar program.

Savings on reduction in traffic stopage

The time saving and the resulting cost savings due to the collision reduction are estimated by equation 7.4a and 7.4b. The parameters in the equation are not readily available from a search of existing literature. Consequently, it was sought and obtained as expert opinions from the Ministry of Transportation and Highways. It was estimated that the average AADT on BC highways is approximately 1,500 vehicle per day. The average stoppage time for fatal collisions is between 2 to 3 hours. The average stoppage time for serious injury collisions, requiring ambulance services is between 0.5 to 1 hour. Given that few vehicles travel between mid-night and 6 am on highways, the proportion of affected hours is calculated by the impact hour divided by the 18 using hours.

Not all traffic is stopped in every serious collision at all time, even when the cleanup and police investigation is underway. This could cause a potential overestimate of the cost savings in travel time due to collision reduction. This is partly addressed by using the lower end of the estimates i.e., 2 hours delay for a fatal collision and 0.5 hr for a serious injury collision, in the calculation of time savings. Given that the study only includes the savings due to reduction in the number of traffic injuries being picked up and sent to medical facilities, therefore excluding minor injuries or injuries not reported, which also disturb traffic flow, this treatment is not likely to overestimate time saved due to reduction of collisions. The results of the valuation based on these assumptions are presented in Table 7.12.

Table 7.12 Estimated yearly travel time and cost savings due to reduction in traffic collisions ($000's, in 2001 dollars)

Vehicle type	Time savings (hr)	Cost Savings ($)
Car	38,439	564
Truck	4,271	125
Sub total	42,710	689

Table 7.12 shows that time savings due to reduction in collisions are small in comparison to the time lost in the reduction of traffic speed. This could be accounted for by the fact that collisions are isolated incidences and traffic speed is ubiquitous attributes of traffic. Although not likely to change the conclusion of the analysis, the explicit valuation and inclusion of the time savings due to the reduction of traffic collisions make the study more complete and convincing.

Cost of travel time lost

The cost due to lost travel time depends, as shown in equation 7.5a and 7.5b, on the total amount of travel, the unit cost of drivers/passengers, the estimated reduction in speed resulting from the program, and the mean speed of traffic in the province. The data for this analysis were obtained from various sources.

Natural Resources Canada provided the estimates of the total traffic in the province. The data are shown in Table 7.13. The hourly average salary was based on the guidelines from the BC Ministry of Transportation and Highways (1997). The guidelines suggest the value of $10 per person per hour for passenger vehicles and $28 for truck drivers, values provided in 1998 dollars.

Table 7.13 Estimated numbers of vehicle kilometres of travel in BC (000's of km vehicle of travel)

Year	1996	1997	1998
Passenger cars	39,284,363	40,629,875	41,611,084
Trucks	4,139,734	4,565,941	4,260,014

Source: Natural Resources Canada

A very crude estimate of 70km/hr average traffic speed in the province was provided by the Ministry of Transportation and Highways for this study. A previous study of BC photo radar program (Chen, 2001) estimated that traffic speed was reduced by 2.4 km/hr with a 0.4 km/hr standard error, based on a time series-cross sectional study of the 16 monitoring sites across the province. Assuming that the reduction can be generalized to the province as a whole, the total values of time lost due to the reduction in traffic speed by year were estimated, using equation 7.5a and 7.5b in the method section. The cost of travel time lost in the warning letter phase was calculated based on an additional assumption, i.e., mean speed declined in the warning letter phase in a straight line fashion. The result is shown in Table 7.14.

Table 7.14 Estimated incremental travel time cost due to photo radar program ($000's, in 2001 dollars)

Vehicle Type	Mar.96 - Jul. 96	Aug.96 - Jul. 97	Aug. 97 - Jul. 98	Typical Year
Passenger vehicle	121,720	297,965	306,390	306,390
Trucks	25,653	65,266	65,253	65,253
Total	147,374	363,231	371,643	371,643

Table 7.14 shows that, after a gradual increase in the warning letter phase, the cost due to speed reduction levelled off in the study period. This is not unexpected as traffic volume, vehicle occupancy rate, and salary rate change slowly in the years concerned and the speed reduction is estimated over a two year time period. Similar to other costs, second year of photo radar program was selected as the typical year for the standard costs due to travel time lost.

The total cost due to lost of travel time is high, however, relative to other costs accounted for in the study. This significant cost would have been lost in an analysis, had the impact of speed reduction not been included in the cost-benefit analysis, as occurred in most published cost-benefit analysis in traffic safety.

Cost of disputing violation tickets

The cost associated with private citizens disputing photo radar tickets was estimated using equation 7.6 shown in the method section. The number of people disputing the photo radar ticket is presented in Table 7.5 in the court cost sub section. The average hourly wage rate for the years concerned in this study is provided by BC STATS of BC Ministry of Management Services and the rate is presented in Table 7.15.

Table 7.15 BC Average hourly wage ($, in current dollars)

Year	1996	1997	1998
Average wage	16.57	16.83	17.09

Source: BC Stats

The time spent in disputing photo radar tickets is assumed to be 3 hours for each hearing, including travel and waiting time at courthouse. The total cost to citizens disputing photo radar tickets was calculated by multiplying the number of tickets disputed by the average time attending the court and by the average salary of BC workers. The results are presented in Table 7.16.

Table 7.16. Cost to dispute photo radar tickets ($000's, in 2001 dollars)

Photo Radar Program	Aug.96 - Jul. 97	Aug. 97 - Jul. 98	Typical Year
Cost dispute tickets	606	1,041	1,041

In comparison to the cost of travel time lost, the cost of citizens to dispute violation ticket is small. This reflects the fact that the majority of the registered owners of the alleged offending vehicles did not dispute the photo radar tickets. The dispute rate of photo radar program is in line with other tickets of traffic law violations, which is under 10%.

Table 7.16 indicates that the total cost for private citizens to dispute photo radar tickets increased over the 1996 to 1998 period. The peak cost is over 1 million in 1998. The total cost fell however in 1999, corresponding to the decline in the number of disputes of violation tickets, based on more recent ICBC information.

Consistent with treatment of other cost categories, the cost for the second photo radar program year, i.e., August 1997 to July 1998, was assumed to be continuing over the program economic life span. This treatment could introduce bias, overestimating private citizen cost in disputing photo radar tickets. Given that the program was cancelled, which deprived observation of the total cost over the program life time, and that the tendency of dispute is contingent on future court decisions of dispute itself, which diminishes the grounds and circulate the logic for modelling, and keeping consistency with the conservative principle, when error is inevitable, however not estimable, the cost of the second photo radar year was assumed to represent the typical year cost, and used in the annualized cost-benefit comparison in the later sections.

Cost-benefit comparison – societal perspective

The cost and benefit items are compiled and compared from the global societal perspective on an annualised basis. The results are summarized in Table 7.17.

Table 7.17 Net savings of BC Photo Radar program from societal perspective

Cost/benefit category		Annualized cost/benefit, $000
	Capital	4,745
	Process Serving	1,557
	Equip. Maintenance	147
	Ticket/photo Processing	3,470
	Police	11,746
	Court	1,954
Total Cost		**23,620**
	Safety Improvement	513,930
	Time saved	689
	Time lost - travel	-371,643
	Time lost - dispute tickets	-1,041
Total Effects		**141,934**
Net Benefit		**118,314**

As shown in Table 7.17, on an annualized basis, the program generated close to $120 million dollars of net benefit. The program is therefore considered efficient when compared with the no program, status quo option.

Table 7.17 also shows that huge differences exist when the contribution of each of the selected cost item is concerned. Within input categories, the police cost is dominant. This is due to the program design in British Columbia, where police are required to operate the photo radar equipment, as opposed to the un-manned or civilian operated operation as is demonstrated in some other jurisdictions (Hooke, Knox, Portas, 1996). However, the single largest cost item is the negative impact of travel time lost due to traffic speed reduction when all cost items are under consideration. The travel time lost due to reduction in mean speed accounts for more than 94% of the total cost to society.

Paradoxically, the reduction of traffic speed is the direct and the instrumental goal of the photo radar program. It is interesting to note that potentially, there is a point whereby further reduction of speed will be non-economic. The investigation of this critical point is beyond the scope of this current study.

Cost-benefit comparison – ICBC perspective

The cost and saving items are compiled and compared from ICBC perspective. The results are summarized in Table 7.18. It should be noted that ICBC cost does not include the travel time lost due to the reduction in traffic speed and the private citizen time lost in disputing photo radar tickets.

Table 7.18. Net savings of BC photo radar program from ICBC perspective

Cost/benefit category		Annualized cost/benefit, $000
	Capital	4,745
	Process Serving	1,557
	Equip. Maintenance	147
	Ticket Processing	3,470
	Police	11,746
	Court	1,954
Total Cost		**23,620**
	Safety Improvement	65,554
Total Savings		65,554
Net Savings		**41,935**

Table 7.18 shows that from ICBC perspective, the BC photo radar program is a worthwhile investment. The program produced a net savings of close to $38 million, on an annualized investment of $23 million for ICBC stakeholders.

Table 7.18 also shows that the estimated ICBC cost is greatly reduced when compared with the social opportunity cost, used in the calculation of societal cost. At the same time, ICBC recognized a much smaller benefit due to the narrow perspective of insurance savings, as compared to the willingness to pay concept in the societal perspective. The program, based on ICBC perspective, generated over $60 million dollars in net benefit over the warning letter and the two years of violation tickets phase of the program. Political and administrative issues aside, ICBC is better off, in funding and operating the BC photo radar program than its alternative of not having the program on BC roads.

Summary

The base-case cost-benefit analysis shows that the BC photo radar program has resulted in a substantial economic benefit to society in general and produced net cost savings for ICBC. This can be attributed primarily to the effectiveness of the program in improving traffic safety. This substantial improvement in traffic safety provided the substantive footing for an economically efficient social intervention.

A second factor of the high net benefit has to do with the high valuation of human lives and injuries, associated with the willingness to pay model. This factor is not essential however, given that, even from ICBC's corporate viewpoint, the program is still beneficial, generating more savings then cost, over the study period.

The above cost benefit calculation form the base case study for this cost-benefit analysis. However, the base case study is built on a number of un-tested assumptions and error-prone estimates. These uncertainties propagate into the estimates and the results of the cost-benefit analysis. The real results will vary depending on the accuracy of the assumptions and estimates. These concerns are partially addressed in the following sensitivity analysis section.

SENSITIVITY ANALYSIS

Sensitivity analysis has been applied consistently in ex-ante cost-benefit analysis (Drummond, 1984; Hadrovic and Weiss, 1986; Ickovich, 1998; Borissov, 2001). It is also applicable to in media res cost-benefit analysis, although in a slightly difference sense. Ex-ante cost-benefit requires the prediction of the future state of affairs. Assumptions and predictions need to be tested in the traditional probability sense. In the in-media-res cost-benefit analysis, the program has been implemented and the outcome of the program has materialized and is presumably estimable. The predictive aspect of the sensitivity analysis is therefore irrelevant. However, no estimate in a complex study is error free. As a matter of fact, many parameters have been estimated in the current study. The errors in the estimated parameters could render bias in the base case study, and in more serious cases, reverse the findings qualitatively. The effect of the variation in the estimated parameters, within a plausible range, should therefore be investigated.

Moreover, assumptions on important parameters have to be made, if timely cost-benefit analyses are to be implemented in the real world. This can be attributed to two reasons, the under-developed theoretical framework to offer unequivocal parameter values and the limited resources in terms of time and staff expertise in government offices. These assumptions also need verification. The following section tests the most sensible parameters as to their impact on the net benefit.

Partial sensitivity analyses and best-worst case analysis were used in the process to test the robustness of the base case study results.

Parameters tested in sensitivity analysis

A number of parameters are assumed in the base-case cost-benefit analysis. Discount rates, shadow price of tax dollars (Marginal excess burden of taxation, MEB), and the valuation of collisions, were assumed based on theory or obtained from published reliable sources. These variables were tested in their theoretically justifiable and practically probably range. The magnitudes of speed reductions and collision reductions due to the program were estimated from the impact assessments of this study. The margins of errors of these estimates were also investigated in this sensitivity analysis. The parameters and their plausible values investigated in this analysis are presented in Table 7.19.

Table 7.19. Variables and values to be included in sensitivity analysis

Variable	Base Case	Values	Description
Discount rate	6%	1% 5% 7%	Assumption based MoTH guideline
Marginal excess burden of taxation (MEB)	0%	125%	Resource allocation
Value of various collision types (WTP)	Injury = $ 0.12 m Fatality =$ 4.58 m	± 25% ± 10%	Estimates with error
Reduction in speed	2.4 km/hr	2.0 km/hr 2.8 km/hr	Estimates with error (±1σ)
Reduction in injury & fatalities	# Injury = 2,220 # Fatality = 79	±1σ, of each estimate	Estimates with error
Value of time of passenger vehicles	$10	$15 $20	Speeders may give high value to time

Sensitivity Analysis from societal perspective

A partial sensitivity analysis was conduced following standard methods outlined in the literature review chapter of the study. Other things kept equal, the partial sensitivity analysis changes one parameter at a time and assesses the impact on the estimated annualized net benefit. The method was applied to all the selected sensitivity analysis parameters listed in Table 7.19, except for traffic safety. Because the construct of traffic safety is measured in two variables, the number of fatalities and the number of injuries, which tends to move in the same direction, the two variables were varied simultaneously to test the impact on net benefit, due to the potential errors of in estimating the safety effect of the program.

Within the limited data and expertise of the author, the fuel savings as it relate to operating and environment cost were estimated. The estimated is based on the argument that fuel savings accrue mostly to excessive speeders, who exceed the speed limit by 16 or more kilometres. The provincial study showed that excessive speeding was reduced by about 4 percentage points. We have assumed that fuel consumption for those who drop from excessive speed to within 15 km/h of the limit is reduced by approximately 2%. Given that the total gasoline sales in the photo radar typical year is 4,562 million litres and the per litre cost of gas is approximately $0.60, the total saving of gasoline cost to the excessive speeders is estimated to be $2 million dollar range ($4,562 x 0.6 x 0.04 x 0.02 = $2.2 million), which is not material relative to the $118 million dollar net benefit, mainly accrued from traffic safety improvement.

An offsetting argument must be made for the reduction of traffic speed in cities and with highway drivers at moderate speeds. It is well known to engineers that fuel efficiency displays a U- shaped curve relative to speed. For the majority of the traffic volume, already within ±15 km/hour of the speed limit, reducing speed may actually lower fuel efficiency and increase fuel costs. The real balance (between fuel reductions for excessive speeders and fuel increases for moderate drivers) is not estimable with certainty under the current data limitation. Given the immaterial and unreliable quality of the estimate, this potential impact is not discussed further in the following sections.

Table 7.20 provides the results of the partial sensitivity analysis from a societal perspective, breaking down cost and benefit categories for close inspection. For comparison purposes, the base case results are shown in the first column.

Table 7.20 shows that the annualized cost-benefit categories and the resulting net benefit varies with the testing parameters concerned. The results of the base case cost-benefit analysis is very robust, with respect to the MEB treatment of tax dollars to finance the program, i.e., a 25% increase in the valuation of tax dollars due to the inefficiency of collecting tax dollars). It is also robust to a change of discount rate in the range of 1% to 7%.

Table 7.20 Sensitivity analysis - Societal Perspective, in Thousand of 2001 Canadian Dollars

		MEB	Discount Rate			Human Life/Inj. Valuation		Speed reduction (km/hr)		Safety Improvement		Time Value	
Components	**Base Case**	**(125%)**	**1%**	**5%**	**7%**	**+10%**	**-10%**	**2.0**	**2.8**	**+1 SD**	**-1 SD**	**$15**	**$20**
Capital	4,745	5,931	3,687	4,523	4,972	4,745	4,745	4,745	4,745	4,745	4,745	4,745	4,745
Process Serving	1,557	1,946	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557
Equip. Maintenance	147	184	147	147	147	147	147	147	147	147	147	147	147
Ticket/photo Processing	3,470	4,338	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470
Police	11,746	14,683	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746
Court	1,954	2,442	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954
Total Cost	23,620	29,525	22,562	23,397	23,847	23,620	23,620	23,620	23,620	23,620	23,620	23,620	23,620
Safety Improvement	513,930	513,930	513,930	513,930	513,930	565,323	462,537	428,275	599,585	628,946	384,584	513,930	513,930
Time saved	689	689	689	689	689	689	689	689	689	782	517	932	1,202
Time lost - travel	-371,643	-371,643	-371,643	-371,643	-371,643	-371,643	-371,643	-307,881	-436,165	-371,643	-371,643	-492,898	-661,702
Time lost - dispute tickets	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041	-1,041
Total Effects	141,934	141,934	141,934	141,934	141,934	193,327	90,541	120,042	163,068	257,044	12,417	20,923	-147,612
Net Benefit	118,314	112,409	119,372	118,537	118,087	169,707	66,921	96,422	139,448	233,424	-11,202	-2,697	-171,232

However, the annualized net benefit of the photo radar program varied quantitatively and substantively within the range of plausible estimation of speed reductions and the valuation of human life and injuries. Given the predominance of the traffic speed reduction in accounting for the total costs of the program as alluded in the previous subsection, the degree of sensitivity toward the estimated speed reduction is not unexpected. The valuation of human life and injury affect the net benefit due mainly to its weight on the benefit side. As the predominant benefit item, a reduction of 10% makes a big difference.

A key parameter in impacting the conclusion of the cost-benefit analysis is the estimates of traffic safety. The change of the estimated safety improvement qualitatively change the conclusion of the efficiency of the program. Table 7.20 shows that if the real safety improvement is at the lower bound of the one standard error range, than the program turns to negative. The program is no longer efficient in economic terms.

The results of the benefit analysis is most sensitive to the values drivers and passengers assign to time. Given the significant cost impact of travel time lost, higher values of travel time would shift the overall valuation into negative territory.

In sum, the societal perspective sensitivity analysis suggests that the economic benefit of the BC photo radar program is sensitive to change in critical estimates and assumptions underpinning the analysis of the base case, the most probable case based on available information. The credibility and reliability of the conclusion in informing decision-making should be evaluated and used in this context. Further study to narrow down the errors in estimating the traffic safety effect of the program should be performed if the need for more accurate information for knowledge or for significant decisions arises.

Sensitivity Analysis from ICBC perspective

A partial sensitivity analysis was conduced following the same methods, however, from the ICBC perspective. ICBC, as the funding provider has an innate interest in the success of the program. The success of the program in terms of reducing collisions and injuries would lead to a reduction of insurance claims, which would in turn, affect ICBC bottom line and potential insurance premiums, upon which ICBC performance is judged by politicians and the public.

ICBC does not concern itself primarily with the economic well being of the society in general. ICBC valuation of fatal and injury collision is based on the monetary outlay for the affected policyholders or their families, not under the willingness to pay concept. Traffic speed and the economic cost due travel time lost, as a result of speed reduction is not a category in the cost-benefit calculation. Consequently, the impact of these parameters on their benefit is not assessed in the sensitivity analysis addressed in this section. The results of the sensitivity analysis within ICBC perspective are presented in Table 7.21.

From ICBC perspective, the sensitivity analysis is robust with respect to the parameters concerned. Table 7.21 shows that the net benefit of photo radar program from ICBC's perspective is always positive in the full range of the parameters tested. The program generates a net benefit in the range between $22 million and $53 million dollars for the insurance company.

Table 7.21 Sensitivity analysis - ICBC Perspective, in Thousand of 2001 Canadian Dollars

Components	Base Case	MEB (125%)	Discount Rate (%)			Human Life/Inj. Valuation		Speed reduction (km/hr)		Safety Improvement	
			1%	5%	7%	+10%	-10%	2.0	2.8	+1 SD	-1 SD
Capital	4,745	5,931	3,687	4,523	4,972	4,745	4,745	4,745	4,745	4,745	4,745
Process Serving	1,557	1,946	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557
Equip. Maintenance	147	184	147	147	147	147	147	147	147	147	147
Ticket/photo Processing	3,470	4,338	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470
Police	11,746	14,683	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746	11,746
Court	1,954	2,442	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954
Total Cost	23,620	29,525	22,562	23,397	23,847	23,620	23,620	23,620	23,620	23,620	23,620
Insurance savings	65,554	65,554	65,554	65,554	65,554	72,110	58,999	65,554	65,554	81,880	49,073
Total Savings	65,554	65,554	65,554	65,554	65,554	72,110	58,999	65,554	65,554	81,880	49,073
Net Savings	41,935	36,030	42,992	42,157	41,707	48,490	35,379	41,935	41,935	58,260	25,454

Summary

In summary, the partial sensitivity analysis of BC photo radar program indicates that the BC photo radar program is not completely robust in its economic performance from a societal perspective. If the real safety effect is at the low bound of one standard error of estimates, the program would have generated a negative impact on the social well being of the society at large.

However, from ICBC's corporate perspective, the BC photo radar program is efficient in producing economic returns. Within the parameters tested, ICBC will be always receiving greater savings than its cost, although, for many policy holders, the investment is to address a social purpose, as often encouraged, if not mandated to Crown Corporations. ICBC is a winner and ICBC's support to the program is expected, if economic considerations prevail in corporation decision making with regard to BC photo radar program.

8. CONCLUSIONS AND LIMITATIONS

The BC photo radar program started operation on BC highways in March 1996. The program was introduced in two phases, the warning letter phase and the violation ticket phase.

The BC photo radar program was implemented through an extensive publicity campaign and the deployment of 30 photo radar units across the highway systems in the province. About 95% of BC residents were aware of the photo radar program before its introduction, and about two-thirds supported the photo radar program. Support for the program continued in the first two-year of program operation, based on ICBC public and policyholder surveys.

The level of enforcement increased in the warning letter phase and stabilized in the violation ticket phase. The hours of deployment of photo radar vans exceeded 3,500 hours per month on average in the second year of operation. In total, 70,000 hours of photo radar enforcement occurred on BC highways in the two-year study period. More than half a million photo radar speed violation tickets were delivered to registered owners of the alleged offending vehicles in the two years of period after the commencement of the violation ticket phase.

Traffic speed and speed variance declined following the introduction of the photo radar program. At the photo radar deployment sites, the proportion of speeding vehicles decreased from more than 60% in the warning letter phase, to 37% in the first year in the violation ticket phase, and to 29% in the second year of violation ticket phase. The proportion of excessive speeding vehicles decreased from more than 10% in the warning letter phase to 3% in the first year and to 2% in the second year.

Across the province at the non-photo radar, monitoring sites, the proportion of speeding vehicles declined from 78% in the pre-PRP period to 73% in the first year and then increased slightly to 74% in the second year. The proportion of excessive speeding vehicles declined from 27% in the pre-PRP period to 22% in the first year and rebounded slightly to 23% in the second year.

Corresponding, in time, to the reduction in speed and speed variance, traffic collisions decreased across the province. The program is attributed to a 2, 220 (14%) reduction in traffic collision injuries requiring ambulance services, and a 79 (26%) reduction in traffic fatalities, in the province-wide study. With better information and control of treatment and other exogenous variables, a site-specific analysis of the program confirmed and corroborated the results of province-wide study. The evidence from the site-specific study also tested and supported the theory of a program spill-over effect, as opposed to a competing traffic collision migration theory. The results of these studies show that traffic safety was improved across the province as a result of the introduction of the BC photo radar program.

A cost-benefit analysis summarized major inputs and impacts of the program in common monetary terms and concluded that the BC photo radar program produced net benefits. From the global societal perspective, the program is estimated to have generated close to $120 million net benefit per year in its full operation. From a narrower ICBC corporate view, the program is associated with an approximately $40 million-dollar net benefit.

The conclusion of the cost-benefit analysis is sensitive to the errors in the estimation of program safety effects. From a societal perspective, the program could have produced a negative impact, albeit small, on the social well being of the society if the real effect of the program were one standard error below the estimates. From the ICBC perspective, the program is robust. The program generates net cost savings for insurance cost, regardless of the assumptions and estimations in the values of parameters being tested in the sensitivity analysis.

The BC photo radar program was terminated in 2001. A new Government was elected and it canceled the photo radar program in fulfilment of its election promise. Nevertheless the lesson learnt from this study is still of value and may be applied in future decision making within or outside of the province.
Although the program is effective in reducing collisions, the adoption of the program should be considered with caution. The program has negative consequences outside its stated goals and targets consideration. The program is designed to improve traffic safety and reduce health and insurance cost by reducing speed through system wide, general deterrence of speeding behaviour. The reduction of speed across the province causes lost of travel time directly,

which has significant economic consequences. When competing social and economic values are present, political as well as economic considerations determine the priorities and the rule of the day.

The evaluation of the BC photo radar program is limited in many ways. The most significant one relates to its research design. It is recognised that quasi-experimental research design does not control completely all conditions and influences. A detailed site-specific study, which attempts to improve the internal validity, corroborates the province-wide study result. But the site-specific study has its own limitations and assumptions in its comparison group selection process and the questions in external validity in terms of generating the results from one highway section to the BC highway system. Although quasi-experimental study method is considered the most valid and reliable method in highway safety and enforcement studies, and the incorporation of various measures and analytical frameworks to corroborate the results, the limitations in the knowledge it purports to generate need to be fully disclosed and acknowledged.

Like all other economic studies of government programs, the cost-benefit analysis is incomplete and inconclusive, in terms of providing a criterion for investment decisions. The BC photo radar program is assessed against the no-program, status quo condition. The investment and application of the program has to be considered in the overall value framework of the society as reflected in the political process and the ensuing budgeting process, and in the context of other social programs, which did not enter into the cost-benefit comparison in the current study. Global optimisation cannot be achieved by cost-benefit analysis in general. The role of decision-maker is assisted but not replaced by the current analysis.

A future study of the BC photo radar program could be conducted to assess the traffic safety effects of the program on highways and city streets separately. The program could have been effective on a provincial highway, but not as effective on city streets. Public support and the continuation of the program could have been harmed by the way the photo radar program was delivered in the province. The less-than mobile application of the program, the controversial location, such as downhill or speed limit change areas, may affect people's perception of the program intent. Many people sincerely view photo radar program as a cash cow for the provincial coffer. Further work along these lines could be useful in concluding the short lived BC photo radar program.

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APPENDIX A: DEPLOYMENT HOURS AND VIOLATION TICKETS BY MONTH

Month	Hours	Tickets
May-96	186.00	0
Jun-96	384.95	0
Jul-96	712.60	0
Aug-96	1014.95	8,378
Sep-96	1265.67	16,090
Oct-96	936.75	17,905
Nov-96	1861.43	18,000
Dec-96	1762.45	16,459
Jan-97	1988.55	22,490
Feb-97	2422.65	24,534
Mar-97	2913.20	27,943
Apr-97	2840.85	22,293
May-97	3417.88	35,890
Jun-97	3316.42	28,412
Jul-97	3211.47	22,800
Aug-97	3071.93	25,023
Sep-97	3318.40	23,555
Oct-97	3946.13	33,095
Nov-97	3386.58	27,823
Dec-97	3283.22	22,425
Jan-98	3548.68	24,882
Feb-98	3467.48	23,482
Mar-98	3738.23	24,182
Apr-98	3789.12	25,370
May-98	3875.05	27,136
Jun-98	3930.50	25,422
Jul-98	3356.07	21,274

APPENDIX B: SUMMARY DATA FOR THE TIME SERIES ANALYSIS

MONTH	GAS_SALE	EMP_RATE	ALC_SALE	Daytime Injury	Daytime fatality
Jan-91	245947	89	6629.89	797	13
Feb-91	250674	88.7	7932.21	810	18
Mar-91	276462	88.8	7753.87	1076	21
Apr-91	300175	89.7	8237.74	1073	34
May-91	320851	90.3	7931.88	1179	33
Jun-91	299333	90.8	8212.24	1179	22
Jul-91	361435	90.5	8190.72	1428	25
Aug-91	353164	90.5	8223.96	1632	42
Sep-91	325378	91	7554.42	1239	30
Oct-91	319308	91.1	7654.44	1268	29
Nov-91	276967	90	7780.04	1329	35
Dec-91	296232	89.5	8031.94	1219	14
Jan-92	264689	88.4	6100.88	1057	17
Feb-92	261838	88.6	7624.36	966	29
Mar-92	295024	88.6	8232.36	956	16
Apr-92	291777	89.5	7878.11	1092	18
May-92	317926	90.1	7820.17	1081	21
Jun-92	325573	89.4	8668.58	1201	27
Jul-92	350148	89.2	8282.63	1303	31
Aug-92	356196	89.6	7856.77	1477	29
Sep-92	340727	90.2	8172.37	1288	29
Oct-92	308825	90.4	7885.64	1269	26
Nov-92	306566	89.9	7995.95	1227	26
Dec-92	314195	90.1	7085.93	1359	26
Jan-93	262587	89.1	6949.94	925	27
Feb-93	267603	89.1	8074.67	723	17
Mar-93	327927	89.7	8998.56	992	14
Apr-93	308197	89.7	8112.79	1058	18
May-93	328518	89.5	8209.54	1102	13
Jun-93	349022	90.8	8300.49	1236	34
Jul-93	368874	89.8	8064.14	1290	23
Aug-93	391237	90.9	8580.89	1427	26
Sep-93	350200	91.5	8486.64	1234	39
Oct-93	324993	91.6	8322.52	1271	15
Nov-93	331703	91.5	8109.91	1175	32
Dec-93	330626	90.2	7540.16	1322	22
Jan-94	292168	88.6	7281.02	1020	29
Feb-94	289912	88.7	8186.07	1123	20
Mar-94	333550	89.9	9266.34	1014	15
Apr-94	317828	89.1	7844.16	1006	14
May-94	350160	90.8	8687.18	1155	33
Jun-94	364761	91.3	8540.98	1350	29

MONTH	GAS_SALE	EMP_RATE	ALC_SALE	Daytime Injury	Daytime fatality
Jul-94	385081	91	8712.57	1422	36
Aug-94	403335	90.9	8558.6	1416	34
Sep-94	361579	92	8300.92	1267	38
Oct-94	344392	91.8	8574.18	1252	38
Nov-94	332192	91.2	8575.86	1234	21
Dec-94	334334	91.6	7934.84	1333	30
Jan-95	312674	90.2	7065.38	1224	21
Feb-95	294727	90.1	8364.06	922	20
Mar-95	331926	90.5	9043.34	1005	28
Apr-95	320400	90.8	8483.72	1120	24
May-95	362360	91.2	8768.1	1094	15
Jun-95	361125	91.5	8704.61	1180	32
Jul-95	394810	90.6	8825.42	1358	28
Aug-95	405023	91.6	6940.98	1382	24
Sep-95	365856	92.1	8791.59	1283	24
Oct-95	358588	91.9	8218.61	1198	23
Nov-95	335311	90.9	8283.2	1433	23
Dec-95	345915	91.1	8052.82	1262	33
Jan-96	316744	89.7	6991.55	1012	17
Feb-96	320705	90.6	8108.69	1085	14
Mar-96	336082	91	8594.5	1053	15
Apr-96	340479	91.5	8857.45	1025	10
May-96	368412	91.4	8422.67	1044	16
Jun-96	364193	91.6	8909.41	1200	22
Jul-96	405929	91.9	8530.5	1399	21
Aug-96	413409	91.1	8622.2	1328	16
Sep-96	366666	91.6	8370.28	1162	26
Oct-96	376097	91	8015.6	1186	24
Nov-96	338886	90.7	8070.28	1126	22
Dec-96	327788	91.5	7119.34	1142	24
Jan-97	334085	91	7942.41	976	12
Feb-97	307465	90.6	8271.91	795	19
Mar-97	350007	91.2	8326.02	1060	12
Apr-97	365392	90.7	9174.77	945	8
May-97	391859	91.3	8355.6	1147	28
Jun-97	383971	91.9	8581.6	1060	13
Jul-97	424594	91.4	8694.48	1052	21
Aug-97	425223	91.7	8277.28	1210	30
Sep-97	383352	91.8	7858.93	1078	16
Oct-97	390131	91.4	8015.17	1119	27
Nov-97	351069	91	7803.86	1069	12
Dec-97	387210	91.7	7409.09	1028	22
Jan-98	343969	89.4	7370.21	910	18
Feb-98	322523	89.3	7903.86	766	6
Mar-98	375804	89.6	8153.59	873	19

MONTH	GAS_SALE	EMP_RATE	ALC_SALE	Daytime Injury	Daytime fatality
Apr-98	377546	90.7	7950.88	842	23
May-98	398368	90.4	8059.68	1043	25
Jun-98	415102	91.1	8310.86	984	21
Jul-98	444599	91.1	8310.86	1206	19

APPENDIX C: SUMMARY DATA FOR NEGATIVE BINOMIAL MODEL

seg	hwy	rd_class	rd_lane	rlength	a_cnt2	m_aadt2	Pred
304	17	RE	2	15.3	151	19472	152.64772
304	17	UE	2	3.59	14	14366	27.308299
307	17	RE	2	12.8	132	20768	135.25929
307	17	UE	2	2.76	43	16362	23.576905
307	17	UE	2	6.18	29	17461	55.943677
506	1	UF	2	12.97	94	16751	113.14166
508	1	UF	2	10.23	48	14971	80.733689
510	1	UF	2	9.8	250	38778	180.75728
575	1	RF	2	39.7	161	11519	247.9818
575	1	UF	2	3.75	9	10792	22.100522
791	1	RF	2	34.98	91	7474	148.5425
792	1	RF	2	35.17	81	7481	149.4891
2000	5	RF	2	8.87	40	3791	20.560513
2000	5	RF	2	31.36	116	3791	72.69196
2000	5	RF	2	4.23	11	3791	9.8050699
2000	5	RF	2	5.57	18	3791	12.911168
2000	5	RF	2	8.58	13	3791	19.888298
2005	5	RF	2	109.89	381	3808	255.69687
2015	5	RF	2	4	5	3068	7.6766152
2020	5	RF	2	3.5	5	3258	7.0859194
2020	5	RF	2	11.97	16	3258	24.233844
2020	5	RF	2	3.27	5	3258	6.6202732
2025	5	RF	2	66.16	150	3210	132.20969
2030	97C	RA	2	82.11	136	1628	89.549358
2055	1	UF	2	6.7	8	5281	20.873775
2910	99	RF	2	27.9	166	11621	175.64305
2910	99	UF	2	1.3	22	26586	17.123472
2910	99	UF	2	2.84	65	32194	44.371624
2915	99	RF	2	27.73	133	9538	146.3752
2915	99	UF	2	13.01	212	28850	184.32389
3000	91	UF	2	7.93	37	13644	57.610104
3005	91	UF	2	7.95	25	11724	50.447113
3020	91	UF	2	11.43	183	18874	110.90806
3025	91	UF	2	10.93	172	23723	130.05151

APPENDIX D: SAS OUTPUT- FULL MODEL FOR INJURIES

```
                              The ARIMA Procedure

                          Name of Variable = dt_Injury

                       Mean of Working Series    1145.473
                       Standard Deviation        174.7634
                       Number of Observations          91

                                Autocorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1      Std
Error

   0     30542.249        1.00000    |                    |********************|
0
   1     19053.702        0.62385    |                .   |************        |
0.104828
   2     10257.508        0.33585    |               .    |*******             |
0.139795
   3      4164.354        0.13635    |               .    |***  .              |
0.148396
   4     -1212.332        -.03969    |               .   *|     .              |
0.149767
   5     -8256.076        -.27032    |               .*****|    .              |
0.149882
   6    -13614.727        -.44577    |           *********|     .              |
0.155147
   7     -9936.128        -.32532    |             *******|      .             |
0.168635
   8     -3270.528        -.10708    |              .   **|      .             |
0.175397
   9    -36.766800        -.00120    |              .     |      .             |
0.176113
  10      6348.108        0.20785    |              .     |****  .             |
0.176114
  11     13532.021        0.44306    |              .     |*********           |
0.178789
  12     17793.399        0.58258    |             .      |************        |
0.190472
  13     14122.402        0.46239    |             .      |*********           |
0.209139
  14      7732.249        0.25317    |            .       |*****    .          |
0.220087
  15       628.308        0.02057    |            .       |         .          |
0.223264
  16     -3099.360        -.10148    |            .     **|         .          |
0.223285
  17    -10064.960        -.32954    |            . *******|        .          |
0.223791
  18    -13568.720        -.44426    |           *********|         .          |
0.229062
  19    -11381.988        -.37266    |           .  *******|         .         |
0.238342
  20     -6150.205        -.20137    |           .     ****|         .         |
0.244661
  21     -1604.509        -.05253    |           .        *|         .         |
0.246476
  22      2338.279        0.07656    |           .        |**        .         |
0.246599

                        "." marks two standard errors

                          Inverse Autocorrelations

                 Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

                   1       -0.35885    |             *******|   .                |
                   2       -0.03279    |                .  *|   .                |
                   3        0.03747    |                .   |*  .                |
                   4       -0.07271    |                .  *|   .                |
                   5       -0.17633    |                ****|   .                |
                   6        0.25138    |                .   |*****               |
                   7       -0.04751    |                .  *|   .                |
```

```
  8       -0.13979    |                  .***|    .                    |
  9        0.26128    |                  .   |*****                    |
 10       -0.08996    |                  . **|    .                    |
 11       -0.07609    |                  . **|    .                    |
```

The ARIMA Procedure

```
                              Inverse Autocorrelations

 Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  12       -0.06263    |                .  *|   .                |
  13        0.01207    |                .   |   .                |
  14       -0.16204    |                .***|   .                |
  15        0.23727    |                .   |*****               |
  16       -0.08996    |                . **|   .                |
  17        0.02562    |                .   |*  .                |
  18        0.03738    |                .   |*  .                |
  19        0.00363    |                .   |   .                |
  20       -0.05693    |                .  *|   .                |
  21        0.01300    |                .   |   .                |
  22        0.03130    |                .   |*  .                |


                              Partial Autocorrelations

 Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

   1        0.62385    |                .   |************        |
   2       -0.08732    |                . **|   .                |
   3       -0.06102    |                .  *|   .                |
   4       -0.12910    |                .***|   .                |
   5       -0.27784    |              ******|   .                |
   6       -0.22697    |               *****|   .                |
   7        0.19180    |                .   |****                |
   8        0.20432    |                .   |****                |
   9       -0.01270    |                .   |   .                |
  10        0.24605    |                .   |*****               |
  11        0.22105    |                .   |****                |
  12        0.14869    |                .   |***.                |
  13       -0.04949    |                .  *|   .                |
  14       -0.07739    |                . **|   .                |
  15       -0.25167    |               *****|   .                |
  16        0.10269    |                .   |** .                |
  17       -0.09778    |                . **|   .                |
  18       -0.04144    |                .  *|   .                |
  19        0.03689    |                .   |*  .                |
  20        0.02991    |                .   |*  .                |
  21       -0.07300    |                .  *|   .                |
  22       -0.05118    |                .  *|   .                |
```

The ARIMA Procedure

Autocorrelation Check for White Noise

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	76.24	6	<.0001	0.624	0.336	0.136	-0.040	-0.270	-0.446
12	149.71	12	<.0001	-0.325	-0.107	-0.001	0.208	0.443	0.583
18	216.46	18	<.0001	0.462	0.253	0.021	-0.101	-0.330	-0.444

Correlation of dt_Injury and GAS_SALE

Variance of input = 1.7364E9
Number of Observations 91

Crosscorrelations

```
Lag   Covariance   Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22     2710940      0.37226     |                .   |*******             |
-21     2068361      0.28402     |                .   |******              |
-20      883748      0.12135     |                .   |** .                |
-19     -756602      -.10389     |                . **|   .                |
-18    -2534553      -.34804     |             *******|   .                |
-17    -2814034      -.38642     |            ********|   .                |
-16    -2282434      -.31342     |              ******|   .                |
-15    -1633394      -.22429     |                ****|   .                |
-14     -321276      -.04412     |                .  *|   .                |
-13     1415078      0.19431     |                .   |****                |
-12     2894905      0.39752     |                .   |********            |
-11     2777138      0.38135     |                .   |********            |
-10     2018731      0.27721     |                .   |******              |
 -9     1261767      0.17326     |                .   |***.                |
 -8  -87406.758      -.01200     |                .   |   .                |
 -7    -1796012      -.24662     |               *****|   .                |
 -6    -3891505      -.53437     |         ***********|   .                |
 -5    -4031575      -.55360     |         ***********|   .                |
 -4    -3589591      -.49291     |          **********|   .                |
 -3    -2853576      -.39184     |            ********|   .                |
 -2    -1262575      -.17337     |                .***|   .                |
 -1      544537      0.07477     |                .   |*  .                |
  0     2674380      0.36724     |                .   |*******             |
  1     2166096      0.29744     |                .   |******              |
  2     1134712      0.15582     |                .   |***.                |
  3      450453      0.06185     |                .   |*  .                |
  4     -954346      -.13105     |                .***|   .                |
  5    -2772100      -.38066     |            ********|   .                |
  6    -4492747      -.61693     |        ************|   .                |
  7    -4301786      -.59071     |        ************|   .                |
  8    -3607078      -.49531     |          **********|   .                |
  9    -2686398      -.36889     |             *******|   .                |
 10    -1293568      -.17763     |                ****|   .                |
```

```
                              The ARIMA Procedure

                               Crosscorrelations

Lag     Covariance     Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 11         482188         0.06621    |                .   |*  .                |
 12        2127066         0.29208    |                .   |******              |
 13        2002180         0.27493    |                .   |*****               |
 14        1435891         0.19717    |                .   |****                |
 15         725116         0.09957    |                .   |** .                |
 16        -563867         -.07743    |                . **|   .                |
 17       -2067169         -.28386    |              ******|   .                |
 18       -3621562         -.49730    |          **********|   .                |
 19       -3539634         -.48605    |          **********|   .                |
 20       -2830284         -.38865    |            ********|   .                |
 21       -2122327         -.29143    |              ******|   .                |
 22        -950775         -.13056    |                .***|   .                |

                         "." marks two standard errors


                       Correlation of dt_Injury and point03

                        Variance of input =       0.010868
                        Number of Observations          91


                               Crosscorrelations

Lag     Covariance     Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22      -0.207269         -.01138    |                .   |   .                |
-21       1.930694         0.10597    |                .   |** .                |
-20       2.724254         0.14953    |                .   |***.                |
-19       2.658740         0.14593    |                .   |***.                |
-18       1.041842         0.05718    |                .   |*  .                |
-17       0.919329         0.05046    |                .   |*  .                |
-16       0.731849         0.04017    |                .   |*  .                |
-15       1.843970         0.10121    |                .   |** .                |
-14       0.645983         0.03546    |                .   |*  .                |
-13      -2.662377         -.14613    |                .***|   .                |
-12      -1.739001         -.09545    |                . **|   .                |
-11      -0.483057         -.02651    |                .  *|   .                |
-10      -0.760624         -.04175    |                .  *|   .                |
 -9       0.187628         0.01030    |                .   |   .                |
 -8       2.152907         0.11817    |                .   |** .                |
 -7       2.430829         0.13342    |                .   |***.                |
 -6       1.371352         0.07527    |                .   |** .                |
 -5       0.483110         0.02652    |                .   |*  .                |
 -4       3.098431         0.17006    |                .   |***.                |
 -3       1.255957         0.06894    |                .   |*  .                |
 -2      -1.478921         -.08117    |                . **|   .                |
 -1      -0.657224         -.03607    |                .  *|   .                |
  0      -1.016182         -.05578    |                .  *|   .                |
```

The ARIMA Procedure

Crosscorrelations

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  1    -1.365955      -.07497       |                .  *|   .                |
  2    -1.197675      -.06574       |                .  *|   .                |
  3     0.508222      0.02789       |                .   |*  .                |
  4     2.686283      0.14744       |                .   |***.                |
  5     1.910112      0.10484       |                .   |** .                |
  6     0.089985      0.00494       |                .   |   .                |
  7     0.387839      0.02129       |                .   |   .                |
  8    -0.212750      -.01168       |                .   |   .                |
  9    -0.025631      -.00141       |                .   |   .                |
 10    -1.835011      -.10072       |                . **|   .                |
 11    -3.801859      -.20867       |                ****|   .                |
 12    -0.880892      -.04835       |                .  *|   .                |
 13    -2.155313      -.11830       |                . **|   .                |
 14     0.042795      0.00235       |                .   |   .                |
 15    -0.936129      -.05138       |                .  *|   .                |
 16    -1.030499      -.05656       |                .  *|   .                |
 17     0.697979      0.03831       |                .   |*  .                |
 18    -0.745865      -.04094       |                .  *|   .                |
 19    -0.276292      -.01516       |                .   |   .                |
 20    -0.785708      -.04313       |                .  *|   .                |
 21    -1.219046      -.06691       |                .  *|   .                |
 22    -2.500833      -.13726       |                .***|   .                |
```

"." marks two standard errors

Correlation of dt_Injury and point04

```
Variance of input =        0.010868
Number of Observations           91
```

Crosscorrelations

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22     1.935588      0.10624       |                .   |** .                |
-21     2.721903      0.14940       |                .   |***.                |
-20     2.658320      0.14591       |                .   |***.                |
-19     1.021377      0.05606       |                .   |*  .                |
-18     0.877007      0.04814       |                .   |*  .                |
-17     0.721527      0.03960       |                .   |*  .                |
-16     1.819761      0.09988       |                .   |** .                |
-15     0.646167      0.03547       |                .   |*  .                |
-14    -2.672698      -.14670       |                .***|   .                |
-13    -1.750289      -.09607       |                . **|   .                |
-12    -0.475265      -.02609       |                .  *|   .                |
-11    -0.768772      -.04220       |                .  *|   .                |
-10     0.184431      0.01012       |                .   |   .                |
```

The ARIMA Procedure

Crosscorrelations

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -9      2.143672        0.11766     |               .   |** .               |
 -8      2.416643        0.13264     |               .   |***.               |
 -7      1.342917        0.07371     |               .   |*  .               |
 -6      0.437286        0.02400     |               .   |   .               |
 -5      3.065528        0.16826     |               .   |***.               |
 -4      1.219310        0.06692     |               .   |*  .               |
 -3     -1.491295        -.08185     |               . **|   .               |
 -2     -0.676723        -.03714     |               .  *|   .               |
 -1     -1.008872        -.05537     |               .  *|   .               |
  0     -1.323874        -.07266     |               .  *|   .               |
  1     -1.157164        -.06351     |               .  *|   .               |
  2      0.516611        0.02836     |               .   |*  .               |
  3      2.695035        0.14792     |               .   |***.               |
  4      1.906063        0.10462     |               .   |** .               |
  5      0.085936        0.00472     |               .   |   .               |
  6      0.353721        0.01941     |               .   |   .               |
  7     -0.271502        -.01490     |               .   |   .               |
  8     -0.036926        -.00203     |               .   |   .               |
  9     -1.849807        -.10153     |               . **|   .               |
 10     -3.824022        -.20989     |               ****|   .               |
 11     -0.889772        -.04884     |               .  *|   .               |
 12     -2.144629        -.11771     |               . **|   .               |
 13      0.064468        0.00354     |               .   |   .               |
 14     -0.913249        -.05013     |               .  *|   .               |
 15     -1.024042        -.05621     |               .  *|   .               |
 16      0.705765        0.03874     |               .   |*  .               |
 17     -0.752570        -.04131     |               .  *|   .               |
 18     -0.295315        -.01621     |               .   |   .               |
 19     -0.825743        -.04532     |               .  *|   .               |
 20     -1.236258        -.06785     |               .  *|   .               |
 21     -2.515750        -.13808     |               .***|   .               |
 22     -4.083250        -.22412     |               ****|   .               |
```

"." marks two standard errors

Correlation of dt_Injury and point05

```
Variance of input =        0.010868
Number of Observations           91
```

The ARIMA Procedure

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22      2.726797        0.14967     |               .   |***.               |
 -21      2.655969        0.14578     |               .   |***.               |
 -20      1.020958        0.05604     |               .   |*  .               |
 -19      0.856542        0.04701     |               .   |*  .               |
 -18      0.679205        0.03728     |               .   |*  .               |
 -17      1.809439        0.09931     |               .   |** .               |
 -16      0.621959        0.03414     |               .   |*  .               |
 -15     -2.672514        -.14669     |               .***|   .               |
 -14     -1.760610        -.09663     |               . **|   .               |
 -13     -0.486553        -.02671     |               .  *|   .               |
 -12     -0.760979        -.04177     |               .  *|   .               |
 -11      0.176283        0.00968     |               .   |   .               |
 -10      2.140475        0.11748     |               .   |** .               |
  -9      2.407408        0.13214     |               .   |***.               |
  -8      1.328731        0.07293     |               .   |*  .               |
  -7      0.408851        0.02244     |               .   |   .               |
  -6      3.019704        0.16574     |               .   |***.               |
  -5      1.186407        0.06512     |               .   |*  .               |
  -4     -1.527942        -.08386     |               . **|   .               |
  -3     -0.689098        -.03782     |               .  *|   .               |
  -2     -1.028372        -.05644     |               .  *|   .               |
  -1     -1.316565        -.07226     |               .  *|   .               |
   0     -1.115083        -.06120     |               .  *|   .               |
   1      0.557122        0.03058     |               .   |*  .               |
   2      2.703424        0.14838     |               .   |***.               |
   3      1.914815        0.10510     |               .   |** .               |
   4      0.081887        0.00449     |               .   |   .               |
   5      0.349672        0.01919     |               .   |   .               |
   6     -0.305620        -.01677     |               .   |   .               |
   7     -0.095678        -.00525     |               .   |   .               |
   8     -1.861101        -.10215     |               . **|   .               |
   9     -3.838818        -.21070     |               ****|   .               |
  10     -0.911934        -.05005     |               .  *|   .               |
  11     -2.153508        -.11820     |               . **|   .               |
  12      0.075152        0.00412     |               .   |   .               |
  13     -0.891576        -.04894     |               .  *|   .               |
  14     -1.001161        -.05495     |               .  *|   .               |
  15      0.712222        0.03909     |               .   |*  .               |
  16     -0.744784        -.04088     |               .  *|   .               |
  17     -0.302021        -.01658     |               .   |   .               |
  18     -0.844766        -.04637     |               .  *|   .               |
  19     -1.276292        -.07005     |               .  *|   .               |
  20     -2.532961        -.13903     |               .***|   .               |
  21     -4.098167        -.22494     |               ****|   .               |
  22     -2.907426        -.15958     |               .***|   .               |

                          "." marks two standard errors
```

The ARIMA Procedure

Correlation of dt_Injury and point06

```
Variance of input =        0.010868
Number of Observations           91
```

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22      2.660863        0.14605    |                .   |***.               |
 -21      1.018606        0.05591    |                .   |*  .               |
 -20      0.856122        0.04699    |                .   |*  .               |
 -19      0.658740        0.03616    |                .   |*  .               |
 -18      1.767117        0.09699    |                .   |** .               |
 -17      0.611637        0.03357    |                .   |*  .               |
 -16     -2.696723        -.14802    |                .***|   .               |
 -15     -1.760426        -.09662    |                . **|   .               |
 -14     -0.496874        -.02727    |                .  *|   .               |
 -13     -0.772267        -.04239    |                .  *|   .               |
 -12      0.184076        0.01010    |                .   |   .               |
 -11      2.132327        0.11704    |                .   |** .               |
 -10      2.404211        0.13196    |                .   |***.               |
  -9      1.319496        0.07242    |                .   |*  .               |
  -8      0.394665        0.02166    |                .   |   .               |
  -7      2.991268        0.16418    |                .   |***.               |
  -6      1.140583        0.06260    |                .   |*  .               |
  -5     -1.560846        -.08567    |                . **|   .               |
  -4     -0.725744        -.03983    |                .  *|   .               |
  -3     -1.040746        -.05712    |                .  *|   .               |
  -2     -1.336064        -.07333    |                .  *|   .               |
  -1     -1.107774        -.06080    |                .  *|   .               |
   0      0.599203        0.03289    |                .   |*  .               |
   1      2.743935        0.15061    |                .   |***.               |
   2      1.923204        0.10556    |                .   |** .               |
   3      0.090639        0.00497    |                .   |   .               |
   4      0.345624        0.01897    |                .   |   .               |
   5     -0.309668        -.01700    |                .   |   .               |
   6     -0.129795        -.00712    |                .   |   .               |
   7     -1.919854        -.10538    |                . **|   .               |
   8     -3.850112        -.21132    |                ****|   .               |
   9     -0.926730        -.05087    |                .  *|   .               |
  10     -2.175670        -.11942    |                . **|   .               |
  11      0.066272        0.00364    |                .   |   .               |
  12     -0.880892        -.04835    |                .  *|   .               |
  13     -0.979488        -.05376    |                .  *|   .               |
  14      0.735103        0.04035    |                .   |*  .               |
  15     -0.738327        -.04052    |                .  *|   .               |
  16     -0.294235        -.01615    |                .   |   .               |
  17     -0.851471        -.04673    |                .  *|   .               |
  18     -1.295315        -.07110    |                .  *|   .               |
  19     -2.572996        -.14122    |                .***|   .               |
  20     -4.115379        -.22588    |               *****|   .               |
```

```
                              The ARIMA Procedure

                               Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 21     -2.922343       -.16040     |                .***|   .                |
 22     -3.248085       -.17828     |                ****|   .                |

                          "." marks two standard errors

                      Correlation of dt_Injury and point07

                       Variance of input =        0.010868
                       Number of Observations           91

                               Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22      1.023500       0.05618     |                .   |*  .                |
-21      0.853771       0.04686     |                .   |*  .                |
-20      0.658320       0.03613     |                .   |*  .                |
-19      1.746652       0.09587     |                .   |** .                |
-18      0.569315       0.03125     |                .   |*  .                |
-17     -2.707044       -.14858     |                .***|   .                |
-16     -1.784635       -.09795     |                . **|   .                |
-15     -0.496690       -.02726     |                .  *|   .                |
-14     -0.782589       -.04295     |                .  *|   .                |
-13      0.172788       0.00948     |                .   |   .                |
-12      2.140120       0.11746     |                .   |** .                |
-11      2.396064       0.13151     |                .   |***.                |
-10      1.316299       0.07225     |                .   |*  .                |
 -9      0.385430       0.02116     |                .   |   .                |
 -8      2.977082       0.16340     |                .   |***.                |
 -7      1.112147       0.06104     |                .   |*  .                |
 -6     -1.606670       -.08819     |                . **|   .                |
 -5     -0.758648       -.04164     |                .  *|   .                |
 -4     -1.077393       -.05913     |                .  *|   .                |
 -3     -1.348438       -.07401     |                .  *|   .                |
 -2     -1.127273       -.06187     |                .  *|   .                |
 -1      0.606512       0.03329     |                .   |*  .                |
  0      2.786016       0.15292     |                .   |***.                |
  1      1.963715       0.10778     |                .   |** .                |
  2      0.099028       0.00544     |                .   |   .                |
  3      0.354375       0.01945     |                .   |   .                |
  4     -0.313717       -.01722     |                .   |   .                |
  5     -0.133844       -.00735     |                .   |   .                |
  6     -1.953971       -.10725     |                . **|   .                |
  7     -3.908865       -.21455     |                ****|   .                |
  8     -0.938024       -.05149     |                .  *|   .                |
  9     -2.190466       -.12023     |                . **|   .                |
 10      0.044110       0.00242     |                .   |   .                |
```

```
                         The ARIMA Procedure

                          Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 11     -0.889772       -.04884     |                .  *|   .                |
 12     -0.968805       -.05317     |                .  *|   .                |
 13      0.756775       0.04154     |                .   |*  .                |
 14     -0.715447       -.03927     |                .  *|   .                |
 15     -0.287778       -.01580     |                .   |   .                |
 16     -0.843686       -.04631     |                .  *|   .                |
 17     -1.302021       -.07146     |                .  *|   .                |
 18     -2.592019       -.14227     |                .***|   .                |
 19     -4.155413       -.22808     |               *****|   .                |
 20     -2.939554       -.16134     |                .***|   .                |
 21     -3.263002       -.17910     |                ****|   .                |
 22     -1.039294       -.05704     |                .  *|   .                |

                    "." marks two standard errors

                    Correlation of dt_Injury and prp_vt

                    Variance of input =       0.194179
                    Number of Observations          91

                          Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22      4.564003       0.05926     |                .   |*  .                |
-21      3.721271       0.04832     |                .   |*  .                |
-20      2.590893       0.03364     |                .   |*  .                |
-19      0.502056       0.00652     |                .   |   .                |
-18     -1.732053       -.02249     |                .   |   .                |
-17     -2.111918       -.02742     |                .  *|   .                |
-16     -1.259806       -.01636     |                .   |   .                |
-15     -2.601873       -.03379     |                .  *|   .                |
-14     -2.023882       -.02628     |                .  *|   .                |
-13     -3.094847       -.04019     |                .  *|   .                |
-12     -6.186582       -.08033     |                . **|   .                |
-11     -8.263706       -.10731     |                . **|   .                |
-10    -10.320904       -.13402     |                .***|   .                |
 -9    -11.112313       -.14430     |                .***|   .                |
 -8    -14.890681       -.19336     |                ****|   .                |
 -7    -17.121650       -.22233     |                ****|   .                |
 -6    -17.560083       -.22802     |               *****|   .                |
 -5    -19.965790       -.25926     |               *****|   .                |
 -4    -21.154131       -.27469     |               *****|   .                |
 -3    -22.285596       -.28938     |              ******|   .                |
 -2    -21.999599       -.28567     |              ******|   .                |
 -1    -23.905246       -.31041     |              ******|   .                |
  0    -26.201546       -.34023     |             *******|   .                |
```

```
                              The ARIMA Procedure

                               Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  1    -29.217285       -.37939     |             ********|   .                |
  2    -30.371173       -.39438     |             ********|   .                |
  3    -31.017875       -.40277     |             ********|   .                |
  4    -31.013931       -.40272     |             ********|   .                |
  5    -30.878602       -.40096     |             ********|   .                |
  6    -28.919097       -.37552     |             ********|   .                |
  7    -24.248929       -.31488     |               ******|   .                |
  8    -21.899617       -.28437     |               ******|   .                |
  9    -19.425560       -.25224     |                *****|   .                |
 10    -19.087237       -.24785     |                *****|   .                |
 11    -17.616079       -.22875     |                *****|   .                |
 12    -16.375811       -.21264     |                 ****|   .                |
 13    -17.341315       -.22518     |                *****|   .                |
 14    -17.120006       -.22231     |                 ****|   .                |
 15    -17.378228       -.22566     |                *****|   .                |
 16    -16.692845       -.21676     |                 ****|   .                |
 17    -15.588793       -.20242     |                 ****|   .                |
 18    -12.840253       -.16673     |                 .***|   .                |
 19     -8.213679       -.10666     |                 . **|   .                |
 20     -4.258642       -.05530     |                 .  *|   .                |
 21     -0.510706       -.00663     |                 .   |   .                |
 22      0.973373       0.01264     |                 .   |   .                |

                        "." marks two standard errors

                   Correlation of dt_Injury and otherprog

                    Variance of input =        11.88745
                    Number of Observations           91

                               Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22     24.402431       0.04050     |                 .   |*  .                |
-21     19.045916       0.03161     |                 .   |*  .                |
-20      6.558862       0.01089     |                 .   |   .                |
-19     -0.709499       -.00118     |                 .   |   .                |
-18    -31.385540       -.05209     |                 .  *|   .                |
-17    -86.834314       -.14411     |                 .***|   .                |
-16    -95.430896       -.15838     |                 .***|   .                |
-15      -119.097       -.19765     |                 ****|   .                |
-14      -111.658       -.18531     |                 ****|   .                |
-13      -117.980       -.19580     |                 ****|   .                |
-12      -125.581       -.20842     |                 ****|   .                |
-11      -109.725       -.18210     |                 ****|   .                |
-10      -115.539       -.19175     |                 ****|   .                |
```

```
                                 The ARIMA Procedure

                                  Crosscorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  -9      -113.847        -.18894    |                ****|   .                |
  -8      -116.596        -.19350    |                ****|   .                |
  -7      -122.663        -.20357    |                ****|   .                |
  -6      -144.998        -.24064    |               *****|   .                |
  -5      -185.950        -.30860    |              ******|   .                |
  -4      -206.859        -.34330    |             *******|   .                |
  -3      -229.472        -.38083    |            ********|   .                |
  -2      -220.394        -.36577    |             *******|   .                |
  -1      -222.911        -.36994    |             *******|   .                |
   0      -191.217        -.31734    |              ******|   .                |
   1      -176.540        -.29299    |              ******|   .                |
   2      -161.658        -.26829    |               *****|   .                |
   3      -143.861        -.23875    |               *****|   .                |
   4      -127.135        -.21099    |                ****|   .                |
   5      -108.163        -.17951    |                ****|   .                |
   6    -89.933247        -.14925    |                .***|   .                |
   7    -68.385814        -.11349    |                . **|   .                |
   8    -44.722573        -.07422    |                .  *|   .                |
   9    -28.045203        -.04654    |                .  *|   .                |
  10    -13.535205        -.02246    |                .   |   .                |
  11     -2.311283        -.00384    |                .   |   .                |
  12      4.324425        0.00718    |                .   |   .                |
  13      5.277727        0.00876    |                .   |   .                |
  14      3.786276        0.00628    |                .   |   .                |
  15      0.375492        0.00062    |                .   |   .                |
  16     -0.399378        -.00066    |                .   |   .                |
  17     -1.333650        -.00221    |                .   |   .                |
  18     -0.529001        -.00088    |                .   |   .                |
  19      1.753730        0.00291    |                .   |   .                |
  20      6.557896        0.01088    |                .   |   .                |
  21      8.623262        0.01431    |                .   |   .                |
  22     10.413299        0.01728    |                .   |   .                |

                             "." marks two standard errors

                          Correlation of dt_Injury and otherprg

                           Variance of input =        0.130178
                           Number of Observations           91
```

The ARIMA Procedure

Crosscorrelations

```
Lag   Covariance   Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22    -4.746584     -.07528     |                . **|   .                |
-21    -2.524221     -.04003     |                .  *|   .                |
-20    -0.831867     -.01319     |                .   |   .                |
-19    -0.222353     -.00353     |                .   |   .                |
-18     4.513112     0.07157     |                .   |*  .                |
-17     9.052465     0.14356     |                .   |***.                |
-16     8.380491     0.13291     |                .   |***.                |
-15     9.580030     0.15193     |                .   |***.                |
-14     8.549646     0.13559     |                .   |***.                |
-13     8.020529     0.12720     |                .   |***.                |
-12     7.774591     0.12330     |                .   |** .                |
-11     7.773792     0.12329     |                .   |** .                |
-10    11.187194     0.17742     |                .   |****                |
 -9    13.439142     0.21313     |                .   |****                |
 -8    14.331835     0.22729     |                .   |*****               |
 -7    15.869497     0.25168     |                .   |*****               |
 -6    17.845030     0.28301     |                .   |******              |
 -5    21.335355     0.33836     |                .   |*******             |
 -4    22.006577     0.34901     |                .   |*******             |
 -3    20.977037     0.33268     |                .   |*******             |
 -2    20.990609     0.33289     |                .   |*******             |
 -1    20.289049     0.32177     |                .   |******              |
  0    19.743026     0.31311     |                .   |******              |
  1    19.392901     0.30756     |                .   |******              |
  2    18.932886     0.30026     |                .   |******              |
  3    19.759431     0.31337     |                .   |******              |
  4    19.140498     0.30355     |                .   |******              |
  5    18.792909     0.29804     |                .   |******              |
  6    17.895869     0.28381     |                .   |******              |
  7    16.127316     0.25577     |                .   |*****               |
  8    12.717175     0.20168     |                .   |****                |
  9     8.389028     0.13304     |                .   |***.                |
 10     5.187677     0.08227     |                .   |** .                |
 11     1.542539     0.02446     |                .   |   .                |
 12     0.292161     0.00463     |                .   |   .                |
 13    -1.332689     -.02114     |                .   |   .                |
 14    -0.364133     -.00577     |                .   |   .                |
 15    -0.043807     -.00069     |                .   |   .                |
 16     0.046594     0.00074     |                .   |   .                |
 17     0.155593     0.00247     |                .   |   .                |
 18     0.061717     0.00098     |                .   |   .                |
 19    -0.204602     -.00324     |                .   |   .                |
 20    -0.765088     -.01213     |                .   |   .                |
 21    -1.006047     -.01596     |                .   |   .                |
 22    -1.214885     -.01927     |                .   |   .                |

                     "." marks two standard errors
```

The ARIMA Procedure

Conditional Least Squares Estimation

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	101.99787	117.06367	0.87	0.3861	0	dt_Injury	0
NUM1	0.0033151	0.0003558	9.32	<.0001	0	GAS_SALE	0
NUM2	-213.70953	38.51133	-5.55	<.0001	0	prp_vt	0
NUM3	-163.15324	117.77726	-1.39	0.1697	0	point03	0
NUM4	-205.72987	117.83342	-1.75	0.0846	0	point04	0
NUM5	-279.33138	118.67213	-2.35	0.0210	0	point05	0
NUM6	-109.34485	118.49241	-0.92	0.3588	0	point06	0
NUM7	-48.70510	121.07968	-0.40	0.6885	0	point07	0
NUM8	-16.93243	4.70308	-3.60	0.0005	0	otherprog	0

Constant Estimate	101.9979
Variance Estimate	13639.61
Std Error Estimate	116.7887
AIC	1133.157
SBC	1155.754
Number of Residuals	91

* AIC and SBC do not include log determinant.

Correlations of Parameter Estimates

Variable	Parameter	dt_Injury MU	GAS_SALE NUM1	prp_vt NUM2	point03 NUM3	point04 NUM4
dt_Injury	MU	1.000	-0.992	0.279	0.013	0.026
GAS_SALE	NUM1	-0.992	1.000	-0.331	-0.029	-0.043
prp_vt	NUM2	0.279	-0.331	1.000	0.058	0.063
point03	NUM3	0.013	-0.029	0.058	1.000	0.017
point04	NUM4	0.026	-0.043	0.063	0.017	1.000
point05	NUM5	0.109	-0.126	0.090	0.019	0.021
point06	NUM6	0.097	-0.113	0.086	0.019	0.021
point07	NUM7	0.216	-0.234	0.124	0.022	0.025
otherprog	NUM8	0.189	-0.191	-0.525	0.006	0.008

Correlations of Parameter Estimates

Variable	Parameter	point05 NUM5	point06 NUM6	point07 NUM7	otherprog NUM8
dt_Injury	MU	0.109	0.097	0.216	0.189
GAS_SALE	NUM1	-0.126	-0.113	-0.234	-0.191
prp_vt	NUM2	0.090	0.086	0.124	-0.525
point03	NUM3	0.019	0.019	0.022	0.006
point04	NUM4	0.021	0.021	0.025	0.008
point05	NUM5	1.000	0.030	0.045	0.024
point06	NUM6	0.030	1.000	0.042	0.022
point07	NUM7	0.045	0.042	1.000	0.045

The ARIMA Procedure

Correlations of Parameter Estimates

Variable	Parameter	point05 NUM5	point06 NUM6	point07 NUM7	otherprog NUM8
otherprog	NUM8	0.024	0.022	0.045	1.000

Autocorrelation Check of Residuals

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	26.58	6	0.0002	0.408	0.233	0.098	-0.004	-0.103	-0.194
12	52.56	12	<.0001	-0.263	-0.084	-0.102	0.062	0.230	0.324
18	73.42	18	<.0001	0.260	0.181	-0.095	-0.036	-0.179	-0.210
24	100.23	24	<.0001	-0.289	-0.207	-0.095	-0.027	0.151	0.250

Autocorrelation Plot of Residuals

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1      Std Error

  0     13639.606        1.00000    |                    |********************|             0
  1      5565.204        0.40802    |                .   |********            |      0.104828
  2      3183.008        0.23337    |               .    |*****               |      0.121028
  3      1341.950        0.09839    |               .    |**  .               |      0.125876
  4    -51.347461        -.00376    |               .    |    .               |      0.126718
  5     -1409.683        -.10335    |               .  **|    .               |      0.126720
  6     -2650.654        -.19434    |               .****|    .               |      0.127642
  7     -3581.922        -.26261    |               *****|    .               |      0.130853
  8     -1141.278        -.08367    |               .  **|    .               |      0.136522
  9     -1394.807        -.10226    |               .  **|    .               |      0.137085
 10       850.096        0.06233    |              .     |*    .              |      0.137920
 11      3136.021        0.22992    |              .     |*****.              |      0.138230
 12      4418.499        0.32395    |              .     |******              |      0.142370
 13      3547.624        0.26010    |              .     |*****.              |      0.150252
 14      2467.718        0.18092    |              .     |**** .              |      0.155121
 15     -1299.334        -.09526    |              .   **|     .              |      0.157423
 16      -487.401        -.03573    |              .    *|     .              |      0.158055
 17     -2436.913        -.17866    |              . ****|     .              |      0.158144
 18     -2866.170        -.21014    |              . ****|     .              |      0.160346
 19     -3939.607        -.28884    |             .******|      .             |      0.163345
 20     -2821.765        -.20688    |             .  ****|      .             |      0.168864
 21     -1292.390        -.09475    |             .    **|      .             |      0.171626
 22      -367.096        -.02691    |             .     *|      .             |      0.172200
```

"." marks two standard errors

The ARIMA Procedure

Inverse Autocorrelations

```
  Lag    Correlation     -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

    1       -0.24563     |               *****|   .                |
    2        0.00795     |                .   |   .                |
    3       -0.09289     |                . **|   .                |
    4       -0.05688     |                .  *|   .                |
    5       -0.10111     |                . **|   .                |
    6        0.01989     |                .   |   .                |
    7        0.12770     |                .   |***.                |
    8       -0.04380     |                .  *|   .                |
    9        0.13980     |                .   |***.                |
   10        0.02805     |                .   |*  .                |
   11       -0.10901     |                . **|   .                |
   12       -0.13495     |                .***|   .                |
   13        0.01955     |                .   |   .                |
   14       -0.14661     |                .***|   .                |
   15        0.23286     |                .   |*****               |
   16       -0.05170     |                .  *|   .                |
   17        0.06465     |                .   |*  .                |
   18       -0.05170     |                .  *|   .                |
   19        0.07747     |                .   |** .                |
   20       -0.00691     |                .   |   .                |
   21       -0.07848     |                . **|   .                |
   22        0.07554     |                .   |** .                |
```

Partial Autocorrelations

```
  Lag    Correlation     -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

    1        0.40802     |                .   |********            |
    2        0.08025     |                .   |** .                |
    3       -0.02648     |                .  *|   .                |
    4       -0.06179     |                .  *|   .                |
    5       -0.10360     |                . **|   .                |
    6       -0.13348     |                .***|   .                |
    7       -0.14458     |                .***|   .                |
    8        0.13239     |                .   |***.                |
    9       -0.06086     |                .  *|   .                |
   10        0.14103     |                .   |***.                |
   11        0.20458     |                .   |****                |
   12        0.16310     |                .   |***.                |
   13       -0.00430     |                .   |   .                |
   14       -0.03131     |                .  *|   .                |
   15       -0.28358     |              ******|   .                |
   16        0.03002     |                .   |*  .                |
   17       -0.08049     |                . **|   .                |
   18        0.01354     |                .   |   .                |
   19       -0.09652     |                . **|   .                |
   20        0.03553     |                .   |*  .                |
   21        0.04118     |                .   |*  .                |
```

The ARIMA Procedure

Partial Autocorrelations

```
Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
 22       -0.10264     |                . **|    .                |
```

Model for variable dt_Injury

Estimated Intercept   101.9979

Input Number 1

Input Variable	GAS_SALE
Overall Regression Factor	0.003315

Input Number 2

Input Variable	prp_vt
Overall Regression Factor	-213.71

Input Number 3

Input Variable	point03
Overall Regression Factor	-163.153

Input Number 4

Input Variable	point04
Overall Regression Factor	-205.73

Input Number 5

Input Variable	point05
Overall Regression Factor	-279.331

Input Number 6

Input Variable	point06
Overall Regression Factor	-109.345

Input Number 7

Input Variable	point07
Overall Regression Factor	-48.7051

The ARIMA Procedure

Input Number 8

Input Variable	otherprog
Overall Regression Factor	-16.9324

The ARIMA Procedure

Conditional Least Squares Estimation

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	339.03969	172.67616	1.96	0.0531	0	dt_Injury	0
AR1,1	0.28357	0.11132	2.55	0.0128	1	dt_Injury	0
AR2,1	0.25347	0.11753	2.16	0.0341	12	dt_Injury	0
AR2,2	0.28960	0.12649	2.29	0.0247	24	dt_Injury	0
NUM1	0.0026197	0.0005296	4.95	<.0001	0	GAS_SALE	0
NUM2	-47.77860	98.97480	-0.48	0.6306	0	point03	0
NUM3	-93.04825	103.27061	-0.90	0.3703	0	point04	0
NUM4	-207.85157	104.83955	-1.98	0.0509	0	point05	0
NUM5	-68.12734	103.15047	-0.66	0.5109	0	point06	0
NUM6	-36.50136	100.36987	-0.36	0.7171	0	point07	0
NUM7	-184.98029	46.50078	-3.98	0.0002	0	prp_vt	0
NUM8	-13.61722	5.27102	-2.58	0.0116	0	otherprog	0

Constant Estimate	110.9886
Variance Estimate	10574.17
Std Error Estimate	102.8308
AIC	1112.6
SBC	1142.73
Number of Residuals	91

* AIC and SBC do not include log determinant.

Correlations of Parameter Estimates

Variable	Parameter	dt_Injury MU	dt_Injury AR1,1	dt_Injury AR2,1	dt_Injury AR2,2	GAS_SALE NUM1	point03 NUM2
dt_Injury	MU	1.000	-0.144	0.080	0.219	-0.987	0.042
dt_Injury	AR1,1	-0.144	1.000	-0.092	-0.044	0.147	0.005
dt_Injury	AR2,1	0.080	-0.092	1.000	-0.300	-0.085	0.108
dt_Injury	AR2,2	0.219	-0.044	-0.300	1.000	-0.224	0.130
GAS_SALE	NUM1	-0.987	0.147	-0.085	-0.224	1.000	-0.057
point03	NUM2	0.042	0.005	0.108	0.130	-0.057	1.000
point04	NUM3	0.095	0.002	-0.044	0.179	-0.113	0.304
point05	NUM4	0.122	-0.022	0.186	0.036	-0.142	0.134
point06	NUM5	0.038	-0.001	0.131	-0.079	-0.058	0.056
point07	NUM6	0.124	-0.002	0.023	0.006	-0.146	0.044
prp_vt	NUM7	0.299	-0.099	0.055	0.183	-0.350	0.121
otherprog	NUM8	0.254	0.057	0.112	0.050	-0.271	0.071

Correlations of Parameter Estimates

Variable	Parameter	point04 NUM3	point05 NUM4	point06 NUM5	point07 NUM6	prp_vt NUM7	otherprog NUM8
dt_Injury	MU	0.095	0.122	0.038	0.124	0.299	0.254
dt_Injury	AR1,1	0.002	-0.022	-0.001	-0.002	-0.099	0.057

The ARIMA Procedure

Correlations of Parameter Estimates

Variable	Parameter	point04 NUM3	point05 NUM4	point06 NUM5	point07 NUM6	prp_vt NUM7	otherprog NUM8
dt_Injury	AR2,1	-0.044	0.186	0.131	0.023	0.055	0.112
dt_Injury	AR2,2	0.179	0.036	-0.079	0.006	0.183	0.050
GAS_SALE	NUM1	-0.113	-0.142	-0.058	-0.146	-0.350	-0.271
point03	NUM2	0.304	0.134	0.056	0.044	0.121	0.071
point04	NUM3	1.000	0.309	0.101	0.073	0.151	0.087
point05	NUM4	0.309	1.000	0.326	0.136	0.157	0.130
point06	NUM5	0.101	0.326	1.000	0.313	0.121	0.108
point07	NUM6	0.073	0.136	0.313	1.000	0.205	0.097
prp_vt	NUM7	0.151	0.157	0.121	0.205	1.000	-0.357
otherprog	NUM8	0.087	0.130	0.108	0.097	-0.357	1.000

Autocorrelation Check of Residuals

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.57	3	0.3122	-0.027	0.062	0.121	-0.017	0.029	-0.127
12	8.50	9	0.4851	-0.177	0.032	-0.106	0.032	0.061	-0.005
18	18.58	15	0.2335	0.130	0.146	-0.182	0.089	-0.106	-0.023
24	24.72	21	0.2595	-0.153	-0.125	0.046	-0.080	0.053	-0.033

Autocorrelation Plot of Residuals

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1      Std Error

  0     10574.174        1.00000    |                    |********************|            0
  1      -283.157        -.02678    |                .  *|  .                 |     0.104828
  2       654.752        0.06192    |                .   |*  .                |     0.104904
  3      1283.841        0.12141    |                .   |** .                |     0.105304
  4      -174.977        -.01655    |                .   |   .                |     0.106832
  5       309.743        0.02929    |                .   |*  .                |     0.106860
  6     -1343.162        -.12702    |                .***|   .                |     0.106948
  7     -1875.454        -.17736    |                ****|   .                |     0.108593
  8       337.501        0.03192    |                .   |*  .                |     0.111731
  9     -1116.911        -.10563    |                . **|   .                |     0.111831
 10       342.776        0.03242    |               .    |*   .               |     0.112922
 11       642.514        0.06076    |               .    |*   .               |     0.113025
 12    -55.993167        -.00530    |               .    |    .               |     0.113383
 13      1375.254        0.13006    |               .    |*** .               |     0.113386
 14      1546.733        0.14627    |               .    |*** .               |     0.115013
 15     -1919.879        -.18156    |               .****|    .               |     0.117040
 16       936.680        0.08858    |               .    |**  .               |     0.120095
 17     -1118.203        -.10575    |               .  **|    .               |     0.120811
 18      -243.386        -.02302    |               .    |    .               |     0.121824
 19     -1613.362        -.15258    |               . ***|    .               |     0.121872
 20     -1326.400        -.12544    |               . ***|    .               |     0.123953
```

```
                              The ARIMA Procedure

                      Autocorrelation Plot of Residuals

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1     Std Error

 21      483.359        0.04571     |                .    |*   .               |     0.125340
 22     -850.250        -.08041     |                .  **|    .               |     0.125523

                          "." marks two standard errors

                          Inverse Autocorrelations

       Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

         1      0.01887      |                .    |   .                |
         2     -0.01825      |                .    |   .                |
         3     -0.12893      |                .*** |   .                |
         4     -0.06530      |                .   *|   .                |
         5     -0.08073      |                .  **|   .                |
         6      0.07539      |                .    |** .                |
         7      0.13879      |                .    |***.                |
         8      0.02749      |                .    |*  .                |
         9      0.08037      |                .    |** .                |
        10     -0.01918      |                .    |   .                |
        11     -0.03098      |                .   *|   .                |
        12     -0.03104      |                .   *|   .                |
        13     -0.04141      |                .   *|   .                |
        14     -0.12731      |                .*** |   .                |
        15      0.17831      |                .    |****                |
        16     -0.01791      |                .    |   .                |
        17      0.06014      |                .    |*  .                |
        18     -0.00238      |                .    |   .                |
        19      0.10364      |                .    |** .                |
        20      0.01005      |                .    |   .                |
        21     -0.04216      |                .   *|   .                |
        22      0.06400      |                .    |*  .                |

                          Partial Autocorrelations

       Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

         1     -0.02678      |                .   *|   .                |
         2      0.06125      |                .    |*  .                |
         3      0.12517      |                .    |***.                |
         4     -0.01347      |                .    |   .                |
         5      0.01303      |                .    |   .                |
         6     -0.14184      |                .*** |   .                |
         7     -0.19207      |                **** |   .                |
         8      0.03001      |                .    |*  .                |
         9     -0.04747      |                .   *|   .                |
        10      0.07460      |                .    |*  .                |
        11      0.08124      |                .    |** .                |
```

```
                          The ARIMA Procedure

                        Partial Autocorrelations

Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 12       0.00580     |                .   |   .                  |
 13       0.06500     |                .   |*  .                  |
 14       0.12368     |                .   |** .                  |
 15      -0.21996     |                ****|   .                  |
 16       0.01188     |                .   |   .                  |
 17      -0.09284     |                . **|   .                  |
 18       0.01692     |                .   |   .                  |
 19      -0.13735     |                .***|   .                  |
 20      -0.02075     |                .   |   .                  |
 21       0.05329     |                .   |*  .                  |
 22      -0.07509     |                . **|   .                  |

                    Model for variable dt_Injury

                   Estimated Intercept    339.0397

                      Autoregressive Factors

           Factor 1:  1 - 0.28357 B**(1)
           Factor 2:  1 - 0.25347 B**(12) - 0.2896 B**(24)

                          Input Number 1

                Input Variable              GAS_SALE
                Overall Regression Factor    0.00262

                          Input Number 2

                Input Variable               point03
                Overall Regression Factor   -47.7786

                          Input Number 3

                Input Variable               point04
                Overall Regression Factor   -93.0483

                          Input Number 4

                Input Variable               point05
                Overall Regression Factor   -207.852
```

The ARIMA Procedure

Input Number 5

Input Variable	point06
Overall Regression Factor	-68.1273

Input Number 6

Input Variable	point07
Overall Regression Factor	-36.5014

Input Number 7

Input Variable	prp_vt
Overall Regression Factor	-184.98

Input Number 8

Input Variable	otherprog
Overall Regression Factor	-13.6172

The SAS System

Obs	MONTH	dt_Injury	FORECAST	STD	L95	U95	RESIDUAL
1	01JAN1991:00:00:00	797	983.34	102.831	781.80	1184.89	-186.341
2	01FEB1991:00:00:00	810	942.88	102.831	741.34	1144.43	-132.883
3	01MAR1991:00:00:00	1076	1010.61	102.831	809.07	1212.16	65.386
4	01APR1991:00:00:00	1073	1129.01	102.831	927.46	1330.55	-56.008
5	01MAY1991:00:00:00	1179	1164.71	102.831	963.16	1366.25	14.294
6	01JUN1991:00:00:00	1179	1123.03	102.831	921.49	1324.58	55.965
7	01JUL1991:00:00:00	1428	1301.71	102.831	1100.16	1503.25	126.293
8	01AUG1991:00:00:00	1632	1304.52	102.831	1102.97	1506.06	327.485
9	01SEP1991:00:00:00	1239	1295.72	102.831	1094.17	1497.26	-56.718
10	01OCT1991:00:00:00	1268	1189.01	102.831	987.47	1390.56	78.986
11	01NOV1991:00:00:00	1329	1090.83	102.831	889.28	1292.37	238.173
12	01DEC1991:00:00:00	1219	1190.05	102.831	988.50	1391.59	28.953
13	01JAN1992:00:00:00	1057	1014.68	102.831	813.13	1216.22	42.321
14	01FEB1992:00:00:00	966	998.25	102.831	796.71	1199.80	-32.254
15	01MAR1992:00:00:00	956	1111.76	102.831	910.21	1313.30	-155.758
16	01APR1992:00:00:00	1092	1044.99	102.831	843.45	1246.54	47.006
17	01MAY1992:00:00:00	1081	1172.29	102.831	970.75	1373.84	-91.293
18	01JUN1992:00:00:00	1201	1180.34	102.831	978.80	1381.89	20.657
19	01JUL1992:00:00:00	1303	1290.90	102.831	1089.35	1492.44	12.105
20	01AUG1992:00:00:00	1477	1368.40	102.831	1166.86	1569.95	108.598
21	01SEP1992:00:00:00	1288	1275.35	102.831	1073.80	1476.89	12.655
22	01OCT1992:00:00:00	1269	1184.06	102.831	982.52	1385.61	84.935
23	01NOV1992:00:00:00	1227	1236.81	102.831	1035.26	1438.35	-9.806
24	01DEC1992:00:00:00	1359	1193.53	102.831	991.99	1395.07	165.470
25	01JAN1993:00:00:00	925	1027.55	102.831	826.01	1229.10	-102.551
26	01FEB1993:00:00:00	723	955.97	102.831	754.43	1157.52	-232.972
27	01MAR1993:00:00:00	992	1091.85	102.831	890.30	1293.39	-99.847
28	01APR1993:00:00:00	1058	1080.07	102.831	878.52	1281.61	-22.068
29	01MAY1993:00:00:00	1102	1156.50	102.831	954.95	1358.04	-54.496
30	01JUN1993:00:00:00	1236	1250.71	102.831	1049.17	1452.26	-14.712
31	01JUL1993:00:00:00	1290	1348.20	102.831	1146.66	1549.75	-58.202
32	01AUG1993:00:00:00	1427	1503.00	102.831	1301.45	1704.54	-75.999
33	01SEP1993:00:00:00	1234	1257.47	102.831	1055.92	1459.01	-23.467
34	01OCT1993:00:00:00	1271	1233.53	102.831	1031.98	1435.07	37.474
35	01NOV1993:00:00:00	1175	1312.64	102.831	1111.09	1514.18	-137.636
36	01DEC1993:00:00:00	1322	1248.00	102.831	1046.46	1449.55	73.998
37	01JAN1994:00:00:00	1020	1096.15	102.831	894.60	1297.69	-76.145
38	01FEB1994:00:00:00	1123	982.44	102.831	780.89	1183.98	140.561
39	01MAR1994:00:00:00	1014	1150.02	102.831	948.47	1351.56	-136.018
40	01APR1994:00:00:00	1006	1117.17	102.831	915.62	1318.71	-111.168
41	01MAY1994:00:00:00	1155	1165.59	102.831	964.04	1367.13	-10.588
42	01JUN1994:00:00:00	1350	1278.56	102.831	1077.02	1480.11	71.436
43	01JUL1994:00:00:00	1422	1373.67	102.831	1172.12	1575.21	48.334
44	01AUG1994:00:00:00	1416	1489.25	102.831	1287.71	1690.80	-73.253
45	01SEP1994:00:00:00	1267	1281.31	102.831	1079.77	1482.86	-14.311
46	01OCT1994:00:00:00	1252	1288.21	102.831	1086.66	1489.75	-36.207
47	01NOV1994:00:00:00	1234	1212.82	102.831	1011.27	1414.36	21.184
48	01DEC1994:00:00:00	1333	1303.93	102.831	1102.38	1505.47	29.074
49	01JAN1995:00:00:00	1224	1116.15	102.831	914.61	1317.70	107.845
50	01FEB1995:00:00:00	922	1058.62	102.831	857.08	1260.17	-136.625
51	01MAR1995:00:00:00	1005	1069.14	102.831	867.60	1270.69	-64.141

The SAS System

Obs	MONTH	dt_Injury	FORECAST	STD	L95	U95	RESIDUAL
52	01APR1995:00:00:00	1120	1084.28	102.831	882.74	1285.83	35.719
53	01MAY1995:00:00:00	1094	1236.95	102.831	1035.40	1438.49	-142.949
54	01JUN1995:00:00:00	1180	1254.29	102.831	1052.74	1455.83	-74.289
55	01JUL1995:00:00:00	1358	1355.31	102.831	1153.77	1556.86	2.688
56	01AUG1995:00:00:00	1382	1415.07	102.831	1213.53	1616.62	-33.074
57	01SEP1995:00:00:00	1283	1274.32	102.831	1072.77	1475.86	8.684
58	01OCT1995:00:00:00	1198	1303.62	102.831	1102.07	1505.16	-105.616
59	01NOV1995:00:00:00	1433	1183.96	102.831	982.42	1385.50	249.040
60	01DEC1995:00:00:00	1262	1371.05	102.831	1169.51	1572.60	-109.053
61	01JAN1996:00:00:00	1012	1147.72	102.831	946.18	1349.27	-135.722
62	01FEB1996:00:00:00	1085	1096.07	102.831	894.53	1297.61	-11.070
63	01MAR1996:00:00:00	1053	1047.38	102.831	845.84	1248.93	5.619
64	01APR1996:00:00:00	1025	1072.47	102.831	870.93	1274.02	-47.471
65	01MAY1996:00:00:00	1044	1003.48	102.831	801.94	1205.03	40.517
66	01JUN1996:00:00:00	1200	1221.85	102.831	1020.30	1423.39	-21.849
67	01JUL1996:00:00:00	1399	1379.46	102.831	1177.91	1581.00	19.542
68	01AUG1996:00:00:00	1328	1242.76	102.831	1041.21	1444.30	85.244
69	01SEP1996:00:00:00	1162	1130.78	102.831	929.23	1332.32	31.222
70	01OCT1996:00:00:00	1186	1138.11	102.831	936.56	1339.65	47.895
71	01NOV1996:00:00:00	1126	1121.76	102.831	920.22	1323.31	4.237
72	01DEC1996:00:00:00	1142	1057.56	102.831	856.01	1259.10	84.440
73	01JAN1997:00:00:00	976	1034.32	102.831	832.78	1235.87	-58.325
74	01FEB1997:00:00:00	795	871.64	102.831	670.09	1073.18	-76.635
75	01MAR1997:00:00:00	1060	957.57	102.831	756.03	1159.12	102.426
76	01APR1997:00:00:00	945	1087.87	102.831	886.33	1289.42	-142.874
77	01MAY1997:00:00:00	1147	1063.22	102.831	861.68	1264.76	83.780
78	01JUN1997:00:00:00	1060	1109.99	102.831	908.45	1311.54	-49.994
79	01JUL1997:00:00:00	1052	1219.26	102.831	1017.71	1420.80	-167.258
80	01AUG1997:00:00:00	1210	1181.04	102.831	979.49	1382.58	28.965
81	01SEP1997:00:00:00	1078	1092.00	102.831	890.46	1293.54	-14.000
82	01OCT1997:00:00:00	1119	1077.23	102.831	875.68	1278.77	41.771
83	01NOV1997:00:00:00	1069	1072.42	102.831	870.87	1273.96	-3.417
84	01DEC1997:00:00:00	1028	1099.04	102.831	897.49	1300.58	-71.036
85	01JAN1998:00:00:00	910	854.09	102.831	652.54	1055.63	55.913
86	01FEB1998:00:00:00	766	804.12	102.831	602.57	1005.66	-38.117
87	01MAR1998:00:00:00	873	943.72	102.831	742.17	1145.26	-70.715
88	01APR1998:00:00:00	842	882.56	102.831	681.02	1084.11	-40.562
89	01MAY1998:00:00:00	1043	982.59	102.831	781.05	1184.14	60.406
90	01JUN1998:00:00:00	984	1037.26	102.831	835.72	1238.81	-53.264
91	01JUL1998:00:00:00	1206	1068.42	102.831	866.88	1269.97	137.57

APPENDIX E: SAS OUTPUT- FULL MODEL FOR FATALITIES

```
                                   The ARIMA Procedure

                              Name of Variable = dt_fatality

                           Mean of Working Series    23.08791
                           Standard Deviation        7.589247
                           Number of Observations          91

                                     Autocorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1      Std Error

  0     57.596667       1.00000    |                    |********************|             0
  1     14.758881       0.25625    |                .   |*****               |      0.104828
  2     13.686100       0.23762    |                .   |*****               |      0.111499
  3     13.751949       0.23876    |               .    |*****               |      0.116932
  4     -5.083663       -.08826    |               .  **|    .               |      0.122172
  5      3.174796       0.05512    |               .    |*   .               |      0.122871
  6     -4.919601       -.08541    |               .  **|    .               |      0.123142
  7     -8.933574       -.15511    |               . ***|    .               |      0.123791
  8      0.391423       0.00680    |               .    |    .               |      0.125909
  9      2.420441       0.04202    |               .    |*   .               |      0.125913
 10     12.441006       0.21600    |               .    |****.               |      0.126067
 11     18.643553       0.32369    |               .    |******              |      0.130070
 12     13.707470       0.23799    |              .     |*****.              |      0.138640
 13     13.743613       0.23862    |              .     |*****.              |      0.143059
 14      9.300103       0.16147    |              .     |***  .              |      0.147368
 15      4.232152       0.07348    |              .     |*    .              |      0.149300
 16     -3.677364       -.06385    |              .    *|     .              |      0.149696
 17     -7.316382       -.12703    |              .  ***|     .              |      0.149995
 18    -11.349434       -.19705    |              . ****|     .              |      0.151173
 19     -6.726043       -.11678    |              .   **|     .              |      0.153970
 20    -10.422662       -.18096    |              . ****|     .              |      0.154940
 21     -3.319016       -.05763    |              .    *|     .              |      0.157245
 22      5.915533       0.10271    |              .     |**   .              |      0.157477

                              "." marks two standard errors
```

```
                                 Inverse Autocorrelations

                  Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

                    1       -0.06413    |                .  *|   .                |
                    2       -0.05427    |                .  *|   .                |
                    3       -0.20461    |                ****|   .                |
                    4        0.12547    |                .   |***.                |
                    5       -0.15574    |                .***|   .                |
                    6       -0.00075    |                .   |   .                |
                    7        0.06642    |                .   |*  .                |
                    8        0.10329    |                .   |** .                |
                    9       -0.02706    |                .  *|   .                |
```

```
                        The SAS System

                     The ARIMA Procedure

                   Inverse Autocorrelations

Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 10       -0.12851    |                .***|   .                |
 11       -0.19635    |                ****|   .                |
 12        0.00745    |                .   |   .                |
 13       -0.02588    |                .  *|   .                |
 14        0.02358    |                .   |   .                |
 15       -0.10345    |                . **|   .                |
 16        0.13460    |                .   |***.                |
 17       -0.00493    |                .   |   .                |
 18        0.01644    |                .   |   .                |
 19       -0.05773    |                .  *|   .                |
 20        0.14015    |                .   |***.                |
 21        0.03675    |                .   |*  .                |
 22       -0.04126    |                .  *|   .                |

                   Partial Autocorrelations

Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  1        0.25625    |                .   |*****               |
  2        0.18404    |                .   |****                |
  3        0.15722    |                .   |***.                |
  4       -0.23568    |               *****|   .                |
  5        0.05128    |                .   |*  .                |
  6       -0.09930    |                . **|   .                |
  7       -0.07603    |                . **|   .                |
  8        0.05446    |                .   |*  .                |
  9        0.15710    |                .   |***.                |
 10        0.23250    |                .   |*****               |
 11        0.21765    |                .   |****                |
 12        0.06081    |                .   |*  .                |
 13       -0.00426    |                .   |   .                |
 14       -0.03120    |                .  *|   .                |
 15       -0.01723    |                .   |   .                |
 16       -0.14237    |                .***|   .                |
 17       -0.05334    |                .  *|   .                |
 18       -0.08699    |                . **|   .                |
 19        0.04991    |                .   |*  .                |
 20       -0.17839    |                ****|   .                |
 21       -0.03538    |                .  *|   .                |
 22        0.05353    |                .   |*  .                |
```

The SAS System

The ARIMA Procedure

Autocorrelation Check for White Noise

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	18.81	6	0.0045	0.256	0.238	0.239	-0.088	0.055	-0.085
12	43.45	12	<.0001	-0.155	0.007	0.042	0.216	0.324	0.238
18	59.90	18	<.0001	0.239	0.161	0.073	-0.064	-0.127	-0.197

Correlation of dt_fatality and GAS_SALE

```
Variance of input =       1.7364E9
Number of Observations          91
```

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22     66174.422        0.20925    |                .   |****                |
 -21     33066.165        0.10456    |                .   |** .                |
 -20    -14211.977        -.04494    |                .  *|   .                |
 -19    -34655.921        -.10959    |                . **|   .                |
 -18    -85632.283        -.27078    |               *****|   .                |
 -17       -113928        -.36025    |             *******|   .                |
 -16       -100386        -.31743    |              ******|   .                |
 -15       -100170        -.31675    |              ******|   .                |
 -14    -44893.948        -.14196    |                .***|   .                |
 -13      8598.476        0.02719    |                .   |*  .                |
 -12     28046.000        0.08868    |                .   |** .                |
 -11     54573.797        0.17257    |                .   |***.                |
 -10     55083.868        0.17418    |                .   |***.                |
  -9      6549.769        0.02071    |                .   |   .                |
  -8    -37208.015        -.11766    |                . **|   .                |
  -7    -76899.788        -.24317    |               *****|   .                |
  -6       -132070        -.41762    |            ********|   .                |
  -5       -152296        -.48158    |          **********|   .                |
  -4       -152915        -.48353    |          **********|   .                |
  -3       -108339        -.34258    |             *******|   .                |
  -2    -48814.994        -.15436    |                .***|   .                |
  -1    -15190.259        -.04803    |                .  *|   .                |
   0     39005.657        0.12334    |                .   |** .                |
   1     48198.628        0.15241    |                .   |***.                |
   2     18827.654        0.05954    |                .   |*  .                |
   3    -12904.047        -.04080    |                .  *|   .                |
   4    -40764.178        -.12890    |                .***|   .                |
   5    -89471.223        -.28292    |              ******|   .                |
   6       -126550        -.40017    |            ********|   .                |
   7       -149540        -.47286    |           *********|   .                |
   8       -152996        -.48379    |          **********|   .                |
```

```
                              The SAS System

                           The ARIMA Procedure

                             Crosscorrelations

Lag      Covariance      Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  9      -85194.842         -.26940     |               *****|   .                |
 10      -43776.630         -.13843     |                .***|   .                |
 11        3845.288         0.01216     |                .   |   .                |
 12       42960.584         0.13585     |                .   |***.                |
 13       42774.516         0.13526     |                .   |***.                |
 14       51269.183         0.16212     |                .   |***.                |
 15       15147.721         0.04790     |                .   |*  .                |
 16      -26005.068         -.08223     |                . **|   .                |
 17      -70563.181         -.22313     |                ****|   .                |
 18         -102070         -.32276     |              ******|   .                |
 19         -120613         -.38139     |            ********|   .                |
 20         -116606         -.36872     |             *******|   .                |
 21      -75874.851         -.23992     |               *****|   .                |
 22      -44842.131         -.14180     |                .***|   .                |

                        "." marks two standard errors

                  Correlation of dt_fatality and prp_vt

                   Variance of input =       0.194179
                   Number of Observations          91

                             Crosscorrelations

Lag      Covariance      Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22       -0.396017         -.11842     |                . **|   .                |
-21       -0.552507         -.16521     |                .***|   .                |
-20       -0.538365         -.16098     |                .***|   .                |
-19       -0.606942         -.18149     |                ****|   .                |
-18       -0.673708         -.20145     |                ****|   .                |
-17       -0.672850         -.20120     |                ****|   .                |
-16       -0.816539         -.24416     |               *****|   .                |
-15       -0.948635         -.28366     |              ******|   .                |
-14       -0.820014         -.24520     |               *****|   .                |
-13       -0.999569         -.29889     |              ******|   .                |
-12       -1.070441         -.32008     |              ******|   .                |
-11       -1.024539         -.30636     |              ******|   .                |
-10       -1.091909         -.32650     |             *******|   .                |
 -9       -1.059291         -.31675     |              ******|   .                |
 -8       -1.148035         -.34329     |             *******|   .                |
 -7       -1.265761         -.37849     |            ********|   .                |
 -6       -1.240026         -.37079     |             *******|   .                |
 -5       -1.278414         -.38227     |            ********|   .                |
 -4       -1.222611         -.36558     |             *******|   .                |
```

The SAS System

The ARIMA Procedure

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  -3     -1.079499       -.32279     |              ******|                    |
  -2     -0.986139       -.29488     |              ******|   .                |
  -1     -0.991077       -.29635     |              ******|   .                |
   0     -1.001208       -.29938     |              ******|   .                |
   1     -0.952555       -.28483     |              ******|   .                |
   2     -0.999302       -.29881     |              ******|   .                |
   3     -1.015376       -.30362     |              ******|   .                |
   4     -0.971796       -.29059     |              ******|   .                |
   5     -0.953091       -.28499     |              ******|   .                |
   6     -0.834399       -.24950     |               *****|   .                |
   7     -0.783935       -.23441     |               *****|   .                |
   8     -0.607279       -.18159     |                ****|   .                |
   9     -0.421445       -.12602     |                .***|   .                |
  10     -0.458290       -.13704     |                .***|   .                |
  11     -0.312910       -.09357     |                . **|   .                |
  12     -0.316305       -.09458     |                . **|   .                |
  13     -0.409906       -.12257     |                . **|   .                |
  14     -0.314882       -.09416     |                . **|   .                |
  15     -0.378414       -.11315     |                . **|   .                |
  16     -0.271315       -.08113     |                . **|   .                |
  17     -0.265411       -.07936     |                . **|   .                |
  18     -0.198162       -.05925     |                .  *|   .                |
  19      0.012548       0.00375     |                .   |   .                |
  20      0.074605       0.02231     |                .   |   .                |
  21      0.092705       0.02772     |                .   |*  .                |
  22      0.080133       0.02396     |                .   |   .                |
```

"." marks two standard errors

Correlation of dt_fatality and point03

```
Variance of input =        0.010868
Number of Observations           91
```

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22      0.098426       0.12440     |                .   |** .                |
 -21      0.054360       0.06871     |                .   |*  .                |
 -20      0.131414       0.16610     |                .   |***.                |
 -19      0.109326       0.13818     |                .   |***.                |
 -18      0.154621       0.19543     |                .   |****                |
 -17      0.155115       0.19605     |                .   |****                |
 -16     -0.030359       -.03837     |                .  *|   .                |
```

```
                                The SAS System

                             The ARIMA Procedure

                              Crosscorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -15      0.070364      0.08893      |                .   |** .                |
 -14     -0.029131      -.03682      |                .  *|   .                |
 -13     -0.038901      -.04917      |                .  *|   .                |
 -12      0.049263      0.06226      |                .   |*  .                |
 -11     0.0044720      0.00565      |                .   |   .                |
 -10     -0.093573      -.11827      |                . **|   .                |
  -9      0.092768      0.11725      |                .   |** .                |
  -8      0.050151      0.06339      |                .   |*  .                |
  -7     0.0063259      0.00800      |                .   |   .                |
  -6     0.0069403      0.00877      |                .   |   .                |
  -5    -0.0019852      -.00251      |                .   |   .                |
  -4    -0.0014916      -.00189      |                .   |   .                |
  -3      0.108409      0.13702      |                .   |***.                |
  -2     -0.067646      -.08550      |                . **|   .                |
  -1     -0.100361      -.12685      |                .***|   .                |
   0     -0.088878      -.11234      |                . **|   .                |
   1     -0.145041      -.18332      |                ****|   .                |
   2     -0.079722      -.10076      |                . **|   .                |
   3     -0.014040      -.01775      |                .   |   .                |
   4     -0.023711      -.02997      |                .  *|   .                |
   5     -0.077459      -.09790      |                . **|   .                |
   6      0.032300      0.04082      |                .   |*  .                |
   7      0.010552      0.01334      |                .   |   .                |
   8    -0.0091418      -.01155      |                .   |   .                |
   9      0.013671      0.01728      |                .   |   .                |
  10     -0.117483      -.14849      |                .***|   .                |
  11     -0.039122      -.04945      |                .  *|   .                |
  12     -0.117142      -.14806      |                .***|   .                |
  13     -0.161833      -.20455      |                ****|   .                |
  14      0.058661      0.07414      |                .   |*  .                |
  15     -0.107030      -.13528      |                .***|   .                |
  16     -0.019733      -.02494      |                .   |   .                |
  17      0.078916      0.09974      |                .   |** .                |
  18     -0.074457      -.09411      |                . **|   .                |
  19      0.047377      0.05988      |                .   |*  .                |
  20     -0.116744      -.14756      |                .***|   .                |
  21    -0.0061401      -.00776      |                .   |   .                |
  22     -0.049744      -.06287      |                .  *|   .                |

                          "." marks two standard errors

                     Correlation of dt_fatality and point04

                        Variance of input =       0.010868
                        Number of Observations          91
```

The SAS System

The ARIMA Procedure

Crosscorrelations

```
 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22      0.054470      0.06885      |                .   |*  .                |
 -21      0.131283      0.16593      |                .   |***.                |
 -20      0.109436      0.13832      |                .   |***.                |
 -19      0.153282      0.19374      |                .   |****                |
 -18      0.154621      0.19543      |                .   |****                |
 -17     -0.031698      -.04006      |                .  *|   .                |
 -16      0.068542      0.08663      |                .   |** .                |
 -15     -0.028537      -.03607      |                .  *|   .                |
 -14     -0.040120      -.05071      |                .  *|   .                |
 -13      0.049011      0.06195      |                .   |*  .                |
 -12     0.0053067      0.00671      |                .   |   .                |
 -11     -0.094429      -.11935      |                . **|   .                |
 -10      0.093240      0.11785      |                .   |** .                |
  -9      0.048812      0.06169      |                .   |*  .                |
  -8     0.0061945      0.00783      |                .   |   .                |
  -7     0.0063259      0.00800      |                .   |   .                |
  -6    -0.0040487      -.00512      |                .   |   .                |
  -5    -0.0019852      -.00251      |                .   |   .                |
  -4      0.108399      0.13701      |                .   |***.                |
  -3     -0.067415      -.08521      |                . **|   .                |
  -2     -0.100613      -.12717      |                .***|   .                |
  -1     -0.089372      -.11296      |                . **|   .                |
   0     -0.143823      -.18178      |                ****|   .                |
   1     -0.079107      -.09999      |                . **|   .                |
   2     -0.013788      -.01743      |                .   |   .                |
   3     -0.025029      -.03163      |                .  *|   .                |
   4     -0.078656      -.09942      |                . **|   .                |
   5      0.032431      0.04099      |                .   |*  .                |
   6      0.010322      0.01305      |                .   |   .                |
   7     -0.011426      -.01444      |                .   |   .                |
   8      0.012836      0.01622      |                .   |   .                |
   9     -0.118197      -.14939      |                .***|   .                |
  10     -0.040560      -.05127      |                .  *|   .                |
  11     -0.116045      -.14667      |                .***|   .                |
  12     -0.161098      -.20362      |                ****|   .                |
  13      0.057947      0.07324      |                .   |*  .                |
  14     -0.106174      -.13420      |                .***|   .                |
  15     -0.019118      -.02416      |                .   |   .                |
  16      0.079168      0.10006      |                .   |** .                |
  17     -0.074930      -.09471      |                . **|   .                |
  18      0.046422      0.05867      |                .   |*  .                |
  19     -0.117458      -.14846      |                .***|   .                |
  20    -0.0068540      -.00866      |                .   |   .                |
  21     -0.050096      -.06332      |                .  *|   .                |
  22     -0.181613      -.22954      |               *****|   .                |

                         "." marks two standard errors
```

The SAS System

The ARIMA Procedure

Correlation of dt_fatality and point05

```
Variance of input =        0.010868
Number of Observations           91
```

Crosscorrelations

```
Lag   Covariance   Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22     0.131393       0.16607   |                .   |***.                |
-21     0.109305       0.13815   |                .   |***.                |
-20     0.153392       0.19388   |                .   |****                |
-19     0.153282       0.19374   |                .   |****                |
-18    -0.032192       -.04069   |                .  *|   .                |
-17     0.067203       0.08494   |                .   |** .                |
-16    -0.030359       -.03837   |                .  *|   .                |
-15    -0.039526       -.04996   |                .  *|   .                |
-14     0.047792       0.06041   |                .   |*  .                |
-13    0.0050546       0.00639   |                .   |   .                |
-12    -0.093594       -.11830   |                . **|   .                |
-11     0.092384       0.11677   |                .   |** .                |
-10     0.049284       0.06229   |                .   |*  .                |
 -9    0.0048555       0.00614   |                .   |   .                |
 -8    0.0061945       0.00783   |                .   |   .                |
 -7   -0.0046631       -.00589   |                .   |   .                |
 -6   -0.0040487       -.00512   |                .   |   .                |
 -5     0.107905       0.13638   |                .   |***.                |
 -4    -0.067426       -.08522   |                . **|   .                |
 -3    -0.100382       -.12688   |                .***|   .                |
 -2    -0.089624       -.11328   |                . **|   .                |
 -1    -0.144317       -.18241   |                ****|   .                |
  0    -0.077889       -.09845   |                . **|   .                |
  1    -0.013173       -.01665   |                .   |   .                |
  2    -0.024777       -.03132   |                .  *|   .                |
  3    -0.079974       -.10108   |                . **|   .                |
  4     0.031234       0.03948   |                .   |*  .                |
  5     0.010453       0.01321   |                .   |   .                |
  6    -0.011656       -.01473   |                .   |   .                |
  7     0.010552       0.01334   |                .   |   .                |
  8    -0.119032       -.15045   |                .***|   .                |
  9    -0.041274       -.05217   |                .  *|   .                |
 10    -0.117483       -.14849   |                .***|   .                |
 11    -0.160001       -.20223   |                ****|   .                |
 12     0.058682       0.07417   |                .   |*  .                |
 13    -0.106888       -.13510   |                .***|   .                |
 14    -0.018262       -.02308   |                .   |   .                |
 15     0.079783       0.10084   |                .   |** .                |
 16    -0.074678       -.09439   |                . **|   .                |
 17     0.045949       0.05808   |                .   |*  .                |
 18    -0.118414       -.14967   |                .***|   .                |
```

```
                              The SAS System
                           The ARIMA Procedure
                            Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 19    -0.0075680       -.00957     |                .   |   .                |
 20    -0.050810        -.06422     |                .  *|   .                |
 21    -0.181964        -.22999     |               *****|   .                |
 22    -0.038755        -.04898     |                .  *|   .                |

                      "." marks two standard errors

                  Correlation of dt_fatality and point06

                    Variance of input =        0.010868
                    Number of Observations           91

                            Crosscorrelations

Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22     0.109415        0.13829     |                .   |***.                |
-21     0.153261        0.19371     |                .   |****                |
-20     0.153392        0.19388     |                .   |****                |
-19    -0.033531        -.04238     |                .  *|   .                |
-18     0.066709        0.08432     |                .   |** .                |
-17    -0.031698        -.04006     |                .  *|   .                |
-16    -0.041348        -.05226     |                .  *|   .                |
-15     0.048386        0.06116     |                .   |*  .                |
-14     0.0038364       0.00485     |                .   |   .                |
-13    -0.093846        -.11861     |                . **|   .                |
-12     0.093219        0.11782     |                .   |** .                |
-11     0.048428        0.06121     |                .   |*  .                |
-10     0.0053280       0.00673     |                .   |   .                |
 -9     0.0048555       0.00614     |                .   |   .                |
 -8    -0.0047945       -.00606     |                .   |   .                |
 -7    -0.0046631       -.00589     |                .   |   .                |
 -6     0.105841        0.13378     |                .   |***.                |
 -5    -0.067919        -.08584     |                . **|   .                |
 -4    -0.100393        -.12689     |                .***|   .                |
 -3    -0.089393        -.11299     |                . **|   .                |
 -2    -0.144569        -.18272     |                ****|   .                |
 -1    -0.078383        -.09907     |                . **|   .                |
  0    -0.011955        -.01511     |                .   |   .                |
  1    -0.024162        -.03054     |                .  *|   .                |
  2    -0.079722        -.10076     |                . **|   .                |
  3     0.029916        0.03781     |                .   |*  .                |
  4     0.0092559       0.01170     |                .   |   .                |
  5    -0.011525        -.01457     |                .   |   .                |
  6     0.010322        0.01305     |                .   |   .                |
```

```
                                The SAS System

                             The ARIMA Procedure

                              Crosscorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

   7     -0.121316       -.15333      |                .***|   .                |
   8     -0.042109       -.05322      |                .  *|   .                |
   9     -0.118197       -.14939      |                .***|   .                |
  10     -0.161439       -.20405      |                ****|   .                |
  11      0.059779       0.07556      |                .   |** .                |
  12     -0.106153       -.13417      |                .***|   .                |
  13     -0.018976       -.02398      |                .   |   .                |
  14      0.080639       0.10192      |                .   |** .                |
  15     -0.074063       -.09361      |                . **|   .                |
  16      0.046201       0.05840      |                .   |*  .                |
  17     -0.118886       -.15026      |                .***|   .                |
  18    -0.0085234       -.01077      |                .   |   .                |
  19     -0.051524       -.06512      |                .  *|   .                |
  20     -0.182678       -.23089      |               *****|   .                |
  21     -0.039107       -.04943      |                .  *|   .                |
  22     0.0052006       0.00657      |                .   |   .                |

                         "." marks two standard errors


                     Correlation of dt_fatality and point07

                      Variance of input =        0.010868
                      Number of Observations           91


                              Crosscorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 -22      0.153371       0.19385      |                .   |****                |
 -21      0.153261       0.19371      |                .   |****                |
 -20     -0.033421       -.04224      |                .  *|   .                |
 -19      0.065370       0.08262      |                .   |** .                |
 -18     -0.032192       -.04069      |                .  *|   .                |
 -17     -0.042687       -.05395      |                .  *|   .                |
 -16      0.046564       0.05885      |                .   |*  .                |
 -15     0.0044296       0.00560      |                .   |   .                |
 -14     -0.095065       -.12015      |                . **|   .                |
 -13      0.092967       0.11750      |                .   |** .                |
 -12      0.049263       0.06226      |                .   |*  .                |
 -11     0.0044720       0.00565      |                .   |   .                |
 -10     0.0053280       0.00673      |                .   |   .                |
  -9    -0.0061335       -.00775      |                .   |   .                |
  -8    -0.0047945       -.00606      |                .   |   .                |
  -7      0.105227       0.13300      |                .   |***.                |
  -6     -0.069983       -.08845      |                . **|   .                |
```

```
                                  The SAS System

                               The ARIMA Procedure

                                Crosscorrelations

 Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  -5     -0.100886       -.12751     |                .***|   .                |
  -4     -0.089404       -.11300     |                . **|   .                |
  -3     -0.144338       -.18243     |                ****|   .                |
  -2     -0.078635       -.09939     |                . **|   .                |
  -1     -0.012449       -.01573     |                .   |   .                |
   0     -0.022944       -.02900     |                .  *|   .                |
   1     -0.079107       -.09999     |                . **|   .                |
   2      0.030168       0.03813     |                .   |*  .                |
   3     0.0079382       0.01003     |                .   |   .                |
   4     -0.012722       -.01608     |                .   |   .                |
   5      0.010453       0.01321     |                .   |   .                |
   6     -0.121547       -.15363     |                .***|   .                |
   7     -0.044393       -.05611     |                .  *|   .                |
   8     -0.119032       -.15045     |                .***|   .                |
   9     -0.162153       -.20495     |                ****|   .                |
  10      0.058341       0.07374     |                .   |*  .                |
  11     -0.105056       -.13278     |                .***|   .                |
  12     -0.018241       -.02306     |                .   |   .                |
  13      0.079925       0.10102     |                .   |** .                |
  14     -0.073207       -.09253     |                . **|   .                |
  15      0.046816       0.05917     |                .   |*  .                |
  16     -0.118634       -.14994     |                .***|   .                |
  17    -0.0089958       -.01137     |                .   |   .                |
  18     -0.052479       -.06633     |                .  *|   .                |
  19     -0.183392       -.23179     |               *****|   .                |
  20     -0.039821       -.05033     |                .  *|   .                |
  21     0.0048489       0.00613     |                .   |   .                |
  22      0.027179       0.03435     |                .   |*  .                |

                          "." marks two standard errors

                    Correlation of dt_fatality and otherprog

                       Variance of input =      11.88745
                       Number of Observations         91
```

The SAS System

The ARIMA Procedure

Crosscorrelations

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

-22    -5.925140     -.22644        |              *****|   .                |
-21    -5.410885     -.20679        |               ****|   .                |
-20    -5.153362     -.19695        |               ****|   .                |
-19    -4.573172     -.17477        |               .***|   .                |
-18    -5.797113     -.22155        |               ****|   .                |
-17    -5.847765     -.22348        |               ****|   .                |
-16    -6.906870     -.26396        |              *****|   .                |
-15    -8.336583     -.31860        |             ******|   .                |
-14    -6.660511     -.25454        |              *****|   .                |
-13    -7.393448     -.28256        |             ******|   .                |
-12    -6.901654     -.26376        |              *****|   .                |
-11    -5.177641     -.19787        |               ****|   .                |
-10    -5.712293     -.21831        |               ****|   .                |
 -9    -4.527224     -.17302        |               .***|   .                |
 -8    -5.663253     -.21643        |               ****|   .                |
 -7    -5.251883     -.20071        |               ****|   .                |
 -6    -5.397935     -.20629        |               ****|   .                |
 -5    -7.282182     -.27830        |             ******|   .                |
 -4    -7.036131     -.26890        |              *****|   .                |
 -3    -6.133758     -.23441        |              *****|   .                |
 -2    -5.051576     -.19306        |               ****|   .                |
 -1    -4.636704     -.17720        |               ****|   .                |
  0    -4.621423     -.17662        |               ****|   .                |
  1    -4.258610     -.16275        |               .***|   .                |
  2    -3.769363     -.14405        |               .***|   .                |
  3    -3.347500     -.12793        |               .***|   .                |
  4    -2.760198     -.10549        |               . **|   .                |
  5    -2.111429     -.08069        |               . **|   .                |
  6    -1.699951     -.06497        |               .  *|   .                |
  7    -1.202010     -.04594        |               .  *|   .                |
  8    -0.579567     -.02215        |               .   |   .                |
  9    -0.142971     -.00546        |               .   |   .                |
 10     0.223222     0.00853        |               .   |   .                |
 11     0.488583     0.01867        |               .   |   .                |
 12     0.404710     0.01547        |               .   |   .                |
 13     0.363345     0.01389        |               .   |   .                |
 14     0.516883     0.01975        |               .   |   .                |
 15     0.459094     0.01755        |               .   |   .                |
 16     0.385365     0.01473        |               .   |   .                |
 17     0.355109     0.01357        |               .   |   .                |
 18     0.411799     0.01574        |               .   |   .                |
 19     0.526453     0.02012        |               .   |   .                |
 20     0.612125     0.02339        |               .   |   .                |
 21     0.697798     0.02667        |               .   |*  .                |
 22     0.739997     0.02828        |               .   |*  .                |
```

"." marks two standard errors

The SAS System

The ARIMA Procedure

Augmented Dickey-Fuller Unit Root Tests

Type	Lags	Rho	Pr < Rho	Tau	Pr < Tau	F	Pr > F
Zero Mean	0	9.3103	0.9999	15.28	0.9999		
	1	0.0000	0.6806	0.00	0.6806		
Single Mean	0	8.8235	0.9999	13.87	0.9999	124.30	0.0010
	1	-0.0000	0.9557	-0.00	0.9556	0.58	0.9262
Trend	0	7.2707	0.9999	10.04	0.9999	117.49	0.0010
	1	-1.7919	0.9736	-0.15	0.9932	1.75	0.8283

The SAS System

The ARIMA Procedure

Maximum Likelihood Estimation

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	25.17924	0.56654	44.44	<.0001	0	dt_fatality	0
AR1,1	0.03231	0.11229	0.29	0.7736	1	dt_fatality	0
AR1,2	0.01576	0.11018	0.14	0.8862	2	dt_fatality	0
AR1,3	0.10590	0.11431	0.93	0.3542	3	dt_fatality	0
AR1,4	-0.21068	0.11012	-1.91	0.0557	4	dt_fatality	0
AR1,5	-0.02733	0.11080	-0.25	0.8052	5	dt_fatality	0
AR1,6	-0.21821	0.11540	-1.89	0.0586	6	dt_fatality	0
AR1,7	-0.25049	0.11666	-2.15	0.0318	7	dt_fatality	0
NUM1	-6.61058	1.55459	-4.25	<.0001	0	prp_vt	0
NUM2	-9.54139	6.59488	-1.45	0.1480	0	point03	0
NUM3	-13.01643	6.55709	-1.99	0.0471	0	point04	0
NUM4	-7.21740	6.47774	-1.11	0.2652	0	point05	0
NUM5	-4.26306	6.48444	-0.66	0.5109	0	point06	0
NUM6	-4.80359	6.52469	-0.74	0.4616	0	point07	0
NUM7	0.09340	0.23417	0.40	0.6900	0	otherprog	0

Constant Estimate	39.0966
Variance Estimate	44.85855
Std Error Estimate	6.697652
AIC	619.1956
SBC	656.8585
Number of Residuals	91

Correlations of Parameter Estimates

Variable	Parameter	dt_fatality MU	dt_fatality AR1,1	dt_fatality AR1,2	dt_fatality AR1,3	dt_fatality AR1,4
dt_fatality	MU	1.000	-0.026	-0.048	-0.028	-0.005
dt_fatality	AR1,1	-0.026	1.000	-0.077	-0.071	-0.184
dt_fatality	AR1,2	-0.048	-0.077	1.000	-0.102	-0.100
dt_fatality	AR1,3	-0.028	-0.071	-0.102	1.000	-0.071
dt_fatality	AR1,4	-0.005	-0.184	-0.100	-0.071	1.000
dt_fatality	AR1,5	-0.017	0.338	-0.104	-0.128	-0.133
dt_fatality	AR1,6	-0.027	0.113	0.345	-0.191	-0.173
dt_fatality	AR1,7	-0.028	0.237	0.070	0.297	-0.203
prp_vt	NUM1	-0.348	0.002	0.005	-0.013	-0.047
point03	NUM2	-0.140	0.175	0.145	-0.157	-0.012
point04	NUM3	-0.146	0.002	0.171	0.134	-0.166
point05	NUM4	-0.132	-0.045	-0.034	0.180	0.121
point06	NUM5	-0.138	-0.003	-0.041	-0.040	0.154
point07	NUM6	-0.119	0.002	-0.006	-0.029	-0.052
otherprog	NUM7	-0.014	-0.000	-0.009	0.036	0.091

The SAS System

The ARIMA Procedure

Correlations of Parameter Estimates

Variable	Parameter	dt_fatality AR1,5	dt_fatality AR1,6	dt_fatality AR1,7	prp_vt NUM1	point03 NUM2
dt_fatality	MU	-0.017	-0.027	-0.028	-0.348	-0.140
dt_fatality	AR1,1	0.338	0.113	0.237	0.002	0.175
dt_fatality	AR1,2	-0.104	0.345	0.070	0.005	0.145
dt_fatality	AR1,3	-0.128	-0.191	0.297	-0.013	-0.157
dt_fatality	AR1,4	-0.133	-0.173	-0.203	-0.047	-0.012
dt_fatality	AR1,5	1.000	-0.087	-0.082	-0.069	0.108
dt_fatality	AR1,6	-0.087	1.000	-0.084	0.012	0.113
dt_fatality	AR1,7	-0.082	-0.084	1.000	0.049	0.037
prp_vt	NUM1	-0.069	0.012	0.049	1.000	-0.027
point03	NUM2	0.108	0.113	0.037	-0.027	1.000
point04	NUM3	0.002	0.117	0.112	-0.066	0.014
point05	NUM4	-0.154	-0.036	0.098	-0.046	-0.035
point06	NUM5	0.128	-0.148	-0.023	-0.075	0.102
point07	NUM6	0.135	0.116	-0.146	-0.075	-0.110
otherprog	NUM7	0.105	-0.034	-0.061	-0.695	0.058

Correlations of Parameter Estimates

Variable	Parameter	point04 NUM3	point05 NUM4	point06 NUM5	point07 NUM6	otherprog NUM7
dt_fatality	MU	-0.146	-0.132	-0.138	-0.119	-0.014
dt_fatality	AR1,1	0.002	-0.045	-0.003	0.002	-0.000
dt_fatality	AR1,2	0.171	-0.034	-0.041	-0.006	-0.009
dt_fatality	AR1,3	0.134	0.180	-0.040	-0.029	0.036
dt_fatality	AR1,4	-0.166	0.121	0.154	-0.052	0.091
dt_fatality	AR1,5	0.002	-0.154	0.128	0.135	0.105
dt_fatality	AR1,6	0.117	-0.036	-0.148	0.116	-0.034
dt_fatality	AR1,7	0.112	0.098	-0.023	-0.146	-0.061
prp_vt	NUM1	-0.066	-0.046	-0.075	-0.075	-0.695
point03	NUM2	0.014	-0.035	0.102	-0.110	0.058
point04	NUM3	1.000	0.022	-0.034	0.106	0.085
point05	NUM4	0.022	1.000	0.014	-0.032	0.076
point06	NUM5	-0.034	0.014	1.000	0.001	0.116
point07	NUM6	0.106	-0.032	0.001	1.000	0.099
otherprog	NUM7	0.085	0.076	0.116	0.099	1.000

The SAS System

The ARIMA Procedure

Autocorrelation Check of Residuals

To Lag	Chi-Square	DF	Pr > ChiSq	--------------------Autocorrelations--------------------					
6	0.00	0	<.0001	-0.039	-0.034	0.011	0.012	0.068	0.063
12	3.78	5	0.5814	0.023	-0.138	-0.050	0.030	0.047	-0.027
18	10.93	11	0.4488	-0.046	-0.116	-0.018	-0.159	-0.093	-0.116
24	15.05	17	0.5918	-0.014	-0.157	-0.013	0.068	-0.046	-0.050

Autocorrelation Plot of Residuals

```
Lag    Covariance    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1      Std Error

  0     44.858546        1.00000    |                    |********************|             0
  1     -1.745993        -.03892    |                .  *|   .                |      0.104828
  2     -1.544733        -.03444    |                .  *|   .                |      0.104987
  3      0.500575        0.01116    |                .   |   .                |      0.105111
  4      0.517642        0.01154    |                .   |   .                |      0.105124
  5      3.030847        0.06756    |                .   |*  .                |      0.105138
  6      2.836116        0.06322    |                .   |*  .                |      0.105614
  7      1.014157        0.02261    |                .   |   .                |      0.106029
  8     -6.196555        -.13814    |                .***|   .                |      0.106082
  9     -2.241601        -.04997    |                .  *|   .                |      0.108041
 10      1.343145        0.02994    |                .   |*  .                |      0.108294
 11      2.087637        0.04654    |                .   |*  .                |      0.108385
 12     -1.191501        -.02656    |                .  *|   .                |      0.108605
 13     -2.047617        -.04565    |                .  *|   .                |      0.108676
 14     -5.219958        -.11636    |                . **|   .                |      0.108887
 15     -0.826851        -.01843    |                .   |   .                |      0.110245
 16     -7.143837        -.15925    |                .***|   .                |      0.110279
 17     -4.153243        -.09259    |               .  **|    .               |      0.112777
 18     -5.201770        -.11596    |               .  **|    .               |      0.113610
 19     -0.624634        -.01392    |               .    |    .               |      0.114903
 20     -7.026840        -.15664    |               . ***|    .               |      0.114921
 21     -0.565326        -.01260    |               .    |    .               |      0.117244
 22      3.049917        0.06799    |               .    |*   .               |      0.117259
```

"." marks two standard errors

The SAS System

The ARIMA Procedure

Inverse Autocorrelations

```
 Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

   1        0.17863    |                .   |****                |
   2        0.14518    |                .   |***.                |
   3        0.04608    |                .   |*  .                |
   4        0.07528    |                .   |** .                |
   5       -0.04046    |                .  *|   .                |
   6       -0.01586    |                .   |   .                |
   7        0.00610    |                .   |   .                |
   8        0.16455    |                .   |***.                |
   9        0.06710    |                .   |*  .                |
  10        0.00169    |                .   |   .                |
  11       -0.03941    |                .  *|   .                |
  12        0.05082    |                .   |*  .                |
  13        0.01933    |                .   |   .                |
  14        0.08651    |                .   |** .                |
  15        0.05206    |                .   |*  .                |
  16        0.21449    |                .   |****                |
  17        0.15180    |                .   |***.                |
  18        0.14880    |                .   |***.                |
  19        0.03726    |                .   |*  .                |
  20        0.13802    |                .   |***.                |
  21        0.01503    |                .   |   .                |
  22       -0.03781    |                .  *|   .                |
```

Partial Autocorrelations

```
 Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

   1       -0.03892    |                .  *|   .                |
   2       -0.03601    |                .  *|   .                |
   3        0.00839    |                .   |   .                |
   4        0.01112    |                .   |   .                |
   5        0.06937    |                .   |*  .                |
   6        0.07000    |                .   |*  .                |
   7        0.03332    |                .   |*  .                |
   8       -0.13433    |                .***|   .                |
   9       -0.06579    |                .  *|   .                |
  10        0.00828    |                .   |   .                |
  11        0.04102    |                .   |*  .                |
  12       -0.02286    |                .   |   .                |
  13       -0.02954    |                .  *|   .                |
  14       -0.10286    |                . **|   .                |
  15       -0.02188    |                .   |   .                |
  16       -0.19815    |                ****|   .                |
  17       -0.13703    |                .***|   .                |
  18       -0.14716    |                .***|   .                |
  19       -0.00413    |                .   |   .                |
```

The SAS System

The ARIMA Procedure

Partial Autocorrelations

```
Lag    Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 20      -0.16904     |                .***|   .                 |
 21      -0.02837     |                .  *|   .                 |
 22       0.04531     |                .   |*  .                 |
```

Model for variable dt_fatality

Estimated Intercept 25.17924

Autoregressive Factors

Factor 1: 1 - 0.03231 B**(1) - 0.01576 B**(2) - 0.1059 B**(3) + 0.21068 B**(4) + 0.02733 B**(5) + 0.21821 B**(6) + 0.25049 B**(7)

Input Number 1

Input Variable	prp_vt
Overall Regression Factor	-6.61058

Input Number 2

Input Variable	point03
Overall Regression Factor	-9.54139

Input Number 3

Input Variable	point04
Overall Regression Factor	-13.0164

Input Number 4

Input Variable	point05
Overall Regression Factor	-7.2174

Input Number 5

Input Variable	point06
Overall Regression Factor	-4.26306

The SAS System

The ARIMA Procedure

Input Number 6

Input Variable	point07
Overall Regression Factor	-4.80359

Input Number 7

Input Variable	otherprog
Overall Regression Factor	0.093398

The SAS System

Obs	MONTH	dt_fatality	FORECAST	STD	L95	U95	RESIDUAL
1	01JAN1991:00:00:00	13	25.1792	7.55312	10.3754	39.9831	-12.1792
2	01FEB1991:00:00:00	18	23.8347	7.50695	9.1213	38.5481	-5.8347
3	01MAR1991:00:00:00	21	23.5302	7.48569	8.8585	38.2019	-2.5302
4	01APR1991:00:00:00	34	23.0451	7.44440	8.4543	37.6358	10.9549
5	01MAY1991:00:00:00	33	28.4196	7.14168	14.4222	42.4170	4.5804
6	01JUN1991:00:00:00	22	28.9404	7.12914	14.9675	42.9132	-6.9404
7	01JUL1991:00:00:00	25	30.8042	6.91820	17.2448	44.3637	-5.8042
8	01AUG1991:00:00:00	42	28.8248	6.69765	15.6976	41.9520	13.1752
9	01SEP1991:00:00:00	30	26.2047	6.69765	13.0776	39.3319	3.7953
10	01OCT1991:00:00:00	29	25.1593	6.69765	12.0321	38.2864	3.8407
11	01NOV1991:00:00:00	35	23.3686	6.69765	10.2415	36.4958	11.6314
12	01DEC1991:00:00:00	14	21.2632	6.69765	8.1360	34.3904	-7.2632
13	01JAN1992:00:00:00	17	24.7377	6.69765	11.6105	37.8648	-7.7377
14	01FEB1992:00:00:00	29	21.2165	6.69765	8.0894	34.3437	7.7835
15	01MAR1992:00:00:00	16	16.5511	6.69765	3.4239	29.6783	-0.5511
16	01APR1992:00:00:00	18	24.1223	6.69765	10.9951	37.2494	-6.1223
17	01MAY1992:00:00:00	21	24.1359	6.69765	11.0087	37.2630	-3.1359
18	01JUN1992:00:00:00	27	23.3570	6.69765	10.2299	36.4842	3.6430
19	01JUL1992:00:00:00	31	30.8264	6.69765	17.6992	43.9535	0.1736
20	01AUG1992:00:00:00	29	27.9318	6.69765	14.8047	41.0590	1.0682
21	01SEP1992:00:00:00	29	27.7099	6.69765	14.5827	40.8371	1.2901
22	01OCT1992:00:00:00	26	29.5758	6.69765	16.4487	42.7030	-3.5758
23	01NOV1992:00:00:00	26	27.1048	6.69765	13.9777	40.2320	-1.1048
24	01DEC1992:00:00:00	26	25.3088	6.69765	12.1817	38.4360	0.6912
25	01JAN1993:00:00:00	27	22.6700	6.69765	9.5429	35.7972	4.3300
26	01FEB1993:00:00:00	17	22.7688	6.69765	9.6417	35.8960	-5.7688
27	01MAR1993:00:00:00	14	23.0445	6.69765	9.9173	36.1716	-9.0445
28	01APR1993:00:00:00	18	23.5505	6.69765	10.4233	36.6776	-5.5505
29	01MAY1993:00:00:00	13	23.1142	6.69765	9.9870	36.2413	-10.1142
30	01JUN1993:00:00:00	34	24.7774	6.69765	11.6503	37.9046	9.2226
31	01JUL1993:00:00:00	23	26.4878	6.69765	13.3606	39.6149	-3.4878
32	01AUG1993:00:00:00	26	27.1048	6.69765	13.9777	40.2320	-1.1048
33	01SEP1993:00:00:00	39	33.3559	6.69765	20.2287	46.4830	5.6441
34	01OCT1993:00:00:00	15	28.2493	6.69765	15.1221	41.3764	-13.2493
35	01NOV1993:00:00:00	32	29.8292	6.69765	16.7020	42.9563	2.1708
36	01DEC1993:00:00:00	22	27.7154	6.69765	14.5882	40.8425	-5.7154
37	01JAN1994:00:00:00	29	19.4380	6.69765	6.3108	32.5651	9.5620
38	01FEB1994:00:00:00	20	28.1085	6.69765	14.9813	41.2357	-8.1085
39	01MAR1994:00:00:00	15	20.3552	6.69765	7.2281	33.4824	-5.3552
40	01APR1994:00:00:00	14	24.4161	6.69765	11.2889	37.5432	-10.4161
41	01MAY1994:00:00:00	33	24.4525	6.69765	11.3253	37.5796	8.5475
42	01JUN1994:00:00:00	29	24.1497	6.69765	11.0225	37.2768	4.8503
43	01JUL1994:00:00:00	36	26.4908	6.69765	13.3636	39.6179	9.5092
44	01AUG1994:00:00:00	34	29.2238	6.69765	16.0967	42.3510	4.7762
45	01SEP1994:00:00:00	38	28.2159	6.69765	15.0887	41.3430	9.7841
46	01OCT1994:00:00:00	38	30.8490	6.69765	17.7218	43.9761	7.1510
47	01NOV1994:00:00:00	21	25.4393	6.69765	12.3121	38.5664	-4.4393
48	01DEC1994:00:00:00	30	21.6573	6.69765	8.5301	34.7844	8.3427
49	01JAN1995:00:00:00	21	20.3665	6.69765	7.2393	33.4937	0.6335
50	01FEB1995:00:00:00	20	16.9910	6.69765	3.8638	30.1181	3.0090
51	01MAR1995:00:00:00	28	20.9795	6.69765	7.8524	34.1067	7.0205

The SAS System

Obs	MONTH	dt_fatality	FORECAST	STD	L95	U95	RESIDUAL
52	01APR1995:00:00:00	24	17.8357	6.69765	4.7085	30.9628	6.1643
53	01MAY1995:00:00:00	15	23.0864	6.69765	9.9592	36.2135	-8.0864
54	01JUN1995:00:00:00	32	26.3308	6.69765	13.2036	39.4579	5.6692
55	01JUL1995:00:00:00	28	24.3660	6.69765	11.2388	37.4931	3.6340
56	01AUG1995:00:00:00	24	26.6483	6.69765	13.5211	39.7754	-2.6483
57	01SEP1995:00:00:00	24	28.7665	6.69765	15.6393	41.8937	-4.7665
58	01OCT1995:00:00:00	23	23.8133	6.69765	10.6861	36.9404	-0.8133
59	01NOV1995:00:00:00	23	26.7013	6.69765	13.5742	39.8285	-3.7013
60	01DEC1995:00:00:00	33	26.1823	6.69765	13.0552	39.3095	6.8177
61	01JAN1996:00:00:00	17	23.1234	6.69765	9.9963	36.2506	-6.1234
62	01FEB1996:00:00:00	14	24.8496	6.69765	11.7224	37.9768	-10.8496
63	01MAR1996:00:00:00	15	17.0474	6.69765	3.9202	30.1745	-2.0474
64	01APR1996:00:00:00	10	10.2826	6.69765	-2.8445	23.4098	-0.2826
65	01MAY1996:00:00:00	16	19.2289	6.69765	6.1017	32.3560	-3.2289
66	01JUN1996:00:00:00	22	22.1692	6.69765	9.0420	35.2963	-0.1692
67	01JUL1996:00:00:00	21	20.4164	6.69765	7.2893	33.5436	0.5836
68	01AUG1996:00:00:00	16	23.3595	6.69765	10.2323	36.4866	-7.3595
69	01SEP1996:00:00:00	26	22.0222	6.69765	8.8950	35.1493	3.9778
70	01OCT1996:00:00:00	24	19.2914	6.69765	6.1642	32.4185	4.7086
71	01NOV1996:00:00:00	22	19.3979	6.69765	6.2708	32.5251	2.6021
72	01DEC1996:00:00:00	24	20.3311	6.69765	7.2040	33.4583	3.6689
73	01JAN1997:00:00:00	12	17.4703	6.69765	4.3431	30.5974	-5.4703
74	01FEB1997:00:00:00	19	17.8622	6.69765	4.7351	30.9894	1.1378
75	01MAR1997:00:00:00	12	17.2047	6.69765	4.0776	30.3319	-5.2047
76	01APR1997:00:00:00	8	13.3829	6.69765	0.2558	26.5101	-5.3829
77	01MAY1997:00:00:00	28	17.3889	6.69765	4.2618	30.5161	10.6111
78	01JUN1997:00:00:00	13	16.2389	6.69765	3.1117	29.3660	-3.2389
79	01JUL1997:00:00:00	21	19.1358	6.69765	6.0087	32.2630	1.8642
80	01AUG1997:00:00:00	30	23.8673	6.69765	10.7401	36.9944	6.1327
81	01SEP1997:00:00:00	16	18.4642	6.69765	5.3370	31.5913	-2.4642
82	01OCT1997:00:00:00	27	24.3420	6.69765	11.2149	37.4692	2.6580
83	01NOV1997:00:00:00	12	20.9137	6.69765	7.7865	34.0408	-8.9137
84	01DEC1997:00:00:00	22	15.4136	6.69765	2.2864	28.5407	6.5864
85	01JAN1998:00:00:00	18	21.5253	6.69765	8.3981	34.6524	-3.5253
86	01FEB1998:00:00:00	6	14.2075	6.69765	1.0804	27.3347	-8.2075
87	01MAR1998:00:00:00	19	18.6209	6.69765	5.4938	31.7481	0.3791
88	01APR1998:00:00:00	23	17.9828	6.69765	4.8557	31.1100	5.0172
89	01MAY1998:00:00:00	25	18.2784	6.69765	5.1513	31.4056	6.7216
90	01JUN1998:00:00:00	21	24.1405	6.69765	11.0133	37.2676	-3.1405
91	01JUL1998:00:00:00	19	20.5685	6.69765	7.4414	33.6957	-1.5685.

APPENDIX F: EXCEL TABLES - COST-BENEFIT ANALYSIS

Cost: ICBC

Raw data							
	Year	**94/95**	**95/96**	**96/97**	**Apr-Dec 1997**	**1998**	**Sub_ total**
	Development	807	10,034	16,812	3,170	2,595	33,418
	Operating						
	Process Serving			364	1,093	1,511	2,968
	Equip. Maintenance			138	111	132	381
	Ticket Processing			2,266	3,342	2,157	7,765
	Advertising		590				590
	Sub_total	807	10,624	19,580	7,716	6,395	45,122

Table 7.2 - ICBC Raw data							
		94/95	**95/96**	**96/97**	**97/98**	**Apr-Jul 98**	**Total**
	Development/Ads.	807	10,624	16,812	3,819	865	32,927
	Process Serving			364	1,471	504	2,338
	Equip. Maintenance			138	144	44	326
	Ticket/photo Processing			2,266	3,881	719	6,866
	Sub_total	807	10,624	19,580	9,315	2,132	42,457

Convert to 2001 dollar							
		94/95	**95/96**	**96/97**	**97/98**	**Apr-Jul 98**	**Sub total**
	Development/Advertising	881	11,343	17,785	4,010	906	34,925
	Process Serving			385	1,544	527	2,457
	Equip. Maintenance			146	151	46	343
	Ticket Processing			2,397	4,076	753	7,226
	Total Operating	0	0	2,928	5,772	1,327	10,026
	Sub_total	881	11,343	23,641	15,553	3,559	54,977

Convert to Photo radar year						
	Items	**Aug 96 - Jul 97**	**Base case 6%**	**1%**	**5%**	**7%**
	Capital	4,745	4,745	3,687	4,523	4,972
	Process Serving	900	1,557	1,557	1,557	1,557
	Equip. Maintenance	196	147	147	147	147
	Ticket Processing	3,756	3,470	3,470	3,470	3,470

Table 7.3 - Annualized Basecase ICBC cost		
	Items	**Typical Year**
	Capital	4,745
	Process Serving	1,557
	Equip. Maintenance	147
	Ticket Processing	3,470

Cost: Police

Table 7.4 - Raw Data		
Parameters for standard costing models		Measures
Dedicated Resources, Attorney General		*# FTE*
	RCMP	82.1
	Independent Police Forces	20.0
	Charging Officers	13.5
	ITCU Admin Staff	4.0
Standard Costing Rates, Attorney General		*$/FTE, On-Going*
	RCMP	85,000
	Independent Police Forces	73,690
	Charging Officers	43,101
	ITCU Admin Staff	71,681
Calculation to derive annualized police cost		
	Calculating using eq. 7.1	9,321,311
	+20% of overhead costs	11,185,573
	Converting into 2001 dollars	11,746,381
	In 2001 real $000 and Reported	11,746

Cost: Court

Raw data of Tickets and Disputes from ICBC				
Photo Radar Program	**1,996**	**1,997**	**1,998**	**1,999**
# Violation Tickets, Photo Radar	63,465	246,188	239,513	146,787
# Disputes, Photo Radar Program	4,511	16,388	21,681	10,509
Cost Calculation				
Criminal Justice Branch	**1996**	**1997**	**1998**	**1999**
Prosecutor	160,658	583,653	772,162	374,275
Support Staff	39,786	144,539	191,223	92,688
Judiciary Branch				
Justice of the Peace	67,854	246,508	326,126	158,076
Court Services Branch				
Sheriffs	14,411	52,354	69,264	33,573
Court/Registry Clerks	77,410	281,222	372,051	180,337
Total Costs	360,120	1,308,277	1,730,825	838,948
Adding 20% overhead				
Photo Radar Program	**1996**	**1997**	**1998**	**1999**
Court cost, staff	360,120	1,308,277	1,730,825	838,948
Court cost, total	432,143	1,569,933	2,076,990	1,006,738
Converting to PRP Year				
Photo Radar Program	1996	1997	1998	1999
Cost dispute tickets $		1,348	1,866	
Converting to 2001 dollars				
Photo Radar Program	**Aug.96 - Jul. 97**	**Aug. 97 - Jul. 98**	**Typical Year**	
Court cost	1,416	1,954	1,954	
itivity Analysis - 25% of MEB				
Sensitivity Analysis				
25% MEB	2,442			

Cost: Private citizen disputing tickets

Table 7.15 -- Wage in current dollars			
Year	**1996**	**1997**	**1998**
Average wage	16.57	16.83	17.09
Number of tickets disputed			
Photo Radar Program	**1996**	**1997**	**1998**
# Violation Tickets, Photo Rada	63465	246188	239513
# Disputes, Photo Radar Progr	4511	16388	21681
Average time disputing tickets			
3			
Photo Radar Program	**1996**	**1997**	**1998**
Cost dispute tickets $	224,201	827,332	1,111,520
Converting to 2001 dollars			
Photo Radar Program	1996	1997	1998
Cost dispute tickets $	237,172	868,812	1,164,064
Table 7.16 -- PRP year cost disputing tickets			
Photo Radar Program	**Aug.96 - Jul. 97**	**Aug. 97 - Jul. 98**	**Typical Year**
Cost dispute tickets	606	1,041	1,041

Effects: Travel Time Cost

Cost - Travle						
Raw Data						
		Table 7.13 - raw data				
		Year	**1996**	**1997**	**1998**	
		Passenger cars	39,284,363	40,629,875	41,611,084	
		Trucks	4,139,734	4,565,941	4,260,014	
Calculation: CBA and SA						
			1996	**1997**	**1998**	**1999**
	70, 2.4	Passenger vehicle	292,128,582	302,134,154	309,430,675	313,183,895
		Trucks	61,568,244	67,907,013	63,357,110	64,932,272
		Total	353,696,826	370,041,167	372,787,785	378,116,167
			1996	**1997**	**1998**	**1999**
	70, 2.0	Passenger vehicle	242,008,482	250,297,412	256,342,079	259,451,364
		Trucks	51,005,065	56,256,300	52,487,017	53,791,932
		Total	293,013,547	306,553,712	308,829,096	313,243,295
	70, 2.8		**1996**	**1997**	**1998**	**1999**
		Passenger vehicle	342,845,350	354,588,000	363,151,279	367,556,099
		Trucks	72,257,175	79,696,425	74,356,608	76,205,236
		Total	415,102,525	434,284,425	437,507,887	443,761,335
Converting to PRP year						
		Table 7.14 - basecase				
		Vehicle Type	**Mar.96 - Jul. 96**	**Aug.96 - Jul. 97**	**Aug. 97 - Jul. 98**	**Typical Year**
	70, 2.4	Passenger vehicle	121,720	297,965	306,390	306,390
		Trucks	25,653	65,266	65,253	65,253
		Total	147,374	363,231	371,643	371,643
Sensitivity Analysis (SA)						
		Photo Radar Program	**Mar.96 - Jul. 96**	**Aug.96 - Jul. 97**	**Aug. 97 - Jul. 98**	**Typical Year**
	70, 2.0	Passenger vehicle	100,837	246,844	253,823	253,823
		Trucks	21,252	54,068	54,058	54,058
		Total	122,089	300,912	307,881	307,881
		Photo Radar Program	**Mar.96 - Jul. 96**	**Aug.96 - Jul. 97**	**Aug. 97 - Jul. 98**	**Typical Year**
	70, 2.8	Passenger vehicle	142,852	349,695	359,583	359,583
		Trucks	30,107	76,597	76,582	76,582
		Total	172,959	426,292	436,165	436,165

Effects: Safety Improvement, Base Case

Collision cost - societal perspective			
Collision Severity	**Cost in 1991' $000**	**Cost in 2001' $000**	
Injury	102	120	
Fatality	3,870	4,578	
Collision cost - ICBC perspective, Table 7.10			
Collision Severity	**Cost in 1991' $000**	**Cost in 2001' $000**	
Injury	34	40	
Fatality	42	50	
Results - Societal, Basecse			
Societal - base model			
Collision Severity	**Reduction**	**Valuation**	**Cost savings**
Injury	1,542	120	185,412
Fatality	72	4,578	328,518
Total savings			513,930
Results - ICBC, Basecse			
ICBC - basecase, table 7.11			
Collision Severity	**Reduction**	**Valuation**	**Cost savings**
Injury	1,542	40	61,989
Fatality	72	50	3,565
Total savings			65,554

Effects:Travel time cost savings due to collision reductions

Equations:			
	For Automobiles:		
	CA = Price_Auto * Occu_rate * VKT_Auto * (1/MSB-1/MSA)		
	For Trucks:		
	CT = Price_Truck * VKT _Truck * (1/MSB-1/MSA)		
CBA - Base case			
		Time savings (hr)	**Cost Savings ($)**
	Car	38,439	564
	Truck	4,271	125
	Sub total	42,710	689
SA: Collision reduction + 1sd			
		Time savings (hr)	**Cost Savings ($)**
	Car	48,006	704
	Truck	5,334	78
	Sub total	53,340	782
SA: Collision reduction - 1sd			
		Time savings (hr)	**Cost Savings ($)**
	Car	28,872	423
	Truck	3,208	94
	Sub total	32,080	517